


# A Digital Surgical Command Center: Integrating Real-Time Data, Automation, and Clinical Decision-Making to Optimize Surgical Pathways

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**How to cite this paper:** Figueiredo, O. and Duarte, J.A.R. (2026) A Digital Surgical Command Center: Integrating Real-Time Data, Automation, and Clinical Decision-Making to Optimize Surgical Pathways. *E-Health Telecommunication Systems and Networks*, 15, 15-27.  
<https://doi.org/10.4236/etsn.2026.152002>

**Received:** April 22, 2026

**Accepted:** June 21, 2026

**Published:** June 24, 2026

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## Abstract

The increasing complexity of surgical care places substantial operational pressure on healthcare systems, creating the need for integrated data-driven management strategies. This study presents a model of a Digital Surgical Command Center. The center aims to optimize surgical workflows with real-time data, automation, and collaborative decision-making. The system uses user-driven data input, automated processing, real-time analytics dashboards, and collaborative platforms. These features support clinical and operational decisions. Tools such as low-code apps, automated workflows, and business intelligence dashboards are integrated. The model supports continuous monitoring, case prioritization, and dynamic resource allocation. A simulated implementation demonstrates the potential impact of the system in reducing waiting times, improving transparency, and enhancing coordination across multi-disciplinary teams. This approach represents a scalable and adaptable framework for healthcare institutions seeking to implement digital transformation strategies in surgical services.

## Keywords

Digital Health, Surgical Pathways, Waiting Lists, Healthcare Management, Data Integration, Clinical Decision Support

## 1. Introduction

Healthcare systems worldwide face increasing challenges in managing surgical demand, particularly in terms of waiting lists, resource allocation, and ensuring timely access to care. Delays in surgical treatment are associated with worse clinical outcomes, reduced patient satisfaction, and inefficiencies [1] in healthcare de-

livery. Centralized hospital command centers integrating predictive analytics and real-time operational monitoring have emerged as potential strategies to improve patient flow and resource coordination [1].

Traditional management of surgical pathways often relies on fragmented data systems, manual processes, and delayed reporting. These limitations hinder the ability of clinical teams to make informed decisions in real time.

Digital transformation offers an opportunity to overcome these barriers. The integration of real-time data, automation, and analytics can support a more proactive and coordinated approach to surgical management [2]. In this context, the concept of a Digital Surgical Command Center emerges as a centralized, data-driven system designed to monitor, analyze, and optimize surgical processes.

This article presents the design, architecture, and potential impact of such a system, with a focus on its applicability in real-world hospital settings.

Several studies have explored the use of digital tools, real-time dashboards, and hospital command centers to improve healthcare operations [2]. Existing approaches have demonstrated the value of centralized monitoring systems in enhancing patient flow, resource allocation, and operational efficiency [2].

However, most implementations focus on isolated components, such as data visualization or operational dashboards, without providing a fully integrated framework that connects data input, automation, analytics, and collaborative decision-making processes.

In addition, limited attention has been given to the specific challenges of surgical pathway management, particularly in terms of waiting list optimization, cancellation analysis, and real-time patient prioritization.

This study addresses these gaps by proposing an integrated and scalable Digital Surgical Command Center that combines real-time data capture, automated workflows, advanced analytics, and multidisciplinary collaboration. The proposed model provides a practical, end-to-end framework specifically tailored to surgical care, supporting data-driven decision-making and improving operational transparency.

This study proposes the development of a comprehensive and implementable digital framework for surgical workflow optimization, which integrates multiple technological components into a unified system. Unlike previous approaches, this model emphasizes end-to-end integration and practical applicability in real-world healthcare settings.

## 2. Methods

### System Architecture and Conceptual Model [1].

The proposed Digital Surgical Command Center was designed as an integrated digital framework aimed at improving the operational management of surgical pathways through real-time monitoring, workflow automation, analytics, and multidisciplinary coordination. The system architecture was conceptually structured into four interconnected operational layers: data input, automation, analyt-

ics and visualization, and collaboration.

The data input layer is responsible for the structured acquisition of operational and clinical information associated with surgical scheduling and waiting-list management. This includes patient registration data, surgical specialty, priority level, waiting times, cancellation events, and operating room scheduling information. The purpose of this layer is to ensure continuous data availability and interoperability between different operational domains involved in surgical care.

The automation layer supports workflow orchestration and event-driven operational processes. Within this operational framework, automated workflows were designed to simulate the dynamic updating of surgical waiting lists, status modifications, scheduling alerts, and notification pathways. This layer aims to reduce manual administrative burden while enabling continuous synchronization between operational components.

The analytics and visualization layer was developed to support operational intelligence and real-time monitoring. Simulated dashboards were conceptually designed to provide continuous visualization of waiting-list dynamics, exceeded waiting times, cancellation causes, specialty-specific workload distribution, and operating room utilization patterns. The integration of operational indicators into centralized dashboards was intended to facilitate rapid identification of bottlenecks and support adaptive resource allocation.

Finally, the collaboration layer was designed to support multidisciplinary coordination between clinical, operational, and administrative teams. This layer conceptually integrates communication and shared decision-making mechanisms that enable coordinated responses to scheduling variability, cancellations, and operational disruptions.

The proposed architecture follows a modular layered design that allows scalability and potential adaptation to different institutional contexts. Although conceptual, the framework was developed to reflect operational challenges commonly described in surgical systems and healthcare operations literature.

The system architecture is presented in **Figure 1**.

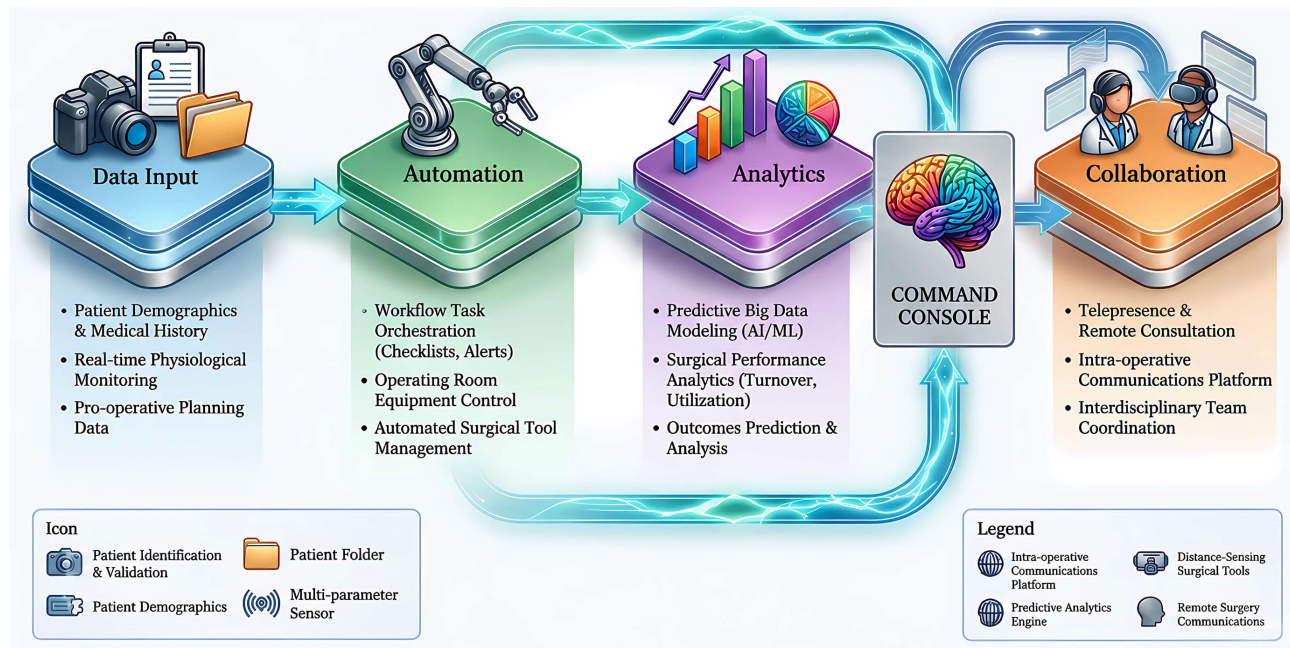
Although the study is based on simulated data, the scenarios were designed to reflect realistic clinical and operational conditions, allowing for the evaluation of system behavior and potential impact in a controlled environment.

The framework was conceptually designed to be deployable within tertiary hospital environments using existing digital infrastructures and interoperable operational platforms. A phased implementation strategy was considered, beginning with pilot operational simulation, followed by limited institutional deployment and prospective operational evaluation.

### **3. Simulated Operational Workflow [3]**

The operational workflow of the Digital Surgical Command Center was modeled to simulate the continuous flow of information across surgical management processes. The system was designed to operate through dynamic interactions between

data acquisition, workflow automation, visualization, and multidisciplinary coordination.



**Figure 1.** Digital surgical command center architecture. Conceptual architecture of the Digital Surgical Command Center. The system integrates four main layers: data input (clinical application), automation workflows, real-time analytics dashboards, and collaborative platforms. Data flows continuously across components, illustrates operational monitoring and decision-making. Source: Author's own elaboration.

Within the simulated workflow, patient data are initially entered into the system following surgical waiting-list registration. Variables include demographic characteristics, surgical specialty, priority category, registration date, waiting time, exceeded waiting days, and procedural status. Once introduced into the operational environment, the data become continuously available for automated processing and visualization.

The automation layer conceptually supports real-time operational updates through event-driven workflow principles. Changes in patient status, scheduling modifications, cancellation events, and exceeded waiting-time thresholds automatically trigger updates across the operational environment. This approach was intended to simulate how a centralized command-center infrastructure could improve visibility and responsiveness within surgical systems.

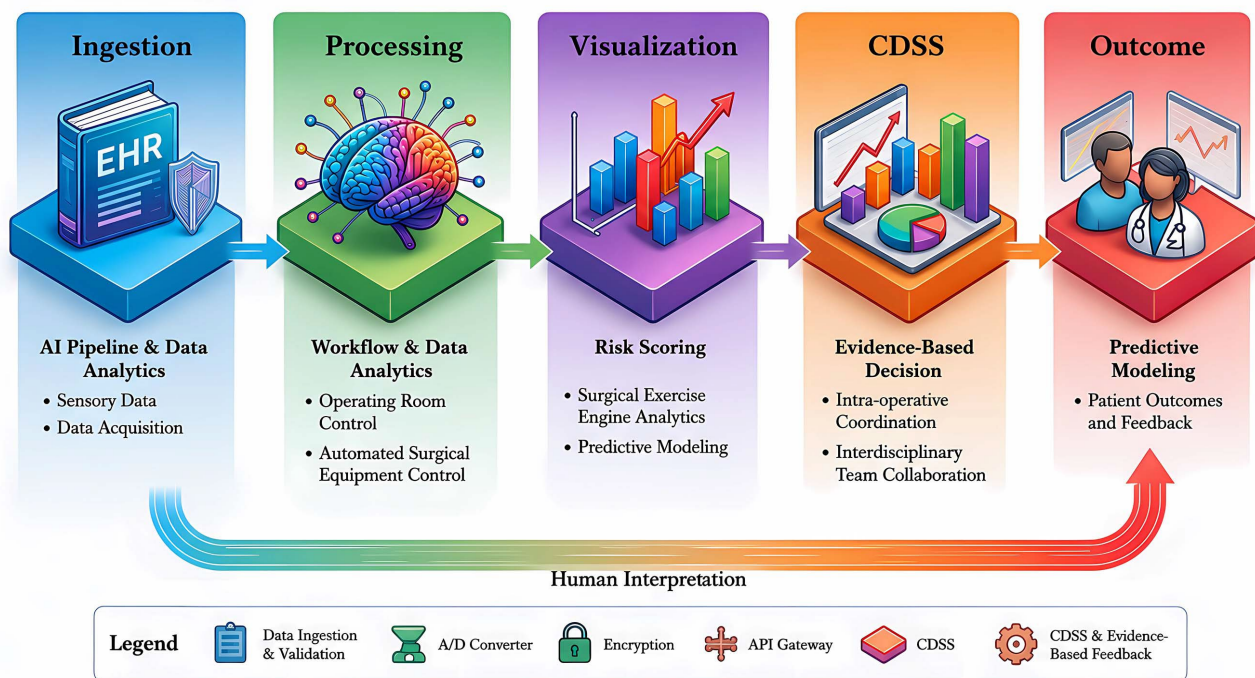
The analytics layer continuously aggregates operational information and presents it through simulated dashboards and performance indicators. These visual interfaces were designed to support monitoring of surgical backlog [3] dynamics, cancellation trends, operating room utilization, and specialty-specific operational variability. The purpose of the dashboards is not only descriptive visualization but also operational support for resource prioritization and scheduling decisions.

The collaboration layer enables multidisciplinary coordination between opera-

tional stakeholders, including surgical teams, administrative staff, and management personnel. Through integrated communication pathways, the framework aims to facilitate coordinated decision-making in response to operational fluctuations and resource constraints.

The workflow was intentionally designed to represent a proof-of-concept operational model rather than a fully implemented hospital information system. Its purpose is to illustrate the potential applicability of integrated digital coordination mechanisms within surgical pathway management.

The operational workflow is illustrated in **Figure 2**.



**Figure 2.** Operational workflow of the system. End-to-end operational workflow of the Digital Surgical Command Center. Clinical data are entered through a digital interface, processed through automated workflows, visualized in dashboards, and used by multi-disciplinary teams to support decision-making and surgical planning. Source: Author's own elaboration

#### 4. Development of Pilot Simulation

This study was developed as a pilot simulation study aimed at evaluating the conceptual applicability of a Digital Surgical Command Center for surgical workflow optimization. Due to the absence of real-world institutional implementation data, a synthetic dataset was generated to simulate operational conditions commonly observed in tertiary hospital surgical systems.

The simulated dataset included 350 fictional patient records distributed across five surgical specialties: Orthopedics, General Surgery, Ophthalmology, Gynecology, and Urology. The simulation incorporated variables associated with surgical waiting-list management, including patient demographic characteristics, surgical priority level, registration date, waiting days, exceeded waiting days, and procedural status.

Priority categories were modeled according to predefined waiting-time thresholds reflecting commonly used surgical prioritization standards. These included normal, priority, very priority, and urgent categories with corresponding operational waiting targets. Patient inflow variability and waiting-time distributions were generated using randomized parameters constrained by operational assumptions derived from published healthcare operations literature.

The simulation environment was intentionally designed to reproduce operational challenges frequently described in surgical systems, including prolonged waiting times, scheduling variability, cancellation events, and specialty-specific workload imbalance. The generated dataset was not intended to reproduce a specific hospital or patient population but rather to provide a proof-of-concept operational environment for evaluating the proposed framework.

The conceptual system architecture follows a layered modular design integrating data ingestion, workflow automation, analytics, visualization, and collaborative operational interfaces. Data processing logic was conceptually modeled according to event-driven workflow principles, allowing continuous propagation of operational updates across the simulated environment.

No real patient data were used in this study. Consequently, ethical approval and informed consent were not required.

## 5. Cost Analysis

A preliminary cost model was developed to estimate the potential financial requirements associated with implementing the proposed Digital Surgical Command Center. The objective of this analysis was not to provide an exact economic evaluation, but rather to explore the potential feasibility and operational implications of deploying such a system within a hospital environment.

Estimated implementation costs include software development and system integration, data infrastructure and licensing, analytics and dashboard tools, and staff training and organizational adaptation processes. Based on the simulated implementation scenario, the estimated initial investment ranges from approximately €40,000 to €95,000, depending on institutional scale, infrastructure requirements, and degree of technological integration.

In addition to initial implementation costs, operational expenses associated with system maintenance, software updates, user support, and data management should also be considered. Annual operational costs were estimated to range between €10,000 and €30,000.

Despite the required investment, the proposed framework may offer potential economic benefits through improved operational efficiency and reduction of avoidable waste associated with surgical delays and cancellations. Within the simulated environment, optimization of scheduling workflows and improved visibility of operational bottlenecks conceptually demonstrated the potential to reduce cancellation-related inefficiencies and may improve operating room utilization.

Although the present analysis remains exploratory and based on simulated as-

sumptions, the findings suggest that integrated digital coordination systems may represent a potentially cost-effective strategy for improving surgical operational management. Future studies should include prospective economic evaluations and cost-effectiveness analyses in real-world implementation settings.

### Cost-Effectiveness Perspective

Although initial investment is required, the system has the potential to be cost-effective by improving operational efficiency and reducing waste associated with delays and cancellations. A summary of the estimated implementation and operational costs is presented in **Table 1**.

**Table 1.** Estimated cost summary for pilot implementation.

Component	Estimated Initial Cost (€)	Estimated Annual Operational Cost (€)
Software development and integration	15,000 - 35,000	3000 - 7000
Data infrastructure and cloud services	8000 - 20,000	2000 - 8000
Analytics and dashboard systems	7000 - 15,000	2000 - 5000
Staff training and organizational adaptation	10,000 - 25,000	3000 - 10,000
<b>Total Estimated Cost</b>	<b>40,000 - 95,000</b>	<b>10,000 - 30,000</b>

The estimated costs presented in **Table 1** are exploratory and intended to illustrate the potential financial requirements associated with pilot implementation of the proposed Digital Surgical Command Center framework. The estimated annual maintenance costs include software updates, user support, infrastructure maintenance, analytics platform licensing, and operational system management.

## 6. Results: Simulated Use Case

The simulated operational environment demonstrated the potential applicability of the Digital Surgical Command Center framework for real-time surgical workflow monitoring and operational coordination. Through the integration of simulated dashboards and automated operational updates, the model enabled continuous visualization of waiting-list dynamics and specialty-specific workload distribution.

The simulation demonstrated the ability of the system to identify patients exceeding recommended waiting-time thresholds and dynamically monitor variations in surgical backlog patterns across specialties. Simulated dashboards provided real-time visualization of cancellation trends, scheduling variability, and procedural status distribution, thereby facilitating operational awareness and identification of bottlenecks.

The framework also demonstrated the conceptual feasibility of integrating au-

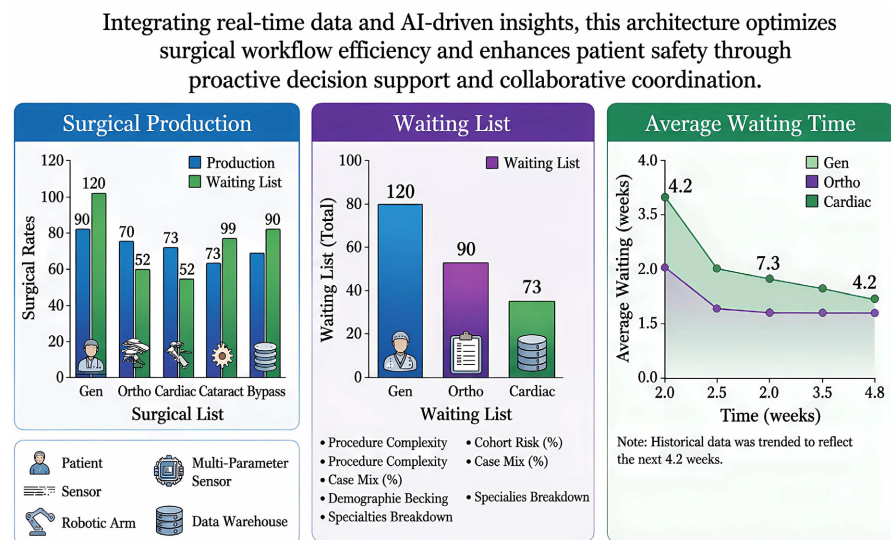
tomated workflow updates with centralized operational visualization. Simulated status modifications and scheduling events were automatically reflected across the operational environment, illustrating how centralized digital coordination mechanisms could potentially improve responsiveness to operational disruptions.

In addition, the simulation illustrated how integrated analytics could support adaptive resource allocation and prioritization decisions based on continuously updated operational indicators. Visualization of exceeded waiting times and cancellation causes enabled rapid identification of operational stress points and specialty-specific capacity constraints.

Although the findings are based exclusively on simulated operational data, the results suggest that centralized digital coordination models may contribute to improved visibility, operational awareness, and multidisciplinary coordination within surgical systems.

Scenario simulations were also performed to assess the impact of increased surgical capacity. Results suggested a potential reduction in waiting times and overdue cases when capacity was optimized.

A simulated dashboard is shown in **Figure 3**.



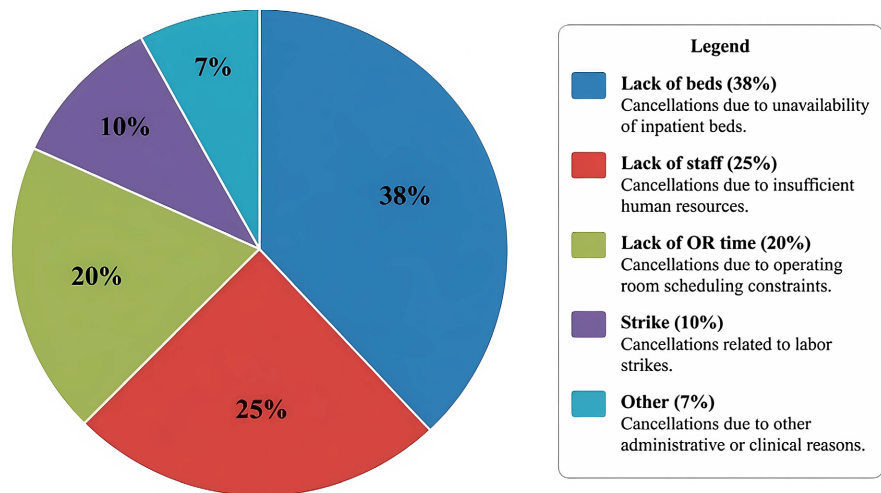
**Figure 3.** Simulated dashboard for surgical monitoring. Simulated dashboard displaying key performance indicators, including surgical production, waiting list distribution, and average waiting time. The dashboard supports real-time monitoring and identification of operational bottlenecks. Source: Author's own elaboration based on simulated data.

Cancellation causes are analyzed in **Figure 4**.

The integration of cost modeling with the simulated operational framework highlights the potential financial feasibility of the proposed system.

The simulated operational environment also illustrated how centralized visualization of waiting-list dynamics may facilitate earlier identification of operational bottlenecks and support adaptive scheduling decisions. Variability in exceeded

waiting times across specialties conceptually demonstrated the importance of integrated operational monitoring for prioritization and resource redistribution within surgical systems.



**Figure 4.** Cancellation analysis by cause. Distribution of surgical cancellations by cause (e.g., lack of beds, staff shortages, operating room constraints, strike, and other factors). This analysis supports targeted interventions to reduce inefficiencies. Source: Author’s own elaboration based on simulated data.

## 7. Benchmarking and International Context

Hospital command centers have been increasingly adopted worldwide as a strategy to improve operational efficiency, patient flow management, and real-time coordination of healthcare resources.

One of the most prominent examples is the Johns Hopkins Hospital Capacity Command Center [4], launched in 2016, which integrates real-time operational data, predictive analytics, and centralized decision-making processes to optimize patient flow across the health system. Previous reports have suggested improvements in patient throughput, reduction of operational delays, and enhanced coordination between departments following implementation of the command-center model [5]. Similar approaches have also been implemented in healthcare institutions in the United States and Europe, particularly in the context of hospital-wide operational management, capacity monitoring, and resource allocation. These systems typically focus on centralized visibility of inpatient flow, bed management, emergency department activity, and institutional operational performance.

However, comparatively limited attention has been given to the specific operational challenges associated with surgical pathway management, including waiting-list monitoring, cancellation analysis, and dynamic surgical prioritization. In contrast to broader hospital-capacity command centers, the proposed Digital Surgical Command Center specifically focuses on surgical operational workflows and integrates real-time waiting-list management, cancellation monitoring, end-to-

end digital coordination processes, and clinical decision-support mechanisms within a unified framework.

The proposed model should therefore be interpreted as a complementary and specialized extension of existing command-center approaches, adapted to the operational complexity of surgical care pathways and multidisciplinary surgical coordination.

## **8. Discussion: Impact and Clinical Relevance**

This study proposes a conceptual Digital Surgical Command Center framework designed to support surgical workflow optimization through the integration of real-time operational data, workflow automation, analytics, and multidisciplinary coordination. The proposed model addresses several operational challenges commonly described in healthcare systems, including prolonged surgical waiting times, fragmented operational visibility, scheduling variability, and inefficient resource allocation.

Previous studies [1] have demonstrated that centralized command-center approaches may improve hospital operational awareness and facilitate coordination between clinical and administrative domains [2]. In contrast to traditional fragmented scheduling models, the proposed framework integrates continuous operational monitoring with automated workflow logic and centralized visualization interfaces. This integrated approach may enable more adaptive operational planning and more efficient identification of surgical bottlenecks.

Similar findings have been described in studies evaluating centralized hospital command-center models, particularly regarding improvements in operational visibility and coordination efficiency [3]. However, unlike broader institutional command-center frameworks primarily focused on inpatient capacity management, the present model specifically emphasizes surgical waiting-list dynamics and multidisciplinary surgical coordination processes.

The integration of analytics and visualization tools within the framework is consistent with the growing emphasis on data-driven healthcare operations management. Real-time operational dashboards may support earlier identification of exceeded waiting-time thresholds, cancellation patterns, and specialty-specific operational variability, thereby improving situational awareness and decision-making capacity.

Although the current study relies on simulated operational data rather than prospective real-world implementation, the findings are conceptually aligned with existing literature suggesting that digital coordination systems may contribute to improved healthcare operational efficiency and reduced variability in resource utilization. The proposed framework should therefore be interpreted as a proof-of-concept operational model illustrating the potential applicability of centralized digital surgical coordination mechanisms.

The study also incorporates a preliminary cost-modeling perspective aimed at evaluating the potential feasibility of future implementation. Estimated costs as-

sociated with software development, infrastructure, analytics integration, and operational maintenance suggest that implementation would require strategic institutional investment. However, potential reductions in surgical cancellations, scheduling inefficiencies, and operational delays may partially offset implementation costs through improved operational performance.

Several limitations should be acknowledged. First, the simulation environment does not fully reproduce the complexity and unpredictability of real-world hospital operations. Second, no prospective clinical validation or implementation study was performed. Third, operational and economic assumptions remain indicative and should be interpreted cautiously. Future research should therefore focus on prospective implementation studies, integration with hospital information systems, and quantitative evaluation of operational outcomes in real-world clinical environments.

The findings of this study should be interpreted cautiously due to the simulated nature of the operational environment and absence of prospective clinical validation. Nevertheless, the framework provides an initial conceptual basis for future implementation studies evaluating centralized digital coordination in surgical systems.

## 9. Conclusion and Future Perspectives

The proposed Digital Surgical Command Center represents a conceptual framework for integrating real-time operational data, workflow automation, analytics, and multidisciplinary coordination within surgical pathway management. The simulated operational environment demonstrated the potential applicability of centralized digital coordination mechanisms for monitoring waiting lists, supporting operational visibility, and facilitating adaptive resource management.

Although the study is based exclusively on simulated data and does not include prospective clinical validation, the findings suggest that integrated digital coordination models may contribute to improved operational awareness and more efficient management of surgical workflows.

The framework should therefore be interpreted as a proof-of-concept model intended to support future implementation studies and real-world validation in healthcare environments undergoing digital transformation.

Despite the potential applicability of the proposed framework, several challenges associated with implementation should be acknowledged. Integration with existing hospital information systems may represent a significant technical and organizational barrier, particularly in healthcare environments characterized by heterogeneous digital infrastructures and limited interoperability between platforms.

In addition, data governance, cybersecurity, and privacy protection remain critical considerations in the implementation of real-time healthcare operational systems. The continuous processing and visualization of operational and clinical information require robust governance mechanisms to ensure compliance with reg-

ulatory and ethical standards.

User adoption and organizational adaptation may also influence implementation success. The introduction of centralized digital coordination systems may require workflow redesign, multidisciplinary engagement, and continuous staff training to ensure effective utilization and operational integration.

Furthermore, variability across healthcare institutions may limit the generalizability of the proposed model. Differences in institutional capacity, digital maturity, operational workflows, and resource availability may influence implementation feasibility and system performance.

This study also presents several methodological limitations. First, the framework was evaluated exclusively through simulated operational data and was not validated in a real-world hospital environment. Second, the simulated dataset does not fully reproduce the complexity and unpredictability of actual clinical operations and no prospective clinical validation was performed. Third, the economic estimates included in the study remain preliminary, costs are only indicative and should be interpreted cautiously.

Future research should therefore focus on prospective implementation studies, integration with existing hospital information systems, and quantitative evaluation of clinical, operational, and economic outcomes in real-world settings.

Future developments of the proposed Digital Surgical Command Center may include the integration of predictive analytics [3] and artificial intelligence models capable of supporting dynamic operational forecasting [3] and surgical demand estimation. The incorporation of real-time optimization algorithms could further enhance operating room allocation, scheduling efficiency, and adaptive resource management.

In addition, future research may explore the expansion of the framework to other clinical pathways and operational domains beyond surgical care, including emergency department coordination, inpatient flow management, and multidisciplinary capacity planning.

Prospective implementation studies are also required to evaluate the real-world clinical, operational, and economic impact of the proposed system. Particular attention should be given to cost-effectiveness analyses, organizational adaptation, interoperability challenges, and user adoption within complex healthcare environments.

Further development of the framework may contribute to the advancement of integrated data-driven operational management models in healthcare systems undergoing digital transformation.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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