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Multi-Criteria Evaluation of Key Performance Indicators in Pharmaceutical Supply Chains

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Abstract

Pharmaceutical Supply Chains (PSCs) represent one of the key segments of modern healthcare systems, given their direct impact on patient safety, therapy availability, and healthcare sustainability. The complexity of these chains stems from stringent logistical and regulatory requirements and the necessity of maintaining product quality and safety, as well as demand uncertainty and global supply disruptions. Effective management of PSCs requires systematic performance monitoring, the identification of key indicators, and decision-making based on objective measures. This paper identifies and describes key performance indicators (KPIs), including strategic collaboration, supply chain security, service quality, sustainability, costs, flexibility, resilience, risk management, and visibility. Using the Analytic Hierarchy Process (AHP), a multi-criteria decision-making method, these indicators were ranked. Safety, resilience, and service quality were found to be the most important for supply chain operations. This study contributes to the theoretical understanding of KPIs in PSCs, identifies a set of relevant indicators, determines their significance through the AHP method, and provides practical guidelines for managers regarding priorities in KPI management and monitoring.

Keywords: *pharmaceutical supply chains, pharmaceutical logistics, efficiency, key performance indicators, analytic hierarchy process*

1. Introduction

The pharmaceutical industry represents one of the most significant and sensitive sectors of the modern economy, given its direct impact on public health, quality of life, and the stability of healthcare systems. Within this industry, Pharmaceutical Supply Chains (PSCs) play a crucial role in ensuring the timely, safe, and continuous flow of medicines and other medical products from manufacturers to end-users, including healthcare institutions, pharmacies, and patients. The specificity of PSCs is reflected in stringent logistical and regulatory requirements, the necessity of maintaining product quality and safety, ensuring full traceability, and managing products with limited shelf lives. Additional challenges involve temperature control, specialized transport and storage conditions, and a high degree of accountability at every segment of the chain. Unlike other industries, errors within PSCs can have severe consequences for human health, further emphasizing the importance of efficient logistics in these systems.

Modern PSCs face numerous challenges, including unpredictable demand, global disruptions, changes in regulatory frameworks, raw material shortages, and rising user expectations. The primary motivation for this research stems from these unique logistical requirements and the extreme sensitivity of PSCs, where any disruption directly affects patient safety. Unlike conventional supply chains, PSCs operate under stringent regulatory frameworks (e.g., GMP, GDP) and face complex challenges such as cold chain integrity. Despite their

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criticality, there is a lack of integrated models that prioritize performance indicators specifically for the pharmaceutical sector, which justifies the need for a specialized evaluation framework. In such an environment, traditional management approaches are becoming insufficient, leading to an increasing emphasis on the systematic monitoring and evaluation of performance through the application of key performance indicators (KPIs). KPIs represent quantitative and qualitative indicators used to manage vital business functions and corporate outcomes. More specifically, KPIs enable the assessment of process efficiency, the identification of weaknesses, and the facilitation of managerial decision-making based on informed data.

This paper aims to identify, describe, and rank the KPIs relevant to PSCs. To objectively assess their importance, the study employs the Analytic Hierarchy Process (AHP) as a multi-criteria decision-making tool. The primary contributions of this work include the identification of a comprehensive set of KPIs in PSCs, which represents an expansion of existing literature, and their ranking using the AHP method. Furthermore, the defined set of KPIs provides a structured framework for evaluating the efficiency of PSCs, which can contribute to improving management and the long-term sustainability of these systems.

Despite the contributions of this study, certain limitations should be acknowledged. The research focuses primarily on the theoretical and expert-based identification of KPIs, using the AHP method, which, while robust, relies on the subjective judgments of a specific group of experts. Furthermore, the model is designed within the context of pharmaceutical supply chains. While many indicators are universal, their specific weights might vary in other industries or different geographical regions. Future research could expand this framework by incorporating fuzzy logic to further address uncertainty or by applying the model to real-time longitudinal data from pharmaceutical companies.

The rest of the paper is organized as follows. After the introduction, the second section provides a comprehensive literature review regarding pharmaceutical supply chains and performance measurement. The third section identifies and describes the KPIs relevant to the pharmaceutical sector. In the fourth section, the methodology of the Analytic Hierarchy Process (AHP) is presented, followed by the results, ranking of KPIs, and a robust sensitivity analysis. Finally, the conclusion summarizes the main findings and provides directions for future research.

2. Literature Review

PSCs play a pivotal role in the healthcare sector. The primary goal of pharmaceutical companies is to ensure the quality, efficacy, and safety of medicines [1]. Karmaker & Ahmed [2] emphasize that pharmaceutical supply chains have a complex and dynamic structure, facing numerous challenges in establishing an efficient supply chain. Logistics within healthcare systems must ensure the availability of necessary resources for patient treatment at the right place, at the right time, and of adequate quality [3]. It is essential to establish an efficient connection between core processes, among the most critical being procurement planning, warehousing and inventory management, distribution, and flow management [3]. Due to demographic shifts, constant fluctuations in demand occur, complicating the maintenance of an uninterrupted flow of medicines [2]. Tadić et al. [3] point out that inventory management is a vital component of logistics in any system and perhaps the most critical within the healthcare sector. Bishara [4] argues that PSC participants have the responsibility to meet a series of globally defined regulatory requirements concerning the proper handling, adequate storage, and secure distribution of pharmaceutical products sensitive to external influences, particularly temperature variations. According to Jaberidoost et al. [5], a PSC must ensure optimal distribution and resource management to meet healthcare system objectives, thereby balancing patient needs with the interests of all stakeholders through a cost-effective and quality-driven approach.

Hald & Mouritsen [6] argue that supply chain performance measurement is essential for organizations, as it provides a clear roadmap for managers and decision-makers toward achieving efficiency and effectiveness. Khan et al. [7] highlighted that organizations must have insight into overall supply chain performance to enable improvement. A comprehensive performance measurement system is vital for adaptation and success in a competitive healthcare environment [8]. This can be achieved through the implementation of effective performance measurement systems based on clearly defined KPIs, which provide a measurable framework for monitoring performance [9]. KPIs are metrics established to measure performance, allowing an organization to assess its progress relative to predefined strategic and operational goals [9]. According to Souza et al. [10], KPIs in PSCs represent a set of indicators that enable the monitoring and improvement of pharmaceutical service quality, as well as data-driven decision-making by relevant stakeholders in the healthcare system. It is of critical importance that KPIs are aligned with the goals, mission, and policies of the chain so that the performance measurement system truly supports overarching objectives [9]. Supply chain resilience in the pharmaceutical industry is often operationalized through appropriate KPIs, such as delivery reliability, flexibility, and recovery time. Karmaker & Ahmed [2] maintain that there are specific significant performance indicators that, if improved, can assist decision-makers in building a more resilient supply chain. Thanks to technological advancements, organizations can now easily collect, store, and analyze data. Although various frameworks exist for evaluating individual supply chain processes, overall performance measurement requires a comprehensive and integrated model that considers diverse key factors and sub-factors.

Numerous authors have proposed various performance measurement frameworks to evaluate the overall performance of the supply chain. Understanding and applying appropriate KPIs in pharmaceutical systems contributes to service quality improvements, better health outcomes, and the more efficient functioning of the healthcare system as a whole [10]. Divsalar et al. [11] proposed a model for evaluating supply chain performance in medical equipment companies based on the Supply Chain Operations Reference (SCOR) model, utilizing the LARG (Lean, Agile, Resilient, Green) approach. A centralized supply chain improves cost efficiency, while a decentralized one enhances the time efficiency of the chain [12]. Cooperation among participants and flow consolidation can improve the economic and environmental performance of supply chains [13]. Hill et al. [14] studied the impact of using Electronic Data Interchange (EDI) on supply chain performance. They concluded that EDI improves coordination among chain actors, leading to an enhancement in overall performance [14]. Song et al. [15] proposed a logical framework for assessing supply chain resilience based on performance indicators, providing insight into the interconnections between specific indicators and a set of performance measures. Banihashemi [16] explored the relationship between reverse logistics and sustainability performance.

The key contributions and research areas addressed in the existing literature are summarized in Table 1.

Table 1. Summary of literature review and key research areas.

Research Area	Focus & Key Topics	References
PSC Specifics & Strategic Issues	Characteristics of pharmaceutical supply chains, sustainability, and strategic management challenges.	[1], [3], [18]
Resilience & Risk Management	Modeling performance indicators for resilience, risk identification, and mitigation strategies in PSCs.	[2], [5], [16], [22], [27]
Performance Measurement Systems	Evolution of measurement systems, KPI frameworks for hospitals and pharmaceutical services.	[6], [8], [10], [26]
Quality & Safety in PSC	Service quality management, cold chain integrity, and health system sustainability.	[4], [9], [17], [19], [24], [28]
Advanced Technologies & Operations	Role of blockchain, EDI, reverse logistics, and digitalization in supply chain efficiency.	[14], [15], [17], [21], [23], [25]
MCDM & AHP Methodology	Multi-criteria decision-making approaches and the application of the Analytic Hierarchy Process (AHP).	[7], [11], [29]

3. Identification of KPIs in PSCs

The efficient functioning of PSCs depends on the system's ability to respond timely and adequately to numerous challenges affecting its stability and reliability. A significant number of authors in the literature have focused on identifying performance indicators relevant to assessing PSC efficiency. Khan et al. [7] identified the 17 most significant indicators through a comprehensive literature review conducted using various electronic databases. Rather than duplicating an already comprehensive literature review, this study builds upon the results of Khan et al. [7] by adopting their validated and evaluated set of KPIs as a foundation. In addition, this initial set was complemented with several widely recognized supply chain indicators that were not explicitly covered in that review, thereby forming a more comprehensive pool of relevant KPIs. In addition to these 17, this paper identifies and describes four more significant KPIs: flexibility, resilience, risk management, and visibility. The inclusion of additional KPIs extends the existing framework and allows for a more comprehensive evaluation of pharmaceutical supply chains, particularly by capturing dimensions that were not considered in previous studies. The identified KPIs are categorized into three primary functional groups (Operational, Security & Risk, and Strategic & Quality) and are visually presented in the conceptual framework in Figure 1.

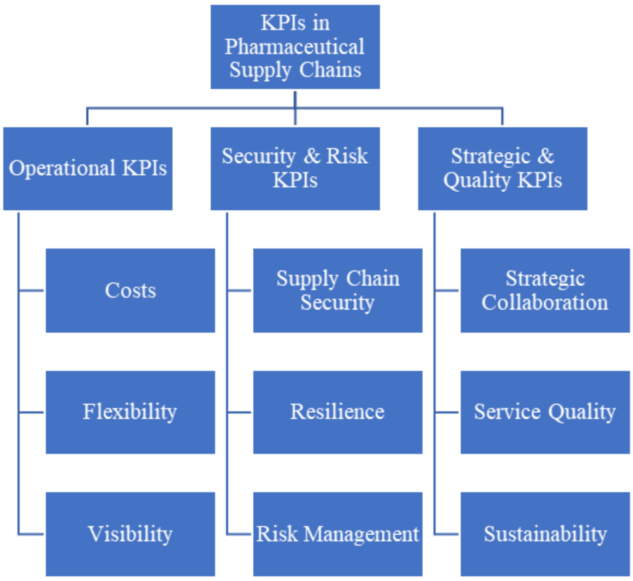

Figure 1. Conceptual framework and categorization of Key Performance Indicators (KPIs) in PSCs.

The degree of information technology (IT) implementation within the supply chain is crucial for achieving high efficiency, flexibility, and transparency [17]. IT enables process digitalization, automated data collection, and enhanced activity monitoring in PSCs, thereby improving coordination between segments, from raw material procurement to final product delivery [17]. By utilizing advanced systems such as Enterprise Resource Planning (ERP), Transportation Management Systems (TMS), and Warehouse Management Systems (WMS), pharmaceutical companies can optimize logistical processes, reduce errors, and improve delivery speed [18]. A high level of IT implementation facilitates the introduction of automation, integration with suppliers and distributors, and better tracking of inventory and production levels [19]. IT solutions enable real-time analysis of large data volumes, contributing to faster decision-making, reduced operational costs, and an overall enhancement of supply chain efficiency [19]. Given the increasing challenges in the pharmaceutical industry, such as frequent regulatory changes, growing pressure to reduce costs, and the need for improved efficiency, the effective application of information technologies has become a key indicator for achieving competitive advantage and increasing the resilience of pharmaceutical companies [2].

Process improvement and healthcare reforms have a crucial and comprehensive impact on the efficiency of PSCs [17]. Papalexi et al. [18] emphasize that reforms may encompass the standardization of procedures, enhancement of regulatory frameworks, digitalization of medical records, the introduction of electronic prescriptions and centralized databases, and the development of systems for monitoring and quality control of medicines. Process improvement enables better alignment and collaboration among various supply chain actors, ranging from manufacturers and distributors to healthcare institutions and pharmacies [7]. These changes reduce delivery delays, optimize resource utilization, and ensure continuity in medicine availability. They are vital for achieving the stability and resilience of PSCs, especially within the dynamic and often volatile healthcare sector [7].

Human resources, competencies, and engagement entail individuals with the appropriate knowledge, skills, and a high degree of involvement, representing a key link in the efficient functioning of PSCs [2]. This KPI encompasses the technical and organizational competencies of employees involved in the planning, production, procurement, warehousing, distribution, and quality control of pharmaceutical products [17]. Qualified and continuously educated personnel enable better compliance with regulatory requirements, more accurate inventory management, faster identification of chain disruptions, and more efficient decision-making [18]. In addition to technical expertise, critical aspects include communication and collaboration skills, teamwork capabilities, and employee commitment to organizational goals. A high level of engagement implies active participation in process optimization and the identification of improvement opportunities. According to

Khan et al. [7], a lack of trained staff or low engagement can lead to bottlenecks, errors, and reduced flexibility within the supply chain, directly impacting its efficiency. Therefore, investing in human resource development represents a strategic priority for organizations striving for a sustainable and resilient PSC [8].

The development of alternative and reliable suppliers represents a strategically important element in ensuring the resilience and flexibility of PSCs [17]. This KPI involves the identification, evaluation, and establishment of collaboration with multiple supply sources to reduce dependency on a single or limited number of suppliers. This is particularly crucial in situations involving supply chain disruptions, raw material shortages, or geopolitical risks. In the pharmaceutical industry, characterized by high regulatory levels and stringent quality requirements, all suppliers, including alternative ones, are expected to comply with relevant standards such as GMP and ISO norms [2]. Effective development of a supplier network includes continuous two-way communication, regular performance evaluation, and the provision of technical and organizational support, aimed at achieving high levels of reliability and regulatory compliance. Such an approach contributes to PSC stability, reduces operational risks, and directly impacts overall efficiency and resilience [2].

Supplier selection and evaluation represent key components in building an efficient and reliable PSC. The selection process involves the systematic choice of suppliers based on clearly defined criteria, including the quality of delivered raw materials or products, compliance with regulatory standards, financial stability, delivery reliability, flexibility, and the ability to respond rapidly in crises [17]. Supplier evaluation is a continuous process of monitoring and assessing their performance throughout the duration of the partnership, utilizing both quantitative and qualitative indicators [2]. Based on the collected data, decisions are made regarding the continuation, expansion, or termination of the partnership, enabling dynamic management of supplier risks and the maintenance of a high level of operational efficiency. Through proper selection and regular supplier evaluation, a PSC can improve its stability, reduce operational costs, and increase product delivery security, thereby contributing to the sustainability and competitiveness of the entire supply chain [2].

Research and Development (R&D) of new products represents a key component in the continuous improvement of PSCs. This KPI encompasses all activities related to innovation and the creation of new pharmaceutical products, as well as the enhancement of existing ones. Singh et al. [17] emphasize that in the pharmaceutical industry, the speed and efficiency of new product development directly impact competitiveness and the ability to meet market demands, including regulatory requirements. The R&D process involves identifying new therapeutic needs, developing new formulations, testing and verifying product efficacy and safety, and ensuring compliance with stringent regulatory norms. An efficient R&D process enables the production of innovative medicines that can contribute to improved healthcare and reduced production costs through optimized formulations and processes [17]. Within the context of PSCs, R&D plays a crucial role in increasing efficiency and optimizing the entire chain. New products often require the alignment of production capacities, logistical networks, and distribution. Therefore, effective management of the R&D process not only contributes to product improvement but also to the optimization of operational efficiency and cost reduction across the entire supply chain [17].

Compliance and regulatory management represent one of the vital elements in assessing PSC efficiency, given that the pharmaceutical industry operates within extremely stringent legal and regulatory frameworks [19]. This involves the implementation and maintenance of procedures that ensure compliance with national and international laws, regulations, and standards, including GMP and GDP, as well as guidelines prescribed by health authorities such as national medicine agencies, the European Medicines Agency (EMA), and the U.S. Food and Drug Administration (FDA) [19]. Effective regulatory compliance management enables the timely identification and mitigation of regulatory risks, thereby preventing legal and financial consequences and ensuring a high level of product safety and quality throughout all stages of the PSC. Within the supply chain, efficient regulatory management ensures full transparency, adherence to standards, and consistent application of regulations at all levels, from raw material procurement through manufacturing and warehousing processes to transportation and final product distribution. In this way, not only are legal and regulatory security ensured, but also the stability and resilience of the supply chain, significantly contributing to its overall efficiency [19].

Strategic collaboration and integration encompass strategic partnerships, alliances, acquisitions, and intra-company integration, representing key mechanisms for enhancing the efficiency, resilience, and competitiveness of PSCs. Alharthi et al. [19] emphasize that in the context of growing challenges, such as global competition and complex regulatory requirements, establishing collaboration between pharmaceutical companies, research institutions, distributors, suppliers, and technology partners enables the collective achievement of long-term strategic goals. Mergers and acquisitions allow companies to rapidly access new markets, production capacities, and advanced technologies while increasing R&D capacity, which is vital for innovation in the pharmaceutical industry. Integration within the organization, by linking processes, information, and business functions, contributes to better coordination, reduced redundancy, and increased agility in decision-making. By combining external and internal integration strategies, pharmaceutical companies can build a functionally interconnected, stable, and efficient PSC, ready to respond to the challenges of the modern market and complex regulatory demands.

Product recall and safety are paramount, primarily for protecting patient health, but also for ensuring regulatory compliance and preserving the reputation of pharmaceutical companies. This KPI encompasses the supply chain's ability to quickly and efficiently identify defective or potentially hazardous products already distributed in the market. Effective systems for batch tracking, quality control, and rapid product recalls enable the reduction of harmful consequences for end-users and minimize legal, financial, and reputational risks [19]. The implementation of digital tracking systems throughout the PSC, such as blockchain technology, which provides secure, transparent, and immutable data records, or the Internet of Things (IoT), which connects devices and enables real-time data collection, improves the accuracy and speed of identifying products within distribution. Furthermore, establishing clear protocols for crisis management, including communication with regulatory bodies, distributors, consumers, and healthcare professionals, is essential for rapid response and informing all chain actors. A high level of product recall readiness and the consistent implementation of safety measures contribute to the reliability, resilience, and efficiency of PSCs.

Procurement and supply management directly impact product availability, operating costs, and a company's ability to respond to changes in market conditions. This KPI encompasses all activities related to strategic planning and the procurement of raw materials, medicines, and other necessary materials, as well as the precise tracking and management of inventory at all levels of the supply chain [2]. Efficient procurement involves supplier selection, negotiation of terms and contracts, and the optimization of purchasing costs, while inventory management ensures timely product availability while minimizing storage costs and avoiding surpluses or stockouts [18]. A high-quality goods coding system is particularly significant for the operational and economic efficiency of procurement (e.g., it can eliminate duplicate purchases) [20]. For pharmaceutical products, which often have specific requirements regarding storage conditions, expiration dates, and legal regulations, inventory management becomes an even more complex process. Utilizing advanced technological solutions, such as real-time inventory tracking systems, enables precise demand forecasting and procurement process optimization [8]. Effective inventory management contributes to cost reduction, decreases the risk of shortages or surpluses, and increases PSC flexibility in responding to changes in demand or market circumstances. By combining strategic procurement planning with innovative technologies for data tracking and analysis, pharmaceutical companies can improve the operational efficiency and competitiveness of the supply chain [7].

Production, distribution, and inventory management involve the synchronization of all activities required to ensure the timely and secure delivery of pharmaceutical products [18]. This KPI encompasses the coordination between production capacities, logistical operations, and inventory management to ensure a balance between supply and demand, reduce costs, and minimize the risks of shortages or surpluses. Efficient production management involves the planning and optimization of manufacturing processes, while distribution coordination ensures the timely delivery of products to end-users in compliance with regulatory requirements [2]. Through the integration of these key activities, pharmaceutical companies can achieve greater flexibility and agility in responding to changes in market conditions or the regulatory environment. Management systems for tracking production, distribution, and inventory allow for better control over operations and reduced operational costs while improving service quality and product safety. By utilizing advanced technologies such as ERP systems and inventory management software, companies can more accurately track product movement through the PSC, optimize warehousing and transportation, and reduce inventory to the minimum required level, thereby further increasing PSC efficiency [8].

Logistics in hospitals and other healthcare institutions play a significant role in ensuring the timely and efficient delivery of medical products, medicines, and equipment, which are essential for providing high-quality healthcare. This KPI encompasses all activities associated with planning, organizing, transporting, storing, and distributing pharmaceutical products within hospitals and other healthcare facilities. Efficient logistics enables the continuous availability of products, thereby minimizing the risk of shortages or delays that could jeopardize patient health [7]. Hospital logistics must comply with stringent health and regulatory standards, including special requirements such as temperature control for specific medicines or equipment (cold chain), secure storage, and expiration date tracking. Furthermore, it is crucial that hospital logistics systems are capable of rapidly adapting to changes in product demand and enabling efficient inventory tracking and replenishment. The integration of advanced technologies and digital systems for inventory monitoring and optimization can significantly improve efficiency, reduce operational costs, and ensure patient safety through the reliable and timely distribution of medical products.

Supply chain security and quality assurance encompass two distinct aspects. First, security involves a wide range of measures aimed at protecting the chain from potential threats, such as counterfeit products, theft, sabotage, manipulation, and other forms of illicit activities that could jeopardize patient safety and business legality [18]. Quality assurance, on the other hand, entails the application of stringent standards, control procedures, and validation to ensure that pharmaceutical products are maintained in optimal condition, from manufacturing to final delivery to end-users [17]. The implementation of modern technologies enables the rapid identification and recall of risky, unsafe, or defective products from the chain, thereby minimizing the possibility of their distribution [19]. Furthermore, regulations that ensure high levels of quality and safety play a key role in this process, such as Good Manufacturing Practice (GMP) and Good Distribution Practice (GDP). GMP covers all aspects of production, from raw materials and equipment to employee training and quality control of finished products, ensuring standardized and safe manufacturing. GDP refers to the proper storage, transport, and distribution of medicines, including temperature control, documentation, and protection against theft and counterfeiting. The consistent application of these standards increases system reliability, reduces errors, and directly contributes to the overall efficiency of PSCs [19].

Service quality is also one of the KPIs in assessing PSC efficiency, as it directly impacts the satisfaction of end-users, whether they are patients, pharmacies, or healthcare institutions. This KPI encompasses all aspects of the services provided during the delivery of pharmaceutical products, ranging from precision in meeting requirements and delivery accuracy to the speed and security of shipping [8]. High service quality includes efficient order management, timely delivery, and flexibility in responding to changing user needs [18]. Monitoring and analyzing service performance enables the identification of weak points and the continuous improvement of processes, which directly contribute to the reliability and efficiency of the PSC [8].

Sustainability is one of the most significant imperatives and goals in modern times. Lambert [21] emphasizes that sustainable supply chain management is becoming a key element of modern business, as it enables companies to find a balance between economic benefits, environmental preservation, and social responsibility. This KPI encompasses the application of sustainable development principles during raw material and supply procurement, as well as in the design and selection of packaging solutions that reduce negative environmental impact [19]. Within sustainable procurement, the focus is on selecting suppliers who adhere to environmental standards, use renewable resources, and apply responsible manufacturing practices. This supports the concept of a sustainable value chain, complemented by certifications such as ISO 14001, which helps organizations improve environmental performance through efficient resource use, waste reduction, and the mitigation of negative environmental impacts. Regarding packaging, the emphasis is on using recyclable, biodegradable, or reusable materials, reducing packaging waste, and designing packaging that optimizes logistical space and contributes to energy efficiency during transport. Innovations in packaging, such as the use of bioplastics or the reduction of plastic components, can significantly decrease the ecological footprint. Implementing sustainable solutions in packaging not only lessens environmental impact but can also contribute to cost reduction, brand enhancement, and compliance with increasingly stringent regulatory requirements. The implementation of sustainable procurement and packaging in the PSC contributes to its long-term stability, corporate reputation, and responsible business conduct aligned with circular economy principles, while simultaneously reducing operational costs in the long run.

Recycling and disposal represent important aspects of sustainability and effective PSC management, with a significant impact on environmental protection, operational cost reduction, and compliance with legislative requirements. This KPI encompasses strategies and practices related to responsible waste management throughout all stages of the supply chain, from production and packaging to distribution and end-use of the product. In the pharmaceutical industry, this involves the proper disposal of hazardous and chemical waste, as well as the recycling of packaging materials and production residues, while strictly adhering to environmental and safety standards [7]. The effective implementation of recycling and responsible disposal reduces the ecological footprint, preserves resources, and prevents pollution. Furthermore, it can lead to a reduction in operational costs through material reuse, decreased energy consumption, and process optimization. Implementing waste separation systems, collaborating with certified waste management operators, and continuously educating employees on sustainable practices are key elements of this KPI. The use of innovative recycling technologies and the introduction of transparent waste reporting procedures further enhance efficiency and accountability. By integrating recycling and responsible disposal into the PSC management strategy, pharmaceutical companies not only increase their sustainability and regulatory compliance but also improve their reputation as socially responsible enterprises.

Costs represent an indispensable performance indicator for the PSC. Within this KPI, logistical costs are particularly significant, as they directly impact delivery speed, supply reliability, and the overall operational performance of the PSC [18]. This KPI encompasses all expenses associated with the physical movement of pharmaceutical products (from manufacturers to end-users), including route planning and optimization, the selection of appropriate transport modes, warehousing, and additional costs arising from stringent requirements such as temperature control, secure packaging, and specialized transportation [2]. Effective management of logistical costs implies the timely, safe, and efficient delivery of medicines while minimizing delays, losses, and inventory surpluses.

Flexibility in PSCs represents the system's ability to adapt quickly and efficiently to changes in demand, market conditions, and operational constraints without compromising product quality and safety. Within the pharmaceutical context, this KPI encompasses adaptive production planning, inventory management, and distribution, as well as the ability to switch suppliers, production batches, or distribution routes within a short timeframe [7]. A high level of flexibility allows companies to respond to sudden surges or drops in demand, the emergence of new therapies, or regulatory changes, while simultaneously maintaining compliance with stringent quality and safety standards. Flexibility can be further enhanced through the implementation of adaptive production plans, agile distribution strategies, and proactive inventory management, thereby reducing the negative effects of unexpected demand fluctuations or supply chain disruptions [17]. As such, flexibility contributes to supply continuity and increases the PSC's capacity to function in a dynamic and uncertain environment [18].

Resilience represents one of the key KPIs for PSC stability, particularly in conditions where supply disruptions can directly jeopardize therapy availability and patient health. This KPI refers to the system's ability to maintain core functions, absorb shocks, adapt to unforeseen circumstances, and sustain operational functioning, as well as to recover as quickly as possible following disruptive events such as pandemics, transportation halts, raw material shortages, natural disasters, or geopolitical instabilities [8]. Resilience is reflected not only in the capacity to overcome crisis situations but also in strategic planning and the integration of information systems that enable rapid impact assessment and optimal resource allocation under extraordinary circumstances [8]. A high level of resilience implies the existence of alternative suppliers, flexible distribution networks, safety stocks, and effective crisis management mechanisms [7]. Resilience is closely linked to security and risk management but differs conceptually, as it pertains to the PSC's ability to function and recover during and after a disruption, thereby serving as the foundation for the long-term reliability and continuity of its operations.

Risk management represents a systematic approach to identifying, assessing, and mitigating risks that can negatively impact the functioning of the PSC. According to Papalexi et al. [18], this KPI encompasses risks associated with suppliers, production, transportation, storage, regulatory changes, and market uncertainties. Effective risk management involves developing preventive and corrective measures, as well as continuous monitoring of potential threats to reduce the probability and consequences of adverse events. In the pharmaceutical context, risk management is of particular importance due to its direct impact on patient safety and therapy continuity [18]. As such, it contributes to the stability, predictability, and resilience of the PSC, while supporting strategic and operational decision-making. Integrating risk management with digital tools and real-time monitoring enables rapid response and the reduction of potential losses, thereby strengthening the resilience and stability of the entire PSC [17]. The risk management KPI has a predominantly preventive role, as it focuses on pre-identified threats and response planning before a disruption occurs.

Visibility in the PSC refers to the ability to track the flow of products, information, and inventory throughout all stages of the chain, from raw material procurement to final delivery to end-users. This KPI enables timely decision-making, increases transparency, and facilitates process control, which is of particular importance in an industry with stringent regulatory requirements [8]. A high level of visibility allows for the identification of potential delays, deviations from prescribed conditions (e.g., temperature regimes), and a timely response to supply disruptions. The implementation of digital technologies, such as information systems, IoT devices, and real-time tracking systems, significantly contributes to enhancing visibility and strengthening trust among PSC participants [18]. Increased visibility enables analytical demand forecasting, the identification of potential bottlenecks, and better capacity planning, which directly contributes to risk reduction and increased efficiency within the PSC [7].

4. Evaluation of PSC KPIs

When discussing the efficiency assessment of PSCs, both literature and practice emphasize the need for a systematic approach that enables an objective comparison of various KPIs critical to chain functioning. The efficiency of chains is reflected not only in delivery speed and reliability but also in the ability to respond to environmental changes, maintain supply continuity, ensure product quality and safety, and achieve these goals sustainably and cost-effectively. Due to the complexity and multidimensionality of this problem, it is necessary to rank KPIs based on their relative importance. To reduce the defined set of KPIs to a smaller set, 22 experts were interviewed (Table 2). From the total of 21 described KPIs, the 9 most relevant ones were selected based on their relative significance to be included in the evaluation and assessment. The selection of these nine KPIs was guided by their frequent occurrence in the literature, their practical relevance, and the intention to include both established and newly introduced indicators for a more comprehensive evaluation. Within the scope of this research, the ranked KPIs are flexibility, strategic collaboration, resilience, security, service quality, sustainability, visibility, risk management, and costs. These KPIs are consistently recognized as key dimensions of supply chain performance in the literature (e.g., [22], [23], [24], [25], [26], [27], [28]).

Table 2. Characteristics of experts.

Sector	Number of experts	Experience (Years)
Pharmaceutical logistics, pharmaceutical supply chains	3	<5
	3	5-10
	2	>10
Logistics, supply chain management	4	<5
	5	5-10
	5	>10

The described multi-criteria decision-making problem will be analyzed using the AHP method. AHP was selected due to its suitability for structuring expert-based evaluations, its ability to ensure consistency of judgments, and its proven effectiveness in handling problems with a moderate number of criteria and a clear hierarchical structure. This method was developed by Saaty [29] to determine the relative importance of elements in multi-criteria decision-making problems. The AHP method is based on three principles: model structuring, comparative analysis of structural elements, and priority synthesis. The first step in applying the method is to formulate a hierarchical structure for the problem at hand. AHP first decomposes a complex multi-criteria decision-making problem into hierarchically organized decision elements (goals, criteria, and alternatives). In a general case, based on such a framework, an analysis is performed to determine the relative weights of the criteria and the values of the alternatives in relation to those criteria. In this paper, the hierarchical structure is simplified. The performance indicators (KPIs) themselves are being ranked. Therefore, the problem consists of only two levels. The first level defines the goal, assessing PSC efficiency, while the second level consists of the decision elements, namely the nine KPIs. The analysis involves exclusively determining the relative weights (priorities) of the nine KPIs, achieved through their mutual pairwise comparison relative to the defined goal. Pairwise comparisons are conducted using a standardized nine-point scale (Saaty's scale) (Table 3).

Table 3. Saaty's scale for pairwise comparison [22].

Numerical Value	Linguistic Assessment
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

The steps for applying the AHP method are described below:

Step 1: Defining the problem structure. First, it is necessary to define the structural elements, namely the goal, alternatives (variants), and the criteria for their prioritization.

Step 2: Constructing the pairwise comparison matrix:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, a_{kk} = 1, a_{lk} = 1/a_{kl}, a_{kl} \neq 0, \quad (1)$$

where n denotes the total number of structural elements and a_{kl} $(k,l=1,2,...,n)$ represents the relative importance of element k to element l.

Step 3: Obtaining relative weights between elements via an eigenvector analysis. Given the fact that matrix A in (1) has all positive entires, the Perron-Frobenius theorem guarantees that A has a unique real, positive eigenvalue λ_{max} such that λ_{max} is strictly greater in absolute value than any of the other eigenvalues of A. Moreover, there exists a column vector $w = [w_1;\ w_2;\ \dots;\ w_n]$ such that all of its components are positive and that satisfies the following matrix-vector relation:

$$Aw = \lambda_{max} w. \quad (2)$$

In other words, w is an eigenvector with positive entries corresponding to the principal (largest) eigenvalue of A. Now one can apply the power method on A to compute λ_{max} and w that satisfy equation (2), or simply use one of the standard software pacakages on A directly. Finally, since a nonzero multiple of an eigenvector remains an eigenvector, one can always find a vector w that satisfies equation (2) *and* whose sum of all its components equals one. In this context, such w is referred to as the priority vector, and its components w_i represent the element weights.

Step 4: Consistency Verification. To monitor and control the results of the method, it is necessary to calculate the consistency ratio (CR) for each matrix and the overall inconsistency of the hierarchical structure. Following [29], CR is given by:

$$CR = \frac{CI}{RI}, \quad (3)$$

where CI denotes the consistency index determined by:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

and RI refers to the random index. Values of RI for different matrix dimensions can be found in Saaty [29]. Then CR is used to verify the consistency of pairwise comparisons, and it must be less than 0,10 for the comparisons to be considered acceptable.

In the context of this paper, nine KPIs were analyzed (*n=9*). In such a case, according to Saaty, the random index was found to be $RI \approx 1{,}45$. Moreover, the entries of the corresponding *9 x 9* comparison matrix *A* can be found in Table 4. The values in this table were obtained based on individual expert evaluations provided in Table A1 in the appendix, as follows. The arithmetic means of the experts' ratings were calculated for each pair of KPIs, and all values greater than 1 were rounded to the nearest integer. The remaining values were obtained as the reciprocals of the corresponding values derived in the previously described manner. For the third step in our analysis, the principal eigenvalue of matrix *A* and the corresponding priority vector were obtained by solving equation (2) using the AHP online calculator (https://bpmsg.com/ahp/ahp-calc.php?lang=en). It was found that $\lambda_{max} \approx 9{,}181$ and that the priority vector of weights for the criteria was given by:

$$w = [0{,}117; 0{,}103; 0{,}184; 0{,}227; 0{,}117; 0{,}032; 0{,}066; 0{,}110; 0{,}043]$$

Using Equation (3) the value of CI was found to be

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{9{,}181 - 9}{9 - 1} = 0{,}022625\,,$$

which together with the subsequent use of equation (4) resulted in the following value for the Consistency Ratio

$$CR = \frac{CI}{RI} = \frac{0{,}022625}{1{,}45} \approx 0{,}0156\,.$$

Based on the consistency rule (CR < 0,10), it was determined that the conducted comparisons are consistent; therefore, the obtained results can be considered valid (there are no contradictory preferences). Table 5 presents the normalized weights of the KPIs, expressed in percentages, as well as their ranking, which serves as the basis for assessing the relative importance of the KPIs within the analysis. A detailed description of each KPI relative to its importance in the PSC is provided below.

It is particularly important to highlight that the KPIs introduced in this study, which were not included in Khan et al. [7], are ranked among the top five positions. This clearly indicates their high relevance and suggests that certain important dimensions of PSC performance were not captured in previous analyses.

To provide a clearer visual representation of the established priorities, the normalized weights and final ranking of the KPIs are illustrated in Figure 2.

Table 4. Pairwise comparison matrix of KPIs.

Pairwise comparison matrix of KPIs	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
Strategic Collaboration (KPI1)	1,00	0,50	1,00	4,00	2,00	0,50	0,50	1,00	2,00
Supply Chain Security (KPI2)	2,00	1,00	2,00	7,00	4,00	2,00	2,00	2,00	3,00
Service Quality (KPI3)	1,00	0,50	1,00	5,00	3,00	1,00	0,50	1,00	2,00
Sustainability (KPI4)	0,25	0,14	0,20	1,00	1,00	0,33	0,17	0,33	0,50
Costs (KPI5)	0,50	0,25	0,33	1,00	1,00	0,50	0,25	0,33	0,50
Flexibility (KPI6)	2,00	0,50	1,00	3,00	2,00	1,00	0,50	1,00	2,00
Resilience (KPI7)	2,00	0,50	2,00	6,00	4,00	2,00	1,00	2,00	2,00
Risk Management (KPI8)	1,00	0,50	1,00	3,00	3,00	1,00	0,50	1,00	2,00
Visibility (KPI9)	0,50	0,33	0,50	2,00	2,00	0,50	0,50	0,50	1,00

Table 5. Normalized weights and ranking of KPIs using the AHP method.

KPI	Normalized weights	Rank
KPI1	0,103	6
KPI2	0,227	1
KPI3	0,117	3
KPI4	0,032	9
KPI5	0,043	8
KPI6	0,117	4
KPI7	0,184	2
KPI8	0,11	5
KPI9	0,066	7

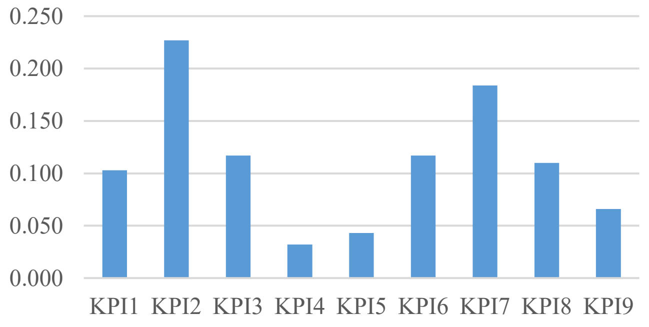

Figure 2. Normalized weights of the KPIs.

Supply chain security and quality assurance are ranked as the most significant KPIs, as they have an immediate and critical impact on patient health and public health as a whole within the PSC. Any deviation from prescribed safety standards can lead to serious health consequences, regulatory sanctions, and a loss of trust in the healthcare system. Therefore, security is logically established as an absolute priority and a fundamental prerequisite for the functioning of the PSC. Resilience is the second most important KPI, indicating the high significance of the PSC's ability to withstand disruptions and recover quickly from crisis situations. The high ranking of resilience confirms that the reliability of drug supply cannot be ensured without developed adaptation and recovery mechanisms. Service quality is the third most significant KPI. A high level of service quality contributes to building trust among all participants in the supply chain, including manufacturers, distributors, pharmacies, and healthcare institutions. Although undoubtedly important and indispensable, costs and sustainability are of lesser significance compared to other criteria. This is largely expected, as in the pharmaceutical and healthcare sectors, priority is given to aspects directly related to human health, while economic, environmental, and other factors remain secondary priorities.

To evaluate the robustness and reliability of the AHP results, a sensitivity analysis was performed through eight distinct scenarios (S1–S8), using the base case as a benchmark. The primary objective was to observe the rank stability of the leading KPI, Supply Chain Security (KPI2), when its relative importance was modified compared to other key criteria. The scenarios were defined as follows. S1–S4: The importance of KPI2 was systematically equalized with its primary competitors in the ranking: Resilience (S1), Service Quality (S2), Flexibility (S3), and Risk Management (S4). S5–S7: More complex scenarios were formed where KPI2 was simultaneously equalized with groups of criteria (e.g., in S7, the importance of KPI2 was equalized with all criteria ranked from 2nd to 5th place). S8: This scenario represents the most significant change, where the comparison scores of KPI2 relative to other indicators were further reduced by one point on the Saaty scale.

The results, illustrated in Figure 3, confirm the exceptional stability of the model. Throughout the first seven scenarios (S1–S7), despite significant adjustments in weights, Supply Chain Security (KPI2) maintained its leading position. Only in the extreme case (S8), where the most rigorous changes were applied cumulatively, did a rank shift occur, resulting in KPI2 dropping to second place while Resilience emerged as the top priority. The fact that the ranking remains unchanged even when the importance of the leading criterion is equalized with multiple other indicators simultaneously demonstrates a high level of robustness, confirming that the identified priorities are reliable for decision-making in the PSCs.

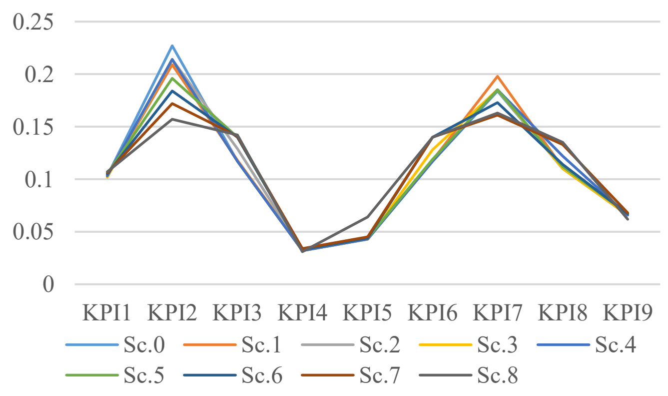

Figure 3. Sensitivity analysis results.

To further validate the robustness and reliability of the obtained results, a comparative analysis was conducted using three additional widely recognized MCDM weighting methods: the Best-Worst Method (BWM), Step-wise Weight Assessment Ratio Analysis (SWARA), and the Factor Relationship (FARE) method. These methods were selected due to their strong presence in the recent MCDM literature, methodological diversity, and their suitability for problems involving expert-based evaluation and weighting of criteria using pairwise evaluations. Specifically, BWM is known for its consistency and reduced number of pairwise comparisons. SWARA is effective in incorporating expert judgment in a step-wise manner, while FARE captures interdependencies among criteria, providing a complementary perspective to AHP.

The comparison results, presented in Figure 4, indicate a high level of agreement among the applied methods. The ranking obtained using the BWM method shows only minor deviations compared to the AHP results, while the application of the SWARA and FARE methods resulted in an identical ranking of KPIs. This strong consistency across different methodological approaches confirms the stability and reliability of the identified priorities and further validates the use of AHP in this research.

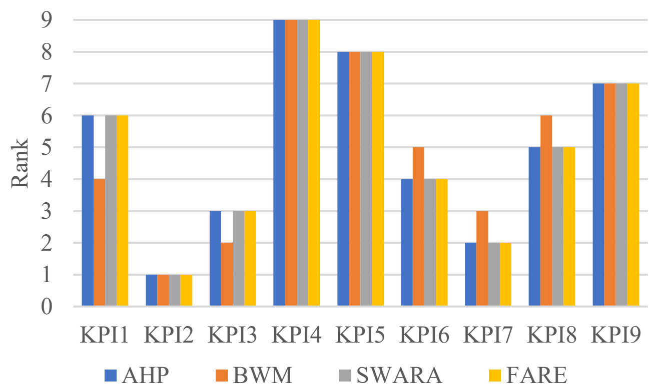

Figure 4. Validation of results.

The convergence of results across multiple methods suggests that the obtained ranking is not method-dependent but rather reflects the inherent importance of the analyzed KPIs within pharmaceutical supply chains.

5. Conclusion

The efficient functioning of PSCs represents a fundamental prerequisite for ensuring the availability, quality, and safety of medicines, which directly impacts treatment outcomes and patient health. The research conducted within this paper has demonstrated that successful PSC management requires a comprehensive and systemic approach that integrates logistical, security, healthcare, technological, economic, and other aspects. In this way, the pharmaceutical sector can respond more effectively to increasing market demands, strict regulatory frameworks, and increasingly prominent global disruptions.

The key contribution of this paper lies in the identification and multi-criteria evaluation of PSC KPIs. KPIs represent a fundamental instrument for the quantitative assessment of process success, the identification of critical points, and support for strategic decision-making aimed at improving system efficiency. In this sense, it is essential to determine the significance of each indicator. The application of the AHP method enabled an objective ranking of KPIs in accordance with their relative importance, thereby providing a reliable and structured framework for evaluating PSC performance.

The results of the multi-criteria evaluation indicate that supply chain security, resilience, and service quality are ranked as the most significant KPIs in PSCs. The dominant importance of security confirms that patient protection and the preservation of pharmaceutical product integrity are perceived as absolute priorities, while the high ranking of the resilience KPI emphasizes the importance of the PSC's ability to adapt to and recover from disruptions. In contrast, KPIs such as cost-efficiency and sustainability have a lower relative weight, which is characteristic of a sector where economic goals are secondary to the requirements of safety and supply continuity. This ranking structure provides a clear insight into the hierarchy of priorities and can serve as a guideline for managers and decision-makers in resource allocation and the enhancement of PSC KPIs.

Competing Interest Statement

The authors declare no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data Availability Statement

All data generated or analysed during this study are included in this article.

Statement on the Ethical Use of AI Tools

An artificial intelligence tool was used for language editing and proofreading of the paper, in an ethical manner.

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Appendix

Table A1. Expert evaluations.

Exp.	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
mean value	KPI1	1	0.73	1.23	4.05	2.18	0.8	0.59	1.27	1.95
	KPI2	1.68	1	1.95	6.68	4.23	2	1.95	2	3.14
	KPI3	1.05	0.55	1	4.95	3.27	1.14	0.64	1.18	2.05
	KPI4	0.26	0.15	0.21	1	1.07	0.53	0.21	0.57	0.86
	KPI5	0.47	0.24	0.32	1.2	1	0.59	0.41	0.39	0.66
	KPI6	1.55	0.56	1	2.52	1.82	1	0.64	1.11	2
	KPI7	1.82	0.54	1.8	5.73	3.52	1.8	1	2.14	2.18
	KPI8	0.93	0.56	0.98	2.55	2.82	1.05	0.51	1	2.05
	KPI9	0.55	0.35	0.54	1.61	1.75	0.53	0.5	0.54	1
1	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	1	3	2	1	0.5	2	2
	KPI2	2	1	2	7	6	2	2	2	4
	KPI3	1	0.5	1	5	3	1	0.5	1	2
	KPI4	0.33	0.14	0.2	1	1	0.33	0.17	0.33	0.5
	KPI5	0.5	0.17	0.33	1	1	0.5	0.25	0.33	0.5
	KPI6	1	0.5	1	3	2	1	0.5	1	2
	KPI7	2	0.5	2	6	4	2	1	2	2
	KPI8	0.5	0.5	1	3	3	1	0.5	1	2
	KPI9	0.5	0.25	0.5	2	2	0.5	0.5	0.5	1
2	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	1	4	2	1	0.5	2	2
	KPI2	2	1	2	7	4	2	2	3	3
	KPI3	1	0.5	1	3	4	1	1	1	2
	KPI4	0.25	0.14	0.33	1	0.5	1	0.17	0.5	2
	KPI5	0.5	0.25	0.25	2	1	1	0.2	0.33	0.5
	KPI6	1	0.5	1	1	1	1	0.5	1	1
	KPI7	2	0.5	1	6	5	2	1	2	2
	KPI8	0.5	0.33	1	2	3	1	0.5	1	2
	KPI9	0.5	0.33	0.5	0.5	2	1	0.5	0.5	1
3	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	1	4	2	1	0.5	1	2
	KPI2	2	1	2	7	4	2	2	3	3
	KPI3	1	0.5	1	5	3	1	0.5	2	3
	KPI4	0.25	0.14	0.2	1	0.5	0.33	0.17	1	0.5
	KPI5	0.5	0.25	0.33	2	1	0.5	0.2	0.33	0.5
	KPI6	1	0.5	1	3	2	1	0.5	0.5	2
	KPI7	2	0.5	2	6	5	2	1	2	2
	KPI8	1	0.33	0.5	1	3	2	0.5	1	2
	KPI9	0.5	0.33	0.33	2	2	0.5	0.5	0.5	1
4	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	1	4	2	0.5	1	0.5	2
	KPI2	2	1	2	7	3	2	2	2	3
	KPI3	1	0.5	1	5	3	0.5	0.5	0.5	2
	KPI4	0.25	0.14	0.2	1	0.5	0.5	0.17	2	0.5
	KPI5	0.5	0.33	0.33	2	1	0.5	0.25	0.33	0.5
	KPI6	2	0.5	2	2	2	1	0.5	1	2
	KPI7	1	0.5	2	6	4	2	1	3	2
	KPI8	2	0.5	2	0.5	3	1	0.33	1	2
	KPI9	0.5	0.33	0.5	2	2	0.5	0.5	0.5	1

Table A1. Continued on next page.

Table A1 (continued). Expert evaluations.

Exp.	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
5	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
	KPI1	1	0.5	1	4	3	2	0.5	1	2
	KPI2	2	1	2	5	4	2	1	2	3
	KPI3	1	0.5	1	7	3	1	2	1	2
	KPI4	0.25	0.2	0.14	1	1	0.33	0.17	0.33	0.5
	KPI5	0.33	0.25	0.33	1	1	1	0.25	0.33	0.5
	KPI6	0.5	0.5	1	3	1	1	1	1	2
	KPI7	2	1	0.5	6	4	1	1	2	2
	KPI8	1	0.5	1	3	3	1	0.5	1	1
	KPI9	0.5	0.33	0.5	2	2	0.5	0.5	1	1
6	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
	KPI1	1	1	0.5	4	3	0.5	0.5	1	1
	KPI2	1	1	1	7	4	3	2	2	1
	KPI3	2	1	1	5	5	1	0.5	1	1
	KPI4	0.25	0.14	0.2	1	1	0.33	0.17	0.33	0.5
	KPI5	0.33	0.25	0.2	1	1	0.5	0.25	0.33	2
	KPI6	2	0.33	1	3	2	1	1	1	2
	KPI7	2	0.5	2	6	4	1	1	2	2
	KPI8	1	0.5	1	3	3	1	0.5	1	2
	KPI9	1	1	1	2	0.5	0.5	0.5	0.5	1
7	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
	KPI1	1	0.5	2	4	2	0.5	0.5	2	2
	KPI2	2	1	2	6	4	1	2	2	3
	KPI3	0.5	0.5	1	5	3	1	0.5	2	3
	KPI4	0.25	0.17	0.2	1	2	0.33	0.17	0.33	0.5
	KPI5	0.5	0.25	0.33	0.5	1	0.5	0.25	0.33	1
	KPI6	2	1	1	3	2	1	0.5	1	2
	KPI7	2	0.5	2	6	4	2	1	3	2
	KPI8	0.5	0.5	0.5	3	3	1	0.33	1	2
	KPI9	0.5	0.33	0.33	2	1	0.5	0.5	0.5	1
8	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
	KPI1	1	0.5	3	4	2	0.5	0.5	1	2
	KPI2	2	1	3	7	4	2	2	1	3
	KPI3	0.33	0.33	1	5	3	1	0.5	1	2
	KPI4	0.25	0.14	0.2	1	1	0.25	0.2	0.33	0.5
	KPI5	0.5	0.25	0.33	1	1	0.5	0.25	0.33	0.5
	KPI6	2	0.5	1	4	2	1	0.5	0.5	3
	KPI7	2	0.5	2	5	4	2	1	2	2
	KPI8	1	1	1	3	3	2	0.5	1	2
	KPI9	0.5	0.33	0.5	2	2	0.33	0.5	0.5	1
9	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
	KPI1	1	0.5	3	4	2	2	0.5	2	2
	KPI2	2	1	2	7	4	1	2	1	3
	KPI3	0.33	0.5	1	5	3	2	0.5	1	2
	KPI4	0.25	0.14	0.2	1	1	1	1	2	0.5
	KPI5	0.5	0.25	0.33	1	1	1	0.25	0.33	1
	KPI6	0.5	1	0.5	1	1	1	1	0.5	2
	KPI7	2	0.5	2	1	4	1	1	2	2
	KPI8	0.5	1	1	0.5	3	2	0.5	1	2
	KPI9	0.5	0.33	0.5	2	1	0.5	0.5	0.5	1

Table A1. Continued on next page.

Table A1 (continued). Expert evaluations.

Exp.	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
10	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	1	4	2	0.5	0.5	1	2
	KPI2	2	1	2	7	4	2	2	2	3
	KPI3	1	0.5	1	5	2	1	0.5	1	1
	KPI4	0.25	0.14	0.2	1	1	2	0.17	0.33	0.5
	KPI5	0.5	0.25	0.5	1	1	0.5	0.25	0.33	1
	KPI6	2	0.5	1	0.5	2	1	0.5	2	2
	KPI7	2	0.5	2	6	4	2	1	2	2
	KPI8	1	0.5	1	3	3	0.5	0.5	1	2
	KPI9	0.5	0.33	1	2	1	0.5	0.5	0.5	1
11	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	0.5	4	2	0.5	0.5	2	2
	KPI2	2	1	1	6	5	3	3	2	3
	KPI3	2	1	1	5	2	1	0.5	1	2
	KPI4	0.25	0.17	0.2	1	1	0.33	0.17	0.33	0.5
	KPI5	0.5	0.2	0.5	1	1	0.5	0.5	0.33	0.5
	KPI6	2	0.33	1	3	2	1	0.5	1	2
	KPI7	2	0.33	2	6	2	2	1	2	2
	KPI8	0.5	0.5	1	3	3	1	0.5	1	2
	KPI9	0.5	0.33	0.5	2	2	0.5	0.5	0.5	1
12	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	2	4	2	0.5	0.5	1	2
	KPI2	2	1	2	8	4	3	2	2	3
	KPI3	0.5	0.5	1	4	3	1	0.5	1	3
	KPI4	0.25	0.13	0.25	1	1	1	0.14	0.25	0.5
	KPI5	0.5	0.25	0.33	1	1	0.5	0.25	0.33	0.5
	KPI6	2	0.33	1	1	2	1	0.5	2	2
	KPI7	2	0.5	2	7	4	2	1	3	2
	KPI8	1	0.5	1	4	3	0.5	0.33	1	1
	KPI9	0.5	0.33	0.33	2	2	0.5	0.5	1	1
13	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	1	6	2	0.5	0.5	2	3
	KPI2	2	1	2	7	4	2	2	1	3
	KPI3	1	0.5	1	5	5	1	0.5	2	2
	KPI4	0.17	0.14	0.2	1	2	0.33	0.2	0.33	0.5
	KPI5	0.5	0.25	0.2	0.5	1	0.5	2	0.33	1
	KPI6	2	0.5	1	3	2	1	2	1	1
	KPI7	2	0.5	2	5	0.5	0.5	1	3	3
	KPI8	0.5	1	0.5	3	3	1	0.33	1	3
	KPI9	0.33	0.33	0.5	2	1	1	0.33	0.33	1
14	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	0.5	4	3	1	0.5	1	3
	KPI2	2	1	2	6	4	3	2	2	2
	KPI3	2	0.5	1	5	3	1	0.5	2	2
	KPI4	0.25	0.17	0.2	1	2	0.33	0.17	0.33	2
	KPI5	0.33	0.25	0.33	0.5	1	0.5	0.2	0.33	0.5
	KPI6	1	0.33	1	3	2	1	0.5	1	2
	KPI7	2	0.5	2	6	5	2	1	2	2
	KPI8	1	0.5	0.5	3	3	1	0.5	1	2
	KPI9	0.33	0.5	0.5	0.5	2	0.5	0.5	0.5	1

Table A1. Continued on next page.

Table A1 (continued). Expert evaluations.

Exp.	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
15	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	2	1	6	2	0.5	1	1	1
	KPI2	0.5	1	2	7	4	2	2	2	4
	KPI3	1	0.5	1	5	2	0.5	1	1	2
	KPI4	0.17	0.14	0.2	1	0.5	0.33	0.17	1	0.5
	KPI5	0.5	0.25	0.5	2	1	0.5	1	0.33	0.5
	KPI6	2	0.5	2	3	2	1	0.5	2	2
	KPI7	1	0.5	1	6	1	2	1	2	3
	KPI8	1	0.5	1	1	3	0.5	0.5	1	2
	KPI9	1	0.25	0.5	2	2	0.5	0.33	0.5	1
16	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	1	2	4	2	0.5	0.5	0.5	2
	KPI2	1	1	2	7	4	2	2	3	3
	KPI3	0.5	0.5	1	5	3	1	0.5	1	2
	KPI4	0.25	0.14	0.2	1	1	0.33	0.17	0.33	0.5
	KPI5	0.5	0.25	0.33	1	1	0.5	0.25	0.33	0.5
	KPI6	2	0.5	1	3	2	1	0.5	1	2
	KPI7	2	0.5	2	6	4	2	1	2	3
	KPI8	2	0.33	1	3	3	1	0.5	1	1
	KPI9	0.5	0.33	0.5	2	2	0.5	0.33	1	1
17	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	1	1	4	2	1	1	1	2
	KPI2	1	1	2	6	6	1	2	2	3
	KPI3	1	0.5	1	5	5	2	0.5	2	2
	KPI4	0.25	0.17	0.2	1	0.5	1	0.17	0.25	0.5
	KPI5	0.5	0.17	0.2	2	1	1	0.25	1	0.5
	KPI6	1	1	0.5	1	1	1	0.5	1	2
	KPI7	1	0.5	2	6	4	2	1	2	3
	KPI8	1	0.5	0.5	4	1	1	0.5	1	2
	KPI9	0.5	0.33	0.5	2	2	0.5	0.33	0.5	1
18	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	1	1	4	2	1	0.5	1	2
	KPI2	1	1	1	7	4	2	2	2	3
	KPI3	1	1	1	5	3	2	0.5	1	2
	KPI4	0.25	0.14	0.2	1	1	0.33	0.17	0.33	0.5
	KPI5	0.5	0.25	0.33	1	1	0.5	0.33	0.33	0.5
	KPI6	1	0.5	0.5	3	2	1	0.5	1	2
	KPI7	2	0.5	2	6	3	2	1	1	1
	KPI8	1	0.5	1	3	3	1	1	1	2
	KPI9	0.5	0.33	0.5	2	2	0.5	1	0.5	1
19	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	2	1	2	2	0.5	0.5	2	2
	KPI2	0.5	1	2	7	4	2	2	2	3
	KPI3	1	0.5	1	5	4	1	0.5	0.5	3
	KPI4	0.5	0.14	0.2	1	2	0.33	0.17	1	2
	KPI5	0.5	0.25	0.25	0.5	1	0.5	0.33	1	0.5
	KPI6	2	0.5	1	3	2	1	0.5	1	2
	KPI7	2	0.5	2	6	3	2	1	2	1
	KPI8	0.5	0.5	2	1	1	1	0.5	1	3
	KPI9	0.5	0.33	0.33	0.5	2	0.5	1	0.33	1

Table A1. Continued on next page.

Table A1 (continued). Expert evaluations.

Exp.	KPI	KPI1	KPI2	KPI3	KPI4	KPI5	KPI6	KPI7	KPI8	KPI9
20	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	1	4	3	0.5	1	1	2
	KPI2	2	1	2	5	5	1	2	1	4
	KPI3	1	0.5	1	5	4	1	0.5	1	1
	KPI4	0.25	0.2	0.2	1	0.5	0.33	0.17	0.33	1
	KPI5	0.33	0.2	0.25	2	1	0.5	0.25	0.33	0.5
	KPI6	2	1	1	3	2	1	0.5	1	2
	KPI7	1	0.5	2	6	4	2	1	1	3
	KPI8	1	1	1	3	3	1	1	1	3
	KPI9	0.5	0.25	1	1	2	0.5	0.33	0.33	1
21	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	1	4	2	1	0.5	1	2
	KPI2	2	1	2	7	4	2	1	3	4
	KPI3	1	0.5	1	5	3	1	0.5	1	2
	KPI4	0.25	0.14	0.2	1	2	0.33	0.17	0.33	2
	KPI5	0.5	0.25	0.33	0.5	1	0.5	1	0.33	0.5
	KPI6	1	0.5	1	3	2	1	0.5	2	2
	KPI7	2	1	2	6	1	2	1	2	3
	KPI8	1	0.33	1	3	3	0.5	0.5	1	3
	KPI9	0.5	0.25	0.5	0.5	2	0.5	0.33	0.33	1
22	**KPI**	**KPI1**	**KPI2**	**KPI3**	**KPI4**	**KPI5**	**KPI6**	**KPI7**	**KPI8**	**KPI9**
	KPI1	1	0.5	0.5	4	2	0.5	0.5	1	1
	KPI2	2	1	3	7	4	2	2	2	5
	KPI3	2	0.33	1	5	3	2	1	1	2
	KPI4	0.25	0.14	0.2	1	0.5	0.33	0.17	0.33	2
	KPI5	0.5	0.25	0.33	2	1	0.5	0.25	0.33	0.5
	KPI6	2	0.5	0.5	3	2	1	0.5	1	3
	KPI7	2	0.5	1	6	4	2	1	3	2
	KPI8	1	0.5	1	3	3	1	0.33	1	2
	KPI9	1	0.2	0.5	0.5	2	0.33	0.5	0.5	1