Towards Efficient Hospital Pharmaceutical Logistics: A Critical Review of Optimization Levers and Decision Modeling Using BWM–DEMATEL

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Abstract

The hospital pharmaceutical supply chain is a strategic lever for ensuring efficiency, safety, and continuity of care. This article offers a critical and structured review of the optimization tools and methods employed in healthcare institutions, analyzing three main dimensions: inventory management, internal distribution, and supporting technologies. The study highlights the shift from traditional approaches to more integrated, intelligent, and digitalized solutions. Complementing this review, a multi-criteria decision-making framework is introduced based on the Best Worst Method (BWM) and DEMATEL approaches. This framework allows for the prioritization of strategic logistics criteria and the modeling of their interdependencies in a complex environment. Although the model has not yet been applied to a real-world case, it provides a useful conceptual foundation to guide hospital logistics decision-making. This work paves the way for future experimentation in actual healthcare settings.

Keywords

Hospital logistics; pharmaceutical supply chain; critical review; optimization; decision support; multi-criteria decision-making; BWM; DEMATEL.

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1. Introduction

The hospital pharmaceutical supply chain represents a critical pillar of the healthcare system, ensuring the continuous, secure, and efficient supply of medications to patients. In a context characterized by intensifying budgetary constraints, evolving regulatory requirements, and rising expectations in terms of care quality, drug logistics has moved beyond a purely operational function. It has become a major strategic lever for hospital performance, clinical safety, and organizational resilience.

Historically, hospital pharmaceutical logistics was based on empirical and poorly integrated practices, largely driven by staff experience. As early as the 1960s, the first quantitative approaches emerged, including economic order quantity models (Harris, 1913; Hadley & Whitin, 1963), ABC/VED classifications (Churchman et al., 1957; WHO, 1970), and the first standardized distribution systems (Kovacs, 1984). These tools progressively enabled a rationalization of internal pharmaceutical flows.

Today, new challenges are driving profound transformation: increasingly complex care processes, rising use of high-cost or temperature-sensitive drugs, stringent traceability requirements, rapid digitalization, health crises (e.g., COVID-19), and increasing pressure on hospital performance. In response to these changes, an integrated, intelligent, and systemic approach is becoming essential to effectively manage the medication circuit.

Recent literature highlights the emergence of advanced technological solutions (RFID, IoT, blockchain), predictive systems, automation tools, and hybrid approaches that combine technology, organization, and decision-making. These innovations are reshaping traditional models and paving the way for more agile, connected, and patient-centered logistics. However, they also introduce new trade-offs among safety, cost, acceptability, and flexibility, making logistics choices more complex.

In this context, the present article pursues two main objectives:

1. To provide a critical and structured review of the optimization tools used in the hospital pharmaceutical supply chain, highlighting the contributions, limitations, and complementarities of both traditional and contemporary approaches;
2. To propose a multi-criteria decision-making (MCDM) framework based on the Best Worst Method (BWM) and DEMATEL, aimed at prioritizing the identified strategic

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levers and modeling their interdependencies. This approach serves to structure decision-making in hospital environments characterized by a multiplicity of criteria and systemic complexity.

The analysis is organized around four main pillars: (1) inventory management, (2) internal distribution, (3) supporting technologies, and (4) an integrated discussion of the overall logistics system performance. The final section introduces a multi-criteria decision model derived from the findings of this review and designed as a strategic decision-support tool for public hospitals.

2. Inventory Management Tools

Effective inventory management is a foundational element of hospital pharmaceutical logistics. It plays a central role in ensuring continuous drug availability, minimizing wastage, reducing holding costs, and maintaining service quality. In healthcare environments characterized by fluctuating demand, limited budgets, and critical medication needs, inventory decisions must be both operationally efficient and clinically safe.

This section presents the main tools and methods used to manage pharmaceutical inventories in hospitals. It is structured around two key components: (1) replenishment policies, which define when and how stock should be replenished; and (2) classification methods, which help prioritize inventory management efforts based on product value, criticality, or consumption patterns.

2.1 Replenishment Policies

Effective management of hospital pharmaceutical inventories relies on rigorous replenishment policies capable of balancing medication availability with cost control. Traditional approaches fall into three main categories:

- Periodic review (T, S): Inventory levels are checked at fixed intervals and replenished up to a predetermined threshold (Hadley & Whitin, 1963).
- Continuous review (s, Q): An order is triggered once the stock falls below a predefined threshold, with a fixed order quantity (Harris, 1913).
- Hybrid models (R, s, Q): These combine periodic reviews with reorder points and fixed quantities (Fathollahi-Fard et al., 2025).

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However, these models show limitations in environments with unstable demand or perishable products. Consequently, innovative approaches based on artificial intelligence and simulation are increasingly being adopted:

- Fathollahi-Fard et al. (2025): Deep Reinforcement Learning (DRL) for managing sensitive drugs.
- Saddikuti et al. (2024): Multi-criteria simulation considering criticality, costs, and delays.
- Tang & Anane (2023): Robust models for emergency inventory management.
- Almulhim & Khader (2023): Cloud-based predictive solutions using consumption history.

Table 1. Summary of Main Replenishment Policy Types

Policy Type	**Principle**	**Advantages**	**Limitations**	**Reference**
Periodic (T, S)	Fixed-interval review, replenishment to threshold	Easy to plan	Risk of stockouts between reviews	Hadley & Whitin (1963)
Continuous (s, Q)	Reorder triggered at threshold, fixed quantity	High responsiveness	Requires constant monitoring	Harris (1913)
Hybrid (R, s, Q)	Periodic review + reorder point + fixed quantity	Balance between flexibility and control	More complex configuration	Fathollahi-Fard et al. (2025)
DRL / MCDM	AI and multi-criteria-based approaches	Contextualized and adaptive	Technological complexity	Saddikuti (2024), Almulhim (2023)

This table illustrates the transition from traditional to intelligent models. While classical policies remain relevant in stable environments, modern methods offer dynamic adaptability—especially useful in cases of fluctuating demand, shortages, or health crises. They also integrate more easily with ERP or WMS systems, enhancing hospital responsiveness.

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2.2 Classification Methods

Pharmaceutical product classification is essential for prioritizing logistics efforts based on value, criticality, or consumption frequency. Key classification methods include:

- ABC: Based on Pareto's law, distinguishing items by annual consumption value (Churchman et al., 1957; Riggs, 1968).
- VED: Categorizes items by clinical criticality (Vital, Essential, Desirable), formalized by WHO (1970).
- ABC–VED combined: Cross-analysis of value and criticality.
- MASTA: A multi-criteria approach integrating frequency, criticality, and accessibility (Sanogo, 2024).

Recent advancements have introduced automation tools to enhance classification reliability:

- Farahani et al. (2023): AI-driven automatic classification.
- Bandyopadhyay & Bhattacharya (2022): Fuzzy logic for dynamic prioritization.
- Al-Werikat et al. (2023): Machine learning-based segmentation.

Replenishment policies and classification methods form the foundation of hospital pharmaceutical logistics. However, their effectiveness depends on adaptability to hospital-specific constraints, such as drug criticality, demand variability, and human resource availability. Current innovations pave the way for more precise, predictive, and integrated inventory management systems.

3. Internal Distribution Methods

Internal distribution represents a crucial link in the hospital pharmaceutical supply chain. It encompasses the physical flows, organizational methods, and technologies involved in the safe and efficient transfer of medications from the central pharmacy to clinical units. Beyond a logistical function, this activity directly influences service quality, patient safety, and overall hospital efficiency.

3.1 Replenishment Cycle Activities

According to Blouin et al. (2000), the hospital replenishment cycle consists of four key steps:

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- Ordering: Identifying needs and submitting requests;
- Preparing: Physically assembling orders in the pharmacy;
- Transporting: Delivering medications to clinical units;
- Storing: Organizing and stocking products locally.

Each of these steps can be affected by the level of automation, available resources, or the organization of care services.

3.2 Replenishment and Distribution Models

Several replenishment and distribution models have been developed for hospitals, ranging from traditional approaches such as the two-bin method to more recent automated systems. These models aim to address the challenges of safety, responsiveness, and efficiency within the constraints of the hospital environment (WHO, 1970; Mahfoudh et al., 2023; Almulhim & Khader, 2023).

Table 2. Replenishment and Distribution Models in Hospital Settings

Model	Principle	Advantages	Limitations	Reference
Manual/Electronic Requisition	Request initiated by staff	Flexibility, close to field reality	Human error risk, inconsistent discipline	Blouin et al. (2001)
Trolley Exchange	Pre-filled trolleys exchanged at regular intervals	Fewer stockouts, time-saving	High cost, logistic rigidity	Kovacs (1984)
Target Level Approach	Replenishment to reach a predefined stock level	Adaptable and easy to understand	Sometimes inaccurate estimation	Ewing-Juul et al. (1989)
Kanban (Two-bin system)	Empty bin triggers replenishment	Simplicity, potential for automation	Risk of error if forgotten or mishandled	Landry & Beaulieu (2001)
Unit Dose Dispensing (UDD)	Personalized daily or weekly patient-specific delivery	High safety, error reduction	Time-consuming, requires robust	Akhdari et al. (2023)

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			organization	

This table illustrates the diversity of practices, which must be adapted to each hospital's context. Centralized models (e.g., trolleys, UDD) offer better security but demand more resources and precise execution. In contrast, more flexible systems (e.g., requisition, target levels) promote agility at the cost of increased logistical risk. The optimal choice depends on the hospital type, drug criticality, and technological infrastructure.

3.3 Unit Dose Dispensing Systems (UDD)

Unit Dose Dispensing (UDD) is emerging as a standard in modern hospitals. It involves preparing and delivering individual medication doses under each patient's name, either centrally (by the pharmacy) or decentrally (by unit).

Advantages:

- Improved traceability,
- Reduced dispensing errors,
- Better return and waste management.

Limitations:

- Requires robust logistical organization,
- High preparation time,
- Material investments (robots, software).

Akhdari et al. (2023) confirm the positive impact of UDD on patient safety. The integration of RFID and mobile robotics (Rajalakshmi et al., 2024) further optimizes these systems and facilitates their adoption in high-volume hospital environments.

3.4 Performance Challenges and Adaptation

According to Bélanger et al. (2018), internal distribution system performance depends on four key factors:

- Operating cost,
- Service level (timeliness, accuracy),

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- Staff workload,
- End-user satisfaction.

A study by Mahfoudh et al. (2023) in Tunisia shows that inefficient distribution models often lead to stockouts, forcing patients to purchase medications outside the hospital system.

Internal distribution is no longer a simple logistics operation it has become a strategic lever for improving care quality, treatment traceability, and organizational effectiveness. Current trends favor automation, personalization (UDD), and the integration of tracking technologies.

4. Supporting Technologies

The growing digitalization of the hospital sector is radically transforming the pharmaceutical supply chain. Supporting technologies including tools for traceability, identification, automation, and monitoring enable more responsive, reliable, and secure management of medication flows.

4.1 Overview of Key Technologies

The modernization of hospital pharmaceutical logistics is increasingly supported by the integration of digital and automated technologies. These technologies serve multiple purposes, including product identification, traceability, inventory management, and decision support. While some solutions are relatively simple and cost-effective (e.g., barcodes), others involve complex systems with higher implementation costs but greater performance gains (e.g., RFID, blockchain, IoT).

To provide a comparative overview, Table 3 summarizes the most prominent supporting technologies used in hospital settings, outlining their key advantages, limitations, and reference studies from the recent literature.

Table 3: Main Supporting Technologies in Hospital Logistics

Technology	Advantages	Limitations / Risks	References
Barcodes (1D/2D)	Secure identification, error reduction, low cost	Requires disciplined scanning, low flexibility	Poon et al. (2006), Franklin et al. (2008)

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RFID	Contactless reading, real-time visibility, bedside tracking	High cost, data privacy concerns	Swedberg (2005), Fathollahi-Fard et al. (2025)
Blockchain	Tamper-proof traceability, fraud prevention, trust among stakeholders	Technical complexity, slow adoption	WHO (2024), Zheng et al. (2023)
Internet of Things	Dynamic tracking, predictive maintenance, automatic alerts	Complex software integration, sensor costs	Piccinini et al. (2013), Zhou et al. (2024)
Automated Equipment	Secure cabinets, robots, smart glasses; saves time and increases accuracy	High initial investment, training required	Franklin et al. (2008), CHU Lille
Hybrid Solutions	Barcode + RFID combinations for enhanced flexibility	Requires interoperability between systems	Swedberg (2005), WHO (2024)

This table illustrates the diversity of available technologies and their varying contributions. While barcodes offer a basic, low-cost solution, RFID and IoT enable proactive real-time management. Blockchain remains underutilized but holds strong potential for traceability. Automated systems represent a high-value optimization path in modernized hospitals.

4.2 Examples of Successful Integration

- RFID + IoT for thermo-sensitive drug management: Automatically sends alerts when temperature thresholds are exceeded, preventing degradation of sensitive medications.
- Blockchain in regional distribution networks: Used to verify batch compliance and track product origins (WHO, 2024).
- Automated pharmacy cabinets (APS) and storage robots at Lille University Hospital: Reduce dispensing errors and free up nursing time (Franklin et al., 2008).

4.3 Success Factors and Recommendations

Successful integration of these technologies depends on several key conditions:

- Interoperability with hospital software systems (ERP, WMS, GHT),

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- Adequate training of clinical and logistics staff,
- Realistic cost-benefit evaluations,
- Institutional support (policies, funding, regulations),
- Progressive implementation adapted to the hospital's means and culture.

The WHO (2024) encourages the rational adoption of these tools, combining simplicity, efficiency, and robustness. Supporting technologies are strategic levers for transforming hospital pharmaceutical logistics. When well integrated, they not only enhance traceability and safety, but also improve the overall efficiency of the healthcare system. The challenge is no longer to choose "the best technology" but to build a technological architecture tailored to the context.

5. Synthesis and Discussion

The analysis of tools, methods, and technologies used in the hospital pharmaceutical supply chain reveals three structuring dynamics:

- An increasing integration of logistical approaches (inventory, distribution, technology),
- A strategic reassessment of internal distribution processes,
- The growing influence of digital technologies on hospital performance.

5.1 Complementarity of Logistical Tools

Traditional inventory management models (periodic, continuous, hybrid) and classification methods (ABC, VED, MASTA) remain essential. However, their performance depends on:

- The hospital context (size, specialty, available resources),
- The degree of digitalization (use of ERP, WMS, system interoperability),
- The capacity to adapt to uncertainty (stockouts, emergencies, demand fluctuations).

Research by Fathollahi-Fard, Saddikuti, and Almulhim emphasizes that the most effective tools combine artificial intelligence, real-time data, and multi-criteria modeling. Therefore, the optimal approach is not universal but rather contextualized and integrated.

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5.2 Internal Distribution: A Strategic Link Often Overlooked

Internal distribution has long been neglected in hospital logistics modernization strategies. Yet it constitutes a critical link inefficiencies at this level can offset upstream improvements.

Studies by Mahfoudh et al. (2023) show that in several Tunisian hospitals, internal distribution issues have caused stockouts, forcing patients to purchase their medications from the private sector.

Mixed systems (e.g., two-bin + UDD) or automated ones (APS, smart trolleys) have proven effective when well integrated into clinical workflows. The key challenge is ensuring smooth synchronization between pharmacy, logistics, and care delivery.

5.3 Technologies as a Catalyst for Transformation

The adoption of RFID, cloud computing, IoT, or blockchain technologies enables:

- Automated alerts (e.g., stockouts, expiration dates),
- End-to-end traceability down to the patient's bedside,
- Reduction in human error,
- Enhanced transparency across logistics processes.

However, successful deployment requires:

- A realistic cost-benefit analysis,
- Change management competencies,
- Strong involvement of end users.

Hybrid approaches (e.g., barcodes + RFID, IoT + APS) appear especially relevant for resource-constrained hospitals, offering a balanced compromise between effectiveness and feasibility.

5.4 Limitations of the Critical Review and Toward Decision Modeling

The critical review presented in previous sections identified numerous levers for optimizing hospital pharmaceutical logistics. However, it also revealed several structural and methodological limitations. First, the literature remains fragmented, often addressing storage,

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distribution, or technology issues in isolation, without systemic integration. Second, most empirical studies are concentrated in high-income countries, with limited data from resource-limited settings.

Moreover, existing studies rarely account for interactions between decision criteria. For instance, how does technology cost affect acceptability? How does traceability influence actual drug availability? This lack of consideration for interdependencies makes it difficult to implement practical solutions.

These findings justify the need for a structured multi-criteria decision-making (MCDM) approach. Faced with numerous and often conflicting objectives in hospital logistics, decision-makers need a framework to prioritize criteria, balance trade-offs, and model cross-influences. The following section introduces a model combining BWM (Best Worst Method) and DEMATEL to address this decision-making complexity.

6. Multi-Criteria Decision Support in Hospital Pharmaceutical Logistics: A BWM–DEMATEL Approach

6.1 Introduction and Methodological Justification

The critical analysis conducted in the previous sections identified several optimization levers for hospital pharmaceutical logistics, grouped into technological (e.g., RFID, IoT, APS), organizational (e.g., UDD, two-bin systems), and human (e.g., staff acceptance, training) dimensions. However, modernization decisions in this context are made complex by the multiplicity of interrelated—and sometimes contradictory—objectives: reducing costs while enhancing safety, automating processes without reducing acceptability, increasing availability without causing waste.

To address this decision-making complexity, a Multi-Criteria Decision-Making (MCDM) approach is adopted. It is based on two complementary tools:

- **Best Worst Method (BWM):** A technique that derives criterion weights through a consistent and reduced set of expert judgments.
- **DEMATEL:** A method used to model causal interrelationships among criteria, identifying key drivers (cause criteria) and resulting effects.

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This combined BWM–DEMATEL methodology aligns with the systemic nature of hospital logistics and supports the prioritization of strategic actions in a structured and justified manner.

MCDM approaches have a well-established theoretical foundation, dating back to the 1960s with the development of ELECTRE by Roy (1968), followed by Analytic Hierarchy Process (AHP) by Saaty (1980). Causal modeling was formalized through DEMATEL, introduced by Gabus and Fontela (1972). More recently, BWM, proposed by Rezaei (2015), has enhanced MCDM methods by combining mathematical rigor, judgmental consistency, and ease of use—particularly due to its limited number of required comparisons. As a descendant of AHP-style weighting approaches, BWM allows structured elicitation of criteria weights and has been used in healthcare contexts such as strategy prioritization (Chen et al., 2022) and medical waste management (Alimoradi et al., 2023). Meanwhile, DEMATEL is especially effective for modeling causal dependencies among criteria, as demonstrated in the analysis of hospital logistics resilience (Li et al., 2023; Zhang et al., 2024).

To rigorously structure the multi-criteria analysis process, the proposed model is based on a three-step methodological sequence. First, the Best-Worst Method (BWM) is applied to derive the weights of the selected criteria based on expert judgments. Next, the DEMATEL method is used to examine the influence relationships among these criteria, distinguishing strategic drivers (causes) from expected outcomes (effects). Finally, a visualization of the criteria according to their roles within the decision-making system helps guide logistical choices. The following figure illustrates this methodological sequence.

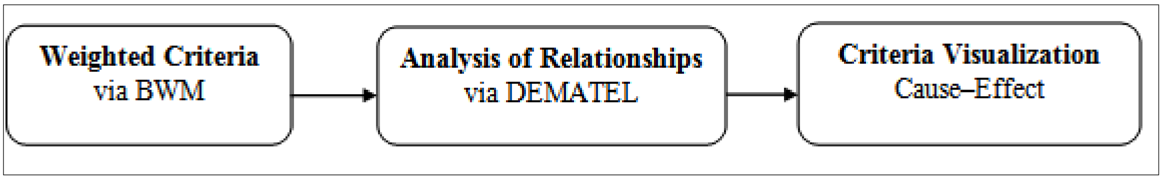

Figure 1 – Steps of the Proposed BWM–DEMATEL Methodology for Decision Support in Hospital Logistics

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6.2 Definition of Decision Criteria

The decision criteria used in the model stem from the critical review in sections 2 to 5. They reflect both key priorities in recent literature and operational constraints in public hospitals.

Table 4. Selected Decision Criteria for Multi-Criteria Evaluation of Hospital Pharmaceutical Logistics

Code	Criterion	Justification
C1	Availability of Medications	Core indicator of system performance and patient satisfaction
C2	Total Implementation Cost	Common constraint in public hospitals; critical budgetary consideration
C3	Patient Safety	Top priority in any health-related logistics system
C4	Traceability and Regulatory Compliance	Increasingly important due to evolving health regulations
C5	Staff Acceptability	Key success factor in adopting new innovations
C6	Flexibility in Uncertain Contexts	System's ability to respond to crises, shortages, and fluctuations
C7	Degree of Automation/Digitalization	Reflects technological integration and its effect on operational efficiency

After defining the decision criteria based on the critical analysis, the following figure presents the structure of the proposed multi-criteria analysis model. It illustrates how the criteria are integrated into the BWM–DEMATEL process, highlighting their role in each phase: weighting, analysis of interdependencies, and final classification into causes and effects. This diagram provides an operational overview of the evaluation framework tailored to hospital pharmaceutical logistics.

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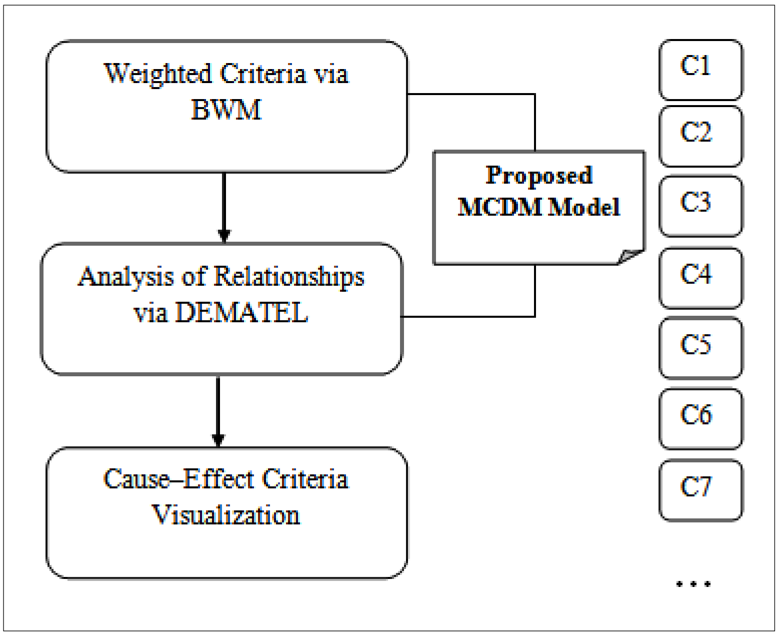

Figure 2 – Diagram of the BWM–DEMATEL Multi-Criteria Analysis Model Applied to Hospital Logistics Criteria

6.3 Weighting Criteria Using the BWM Method

BWM involves identifying the most important (Best) and least important (Worst) criterion through expert judgment. The Best criterion is compared to all others, and each is then compared to the Worst, using a preference scale from 1 to 9.

This dual vector of comparisons is used to solve an optimization model (often linear) that derives a weight vector minimizing maximum inconsistency, ensuring coherent judgments.

Compared to AHP, the main advantage of BWM lies in its reduced number of comparisons while maintaining reliability—especially useful in hospital settings where expert time is limited.

6.4 Analyzing Interdependencies with DEMATEL

Once criteria weights are established, DEMATEL is used to analyze the causal relationships among them. Experts evaluate the degree to which each criterion influences the others, on a scale from 0 (no influence) to 4 (very strong influence).

This data is used to construct a direct influence matrix, which is then transformed into a total influence matrix. From this, two indicators are extracted:

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- Prominence (centrality): the sum of influences received and exerted,
- Relation (cause or effect): the difference between influence exerted and received.

A positive relation score identifies a cause (strategic driver), while a negative score denotes an effect (resultant outcome). This analysis highlights the criteria that should be strengthened to produce a system-wide positive impact.

6.5 Interpretation of Expected Results

Based on the literature (Chen et al., 2022; Li et al., 2023; Zhang et al., 2024), and in the absence of empirical data for this article, the following hypotheses can be made:

- Technological and organizational levers such as automation (C7), traceability (C4), and flexibility (C6) generally act as causal criteria, directly shaping logistics system performance;
- Medication availability (C1) and patient safety (C3) are typically effects, reflecting the system's overall functioning;
- Staff acceptability (C5) acts as a moderating criterion, capable of amplifying or hindering the impact of other levers.

This structural hypothesis, grounded in recent studies, will serve as the basis for future empirical validation of the proposed model.

6.6 Contribution of the BWM–DEMATEL Approach to Hospital Logistics

This dual-method approach provides:

- A rational foundation for prioritizing investments and organizational reforms.
- Identification of high-leverage strategic levers, particularly in resource-constrained environments;
- A tool to support collective decision-making, by structuring dialogue among stakeholders (logisticians, pharmacists, administrators).

By integrating this approach into hospital modernization efforts, institutions can build more robust, agile, and patient-centered logistics strategies.

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Conclusion and Perspectives

The evolution of hospital pharmaceutical logistics marks a decisive shift toward a more proactive, integrated, and technology-supported management approach. Through a critical review of both classical and contemporary tools, this article has identified key levers to address current challenges, including stockouts, traceability requirements, digital transformation, organizational constraints, and uncertainty management.

Building on this review, a structured decision-support framework was proposed—combining the Best Worst Method (BWM) and DEMATEL—to prioritize logistics performance criteria and analyze the interrelationships between strategic levers. This model enables decision-makers to structure trade-offs between safety, cost, acceptability, and efficiency in a hospital environment characterized by decision complexity and systemic constraints.

The empirical application of this model has not been included in this article in order to preserve methodological consistency. However, its implementation in real hospital settings through case studies or expert surveys—represents an immediate research direction. Such applications will help ground the model in operational realities and assess its decision-making value.

This contribution follows a progressive research logic, combining theoretical synthesis, methodological innovation, and practical perspectives, to support the development of more agile, safer, and patient-centered hospital logistics systems.

Several research avenues could further extend this work, including:

- The empirical application of the BWM–DEMATEL model in different hospital types.
- The integration of environmental and sustainability criteria (green logistics, circular economy).
- The development of hybrid models combining MCDM with intelligent methods (e.g., fuzzy logic, AI, adaptive systems).
- The assessment of healthcare professionals' acceptability of the model and its integration into hospital decision-making processes.

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