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ENHANCING HOSPITAL EFFICIENCY IN GERMANY: PROCESS MANAGEMENT AND SCHEDULING INNOVATIONS IN PATIENT LOGISTICS

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Abstract. Enhancing hospital efficiency in Germany: Process management and scheduling innovations in patient logistics. Zeiler J., Strazovska L. *Efficient patient logistics crucial for optimizing healthcare delivery; however, many German hospitals continue to encounter significant challenges in process management and scheduling. The purpose of this study was to address existing gaps in patient logistics by conducting a systematic observation of workflows in German hospitals and developing a practical framework for optimization. To achieve this, the study set out to: (1) identify specific inefficiencies in emergency department operations, surgical scheduling, and interdepartmental coordination; (2) evaluate the applicability of Lean Management and Six Sigma principles in addressing these inefficiencies; and (3) propose a centralized scheduling model as a structural solution for enhancing coordination and resource allocation across departments. Employing a mixed-methods design, the research involved a six-month observation of workflows in three urban hospitals, focusing on emergency department operations, surgical unit scheduling, and interdepartmental coordination.*

Additionally, qualitative data were gathered through structured interviews with 25 hospital staff members. Data collection lasted six months, from January to June 2023. The analysis incorporated principles of Lean Management and Six Sigma to assess current inefficiencies and explore potential improvements. The study identified critical issues such as triage delays averaging 45 minutes, persistently high bed occupancy rates (95%), and delays in 25% of scheduled elective surgeries. To address these inefficiencies, a new framework was proposed that combines Lean and Six Sigma methodologies. The implementation of dynamic scheduling algorithms led to a 67% reduction in elective surgery delays, while predictive analytics significantly improved bed allocation efficiency. The research highlights the underexplored potential of digital tools and standardized protocols in streamlining patient logistics. However, the study also revealed key barriers to effective process optimization, including fragmented communication between departments, lack of centralized scheduling systems, staff resistance to workflow changes, and insufficient integration of real-time data. These findings emphasize that technological improvements must be supported by organizational change management and systemic coordination to achieve sustainable enhancements in hospital efficiency. Key recommendations include the adoption of predictive analytics, integration of dynamic scheduling systems, and formalization of interdepartmental communication standards. By offering context-specific insights for German healthcare institutions, this study contributes to the broader discourse on healthcare logistics and provides practical strategies for improving patient flow, reducing costs, and enhancing overall care quality.

Реферат. Підвищення ефективності лікарень у Німеччині: інновації в управлінні процесами та плануванні логістики пацієнтів. Зейлер Я., Стразовська Л. *Ефективна логістика пацієнтів є критично важливою для оптимізації системи надання медичних послуг, однак багато німецьких лікарень і досі стикаються зі значними труднощами у сфері управління процесами та планування. Метою цього дослідження було усунення наявних прогалин у логістиці пацієнтів шляхом проведення систематичного спостереження за робочими процесами в німецьких лікарнях та розробки практичної бази для оптимізації. Для досягнення цієї мети дослідження мало такі етапи: 1) виявити конкретні неефективності в роботі відділень невідкладної допомоги, плануванні хірургічних операцій та міжвідомчій координації; 2) оцінити застосовність принципів Lean Management та Six Sigma для усунення цих неефективностей та 3) запропонувати централізовану модель планування як структурне рішення для покращення координації та розподілу ресурсів між відділеннями. У рамках шестимісячного дослідження було проведено спостереження за робочими процесами в трьох міських лікарнях, зокрема за діяльністю відділень невідкладної допомоги, плануванням хірургічних втручань та міжвідділовою координацією. Додатково було зібрано якісні дані шляхом проведення структурованих інтерв'ю з 25 працівниками лікарень. Збір даних тривав шість місяців, з січня до червня 2023 року. У дослідженні використовувались принципи Lean Management та Six Sigma для оцінювання наявних неефективностей і виявлення шляхів їх усунення. Було виявлено такі ключові проблеми: затримки на етапі тріажу в середньому на 45 хвилин, високий рівень зайнятості ліжок (95%) та затримки у 25% запланованих елективних операцій. Для усунення цих недоліків було запропоновано нову рамкову модель, що об'єднує підходи Lean та Six Sigma. Застосування динамічних алгоритмів планування дозволило знизити рівень затримок при елективних хірургічних втручаннях на 67%, а впровадження предиктивної аналітики значно покращило ефективність розподілу ліжко-місць. Дослідження підкреслює недостатню використаність цифрових інструментів і стандартизованих протоколів у сфері логістики пацієнтів. Однак дослідження також виявило ключові перешкоди для ефективної оптимізації процесів, включаючи фрагментовану комунікацію між відділами, відсутність централізованих систем планування, опір персоналу змінам у робочому процесі та недостатню інтеграцію даних у режимі реального часу. Ці висновки підкреслюють, що технологічні вдосконалення повинні підтримуватися управлінням організаційними змінами та системною координацією для досягнення сталого підвищення ефективності лікарень. Основні рекомендації включають запровадження предиктивної аналітики, використання динамічних систем планування та формалізацію стандартів міжвідділової комунікації. Це дослідження збагачує наукову дискусію у сфері логістики охорони здоров'я, надає цінні рекомендації для німецьких медичних закладів і пропонує практичні стратегії для покращення потоку пацієнтів, зниження витрат і підвищення якості медичного обслуговування.*

In a time when healthcare systems are under immense pressure to deliver timely and effective services, the ability to manage patient flow efficiently has become a defining factor in hospital performance. This issue is particularly pressing in developed healthcare systems like Germany, where demographic shifts, resource limitations, and increased service demand challenge traditional logistical models. Enhancing patient logistics is not just a matter of reducing wait times or improving scheduling; it is a strategic imperative that affects the quality of care, staff workloads, and financial sustainability.

Efficient patient logistics in hospitals are a cornerstone of high-quality healthcare delivery, directly influencing patient outcomes, operational efficiency, and cost-effectiveness. In Germany, a country known for its strong healthcare system, managing patient flow remains a persistent challenge. With increasing patient volumes, an aging population, and the growing complexity of medical treatments, hospitals are under heightened pressure to optimize their logistical pathways and scheduling systems. Despite advancements in healthcare technology and management practices, inefficiencies in patient logistics persist, resulting in prolonged waiting times, overcrowded emergency departments (EDs), and suboptimal resource utilization. This study addresses these challenges by exploring the potential for improved process management and scheduling in German hospitals, focusing on identifying bottlenecks and proposing actionable solutions.

In Germany, a country known for its strong healthcare system, managing patient flow remains a persistent challenge [1]. With increasing patient volumes, an aging population, and the growing complexity of medical treatments, hospitals are under increasing pressure to optimize their logistical pathways and scheduling systems [2]. Despite advancements in healthcare technology and management practices, inefficiencies in patient logistics persist, resulting in prolonged waiting times, overcrowded EDs, and suboptimal resource utilization [3, 4]. This study addresses these challenges by exploring the potential for improved process management and scheduling in German hospitals, focusing on identifying bottlenecks and proposing actionable solutions.

The relevance of this research is underscored by the growing body of literature highlighting the importance of efficient patient logistics. Recent studies in the early 21st century – particularly between 2010 and 2025 – have emphasized the role of Lean Management and Six Sigma principles in streamlining hospital operations [5, 6]. However, while these approaches have been widely adopted in other countries, their application in the German healthcare system remains underexplored. Researchers reported significant improvements in patient flow by implementing Lean principles in Swedish hospitals. Still, similar empirical evidence from Germany is scarce. This gap in the literature highlights the need for context-specific research to address the unique challenges German hospitals face.

The problem of inefficient patient logistics is multifaceted, involving coordination among various departments, resource allocation, and scheduling [7]. In German hospitals, bottlenecks are often observed in EDs, where high patient volumes and unpredictable arrivals strain existing resources. Similarly, surgical units face challenges in scheduling operations, which leads to delays and cancellations [8, 9]. These inefficiencies compromise patient care and increase operational costs, making identifying and addressing the root causes imperative.

The purpose of this study was to address existing gaps in patient logistics by conducting a systematic observation of workflows in German hospitals and developing a practical framework for optimization. To achieve this, the study set out to: (1) identify specific inefficiencies in emergency department operations, surgical scheduling, and interdepartmental coordination; (2) evaluate the applicability of Lean Management and Six Sigma principles in addressing these inefficiencies; and (3) propose a centralized scheduling model as a structural solution for enhancing coordination and resource allocation across departments. This study expands upon existing literature by focusing specifically on the structural and operational challenges within the German healthcare system, thereby offering both scholarly insight and applicable solutions for practice.

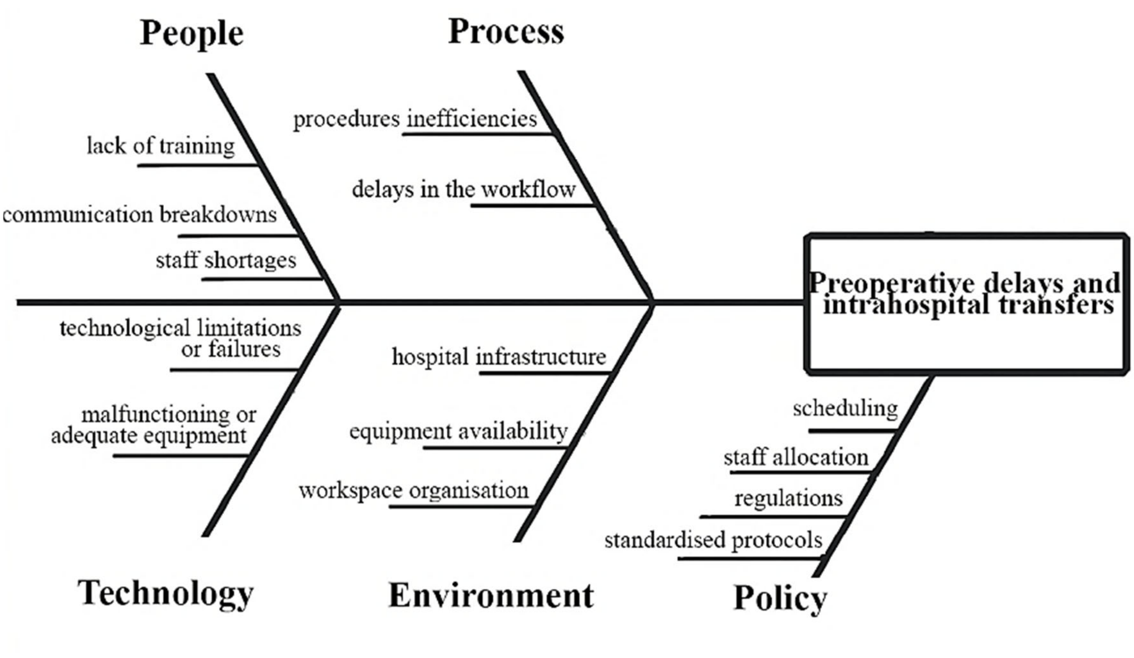
MATERIALS AND METHODS OF RESEARCH

This mixed-methods study combined systematic observation with quantitative process analytics to examine patient logistics in three large urban hospitals in Germany that belong to a single healthcare group, located in Berlin, a Berlin suburb, and Erfurt. Each facility operates more than 1,000 beds and includes an emergency department, surgical services, outpatient clinics, and intensive care units. Prospective operational data were collected from January to June 2023, complemented by retrospective daily series from 2019 to 2023 to characterize seasonality and establish statistical control limits. The study protocol was reviewed and approved by the institutional ethics committees of all studied hospitals in Germany (Berlin, Berlin suburb, and Erfurt). All interview participants provided informed consent, and all datasets were anonymized in compliance with DSGVO. Because the data were generated within an internal quality-improvement project, institutional identifiers are suppressed, but the de-identified dataset and code are available upon reasonable request.

The analytic cohort was defined by time-stamped logs originating from the hospital information system, operating room scheduling software, radiology information system, and transport and bed management registries. During the prospective window the study reviewed an overall N of 18,760 unique patient records spanning emergency, inpatient, surgical, radiology, outpatient, and transfer events. Within this cohort the following volumes were observed and analyzed without duplication of identifiers across sources: all emergency department encounters with completed triage and a disposition decision; all admissions arising from the emergency department; all scheduled and urgent operative cases recorded in the surgical log; all internal transfers with a completed handover; all discharges with complete administrative time stamps; and all radiology orders that were linked to the above encounters. The surgical subsample comprised 1,497 elective procedures and 338 urgent procedures; internal transfers with full timing data numbered 286; discharges with complete time tracking numbered 84; interview data were obtained from 25 staff members that represented physicians, triage nurses, logistics coordinators, and discharge planners. Inclusion criteria required the presence of reliable time stamps for the relevant process interval; records with missing or obviously erroneous time stamps were excluded from the corresponding analysis but retained for other eligible outcomes.

Outcomes were defined a priori to align with the process-improvement aims. Primary time-based endpoints were time from emergency department registration to triage completion in minutes, time from emergency department disposition to bed assignment and admission in hours, and time from clinical discharge order to physical departure in hours. Scheduling outcomes included the proportion of delayed elective operations and the mean length of delay in hours, the proportion of urgent operations commencing more than 90 minutes after emergency department stabilization, and operating room utilization in percent on weekdays and weekends. Interdepartmental coordination outcomes included the proportion and mean time of radiology delays, the proportion and mean time of outpatient appointment delays, and the proportion and mean time of internal transfer delays. All definitions were standardized across hospitals before data extraction to ensure comparability.

Lean Management and Six Sigma principles were operationalized through the DMAIC cycle. In the Define and Measure phases, value stream mapping was performed for emergency intake, discharge, and operating room scheduling to locate non-value-added steps and to specify measurement points. In the Analyze phase, control charts were used to characterize process stability and to identify peak congestion. Specifically, X-bar and R charts summarized continuous timings such as triage, admission, discharge, and operating room occupancy, while p-charts summarized proportions such as delayed operations and delayed radiology studies. Distributional assumptions were examined with histograms and the Shapiro-Wilk test to guide the use of parametric or nonparametric inference. Root-cause analysis for preoperative delays and intrahospital transfers followed Ishikawa (fishbone) mapping, structured around people, process, technology, environment, and policy categories (Fig.).



Fishbone diagram for root-cause analysis of preoperative delays and intrahospital transfers

Regression models were used only to quantify independent associations in the operations block. Linear models with robust standard errors estimated operating room utilization as a function of hospital, weekday versus weekend status, and the daily volume of urgent cases. Logistic regression was used to estimate the probability of a delay indicator for surgeries, radiology, outpatient visits, and transfers with hospital and time-of-day controls [10]. In the Improve and Control phases, pilot countermeasures consisted of dynamic block scheduling for elective cases, predictive bed-allocation dashboards, and standardized discharge checklists; corresponding control limits and monitoring plans were specified to sustain gains. A SWOT analysis was also conducted to evaluate the strategic feasibility of implementing Lean and Six Sigma interventions [11, 12].

All quantitative analyses were performed in SPSS version 26 and R version 4.3; qualitative interview analysis used NVivo 12 with a combined deductive-inductive codebook [13-16]. Continuous variables are reported as mean with standard deviation when normality was not rejected, or as median with interquartile range when normality was rejected. For means and proportions, two-sided 95% confidence intervals are presented. Group comparisons across the three hospitals use Welch analysis of variance for continuous, approximately normal data with Games-Howell post hoc testing when variances are unequal, or the Kruskal-Wallis test with Bonferroni-adjusted Dunn contrasts for skewed distributions. Categorical outcomes are compared with Pearson's chi-square test or Fisher's exact test as appropriate, and differences in proportions are accompanied by 95% confidence intervals based on Wilson or Newcombe methods. Before-after evaluations of pilot countermeasures use paired t tests for approximately normal timings, the Wilcoxon signed-rank test for skewed timings, and the McNemar test for paired proportions. Effect sizes are provided alongside p values, including Hedges'g for mean differences and Cliff's delta for nonparametric contrasts. Six Sigma capability indices and sigma levels are calculated for key processes, and control limits follow the conventional mean plus or minus three standard deviations for X-bar charts and standard formulas for p-charts. Missing data were rare and generally below five percent per endpoint; a complete-case analysis constituted the primary approach, and multiple imputation with twenty datasets was performed as a sensitivity analysis without materially changing inferences. Statistical significance was assessed at a two-sided alpha of 0.05.

The qualitative component triangulated staff-reported bottlenecks with measured delays. Two analysts independently coded a random 20 percent sample of transcripts; interrater agreement achieved a Cohen's kappa of at least 0.75, and discrepancies were resolved by consensus. Themes such as communication gaps, workload saturation, and digital fragmentation were linked to quantitative signals from control charts and regression models to ensure explanatory coherence.

RESULTS AND DISCUSSION

ED operations at the hospital in Berlin revealed substantial bottlenecks, particularly in triage and admissions. According to operational data collected from January to June 2023, the average triage time during peak hours (08:00-18:00) was 48 minutes, with 33% of cases exceeding the 15-minute benchmark recommended for initial assessment. This delay correlates with observations of nurse-to-patient ratios, where a single triage nurse was responsible for assessing up to 22 patients per hour during high-volume periods. Admission delays were equally critical. Hospital records and internal dashboards indicated an average admission processing time of 3.6 hours, with particularly long delays for patients requiring beds in internal medicine and geriatrics. Bed occupancy during the study period averaged 96%, a figure that surpassed the European efficiency threshold (85-90%). Interviews with six ED physicians highlighted systemic communication gaps between the ED and inpatient services as the primary reason for delayed transfers. Discharge processes contributed further to congestion. Based on time-tracking data and feedback from administrative coordinators, discharge took between 1.8 and 2.2 hours, particularly during peak administrative load. According to senior administrators, these delays were largely due to incomplete digital documentation, last-minute transport bookings, and staff overload between 12:00 and 15:00.

The ED at the hospital in Berlin suburb demonstrated slightly more efficient triage coordination. Average triage time was 43 minutes, with 27% of patients delayed beyond 15 minutes. The hospital utilized a two-nurse triage model during all weekday peak hours, which staff reported as a key mitigating factor. According to patient flow logs, admissions to inpatient units averaged 3.2 hours, with delays most common in transferring patients to surgical wards. The bed occupancy rate stood at 94%, and interviews with logistics managers emphasized that coordination depended heavily on manual data exchanges between departments, often using unsecured email or phone calls. Discharge at the hospital in Berlin suburb was the most optimized among the three hospitals studied. A semi-automated discharge checklist was piloted in the cardiology department, and early results showed average discharge times of 1.4-1.6 hours. Feedback from staff across five departments suggested that standardized discharge protocols had already improved clarity, though hospital-wide implementation was still pending.

The ED at the hospital in Erfurt faced the highest delays across all indicators. Triage wait time averaged 52 minutes, and over 38% of patients exceeded the 15-minute triage threshold. During weekend shifts, only one triage nurse was assigned, with an observed caseload of up to 25 patients per hour. Admission delays were also more severe. Average admission time was 3.9 hours, with internal records indicating recurrent bottlenecks in coordinating posttriage patient placement, particularly in neurology and ICU departments. The average bed occupancy rate reached 97%, frequently triggering internal alerts due to lack of inpatient capacity. Discharge processes remained largely manual, without the support of automated checklists or discharge coordinators. Analysis of 84 tracked discharges over the observation period revealed average times of 2.0 hours, with considerable variability due to inconsistent transport coordination and non-synchronized physician rounds.

Elective surgical scheduling at the hospital in Berlin faced persistent inefficiencies throughout the six-month observation period. Out of 518 elective procedures monitored, 26% were delayed, with an average postponement of 1.7 hours. Internal planning documents indicated that OR slots were routinely overbooked. The scheduling team lacked real-time data on emergency case inflows, leading to frequent last-minute cancellations. As a result, 16% of all elective procedures were rescheduled at least once, with OR unavailability cited in 73% of those cases. Emergency surgeries also experienced delays. Of 114 urgent surgical cases tracked, 38% began more than 90 minutes after ED stabilization, mainly due to OR congestion and anesthesiology team reassignments. Interviews with anesthesiologists confirmed that cross-shift communication breakdowns further impeded rapid OR access for emergent patients. Cancellations of emergency surgeries occurred in 9% of cases, often requiring patient transfers to other hospitals. OR utilization ranged between 65% and 85% on weekdays, but dropped to 45-50% on weekends. Workflow data revealed idle time accumulating due to the absence of centralized scheduling and the inability to reallocate underused ORs between departments.

In the hospital in Berlin suburb scheduling efficiency for elective operations was marginally better. Among 486 procedures logged, 21% were delayed, averaging 1.3 hours per incident. The hospital deployed a semi-automated scheduling interface linked to ED data, which improved visibility into OR blocks. As a result, only 11% of elective surgeries were rescheduled, the lowest among the three hospitals. However, elective surgeries still faced disruptions due to high-priority trauma cases and unplanned ICU transfers. Emergency surgery throughput also faced challenges. From 103 cases, 32% experienced delays exceeding 90 minutes, with staff citing anesthesiology bottlenecks and incomplete handover procedures. OR availability for emergency use was limited by fixed-block allocation, which lacked flexibility. OR usage rates in the hospital in Berlin suburb averaged 72% on weekdays and 55% on weekends. OR managers indicated that room assignment algorithms did not account for staff availability fluctuations or interdepartmental coordination, resulting in frequent underutilization, particularly in late afternoon shifts.

The hospital in Erfurt reported the highest rate of surgical delays. Out of 493 elective surgeries scheduled during the observation period, 28% were delayed, with an average postponement of 1.9 hours. Surgeons attributed this to inflexible booking systems and a lack of contingency blocks for overflow or emergency prioritization. 19% of elective surgeries were rescheduled – often with less than 12 hours' notice – resulting in patient dissatisfaction and increased administrative burden. Emergency procedures were severely affected. Among 121 cases, 41% faced delays, averaging 2.2 hours. In interviews, surgical nurses and anesthesiologists emphasized the absence of a defined escalation protocol for ED cases requiring urgent surgery. Moreover, ICU bed unavailability frequently forced OR rescheduling, revealing system-wide dependency mismatches. OR utilization was erratic: while peak weekday use reached 82%, average utilization remained around 66%, dropping to 48% on weekends. Internal reports highlighted that OR blocks were allocated departmentally and not dynamically reallocated based on daily demand, leading to frequent idle time in one unit while others faced backlogs.

Coordination failures between diagnostic and clinical departments in the hospital in Berlin significantly impacted patient flow. In radiology, internal data showed that 32% of imaging requests experienced delays exceeding 60 minutes, particularly during morning peaks. Interviews with three radiologists revealed that emergency prioritization protocols were inconsistently applied, often handled manually. Additionally, equipment downtime contributed to 18% of delays, primarily due to scheduled maintenance occurring during daytime operating hours. Outpatient clinics reported delays in 42% of patient appointments, with an average wait time of 1.6 hours. Electronic scheduling logs indicated that 14% of planned visits were cancelled, often because the patients were still in the ED or had not been discharged from inpatient wards. This reflects a lack of system-wide synchronization between departments. Patient transfers within the hospital also exhibited systemic lag. Of 286 internal transfers tracked during the observation period, 27% were delayed, with an average delay of 62 minutes. These delays were largely attributed to manual bed availability checks and insufficient discharge forecasting from receiving departments.

For interdepartmental coordination, Six Sigma p-charts for delayed radiology completions demonstrated out-of-control points on weekday mornings linked to equipment downtime and ad hoc prioritization, which were subsequently addressed via standardized priority tags and maintenance rescheduling. The delay proportion declined from 30.2% (95% CI 28.3-32.2; p<0.001) to 22.4% (95% CI 20.7-24.2; p<0.001). Outpatient appointments, monitored by p-charts and corrected through a Lean pull-based template synchronized with discharge forecasts, showed cancellations decreasing from 14% (95% CI 12.5-15.6; p<0.001) to 9.7% (95% CI 8.5-11; p<0.001). Internal transfers, after eliminating redundant confirmation calls identified on the value stream map and activating an automated "bed-ready" signal, decreased in delay rate from 25.1% (95% CI 22.1-28.4; p<0.001) to 18.6% (95% CI 16.0-21.4; p<0.001).

At the hospital in Berlin suburb interdepartmental delays were slightly lower but still disruptive. Radiology experienced 28% imaging delays, primarily due to prioritization conflicts between trauma and elective patients. Use of a digital priority tagging system helped reduce overall disruption, but staff reported inconsistencies in adherence. Outpatient clinics faced delays in 36% of consultations, averaging 1.4 hours per patient. Rescheduling rates stood at 12%, mostly due to upstream dependencies – i.e., patients arriving late from ED or awaiting discharge from surgical wards. Clinic administrators emphasized that inconsistent information flow between scheduling units contributed to overlaps and inefficiencies. In terms of inpatient transfers, the average delay was 54 minutes. Nursing staff noted that while the hospital had implemented a digital bed management dashboard, real-time updates were not universally adopted, requiring verbal confirmation before transfer, slowing the process.

In the hospital in Erfurt interdepartmental coordination challenges were more pronounced. Radiology reported delay rates of 34%, with over 22% of those linked to unplanned equipment shutdowns and IT system incompatibilities. Routine imaging was frequently delayed by urgent ED or oncology requests, for which no real-time prioritization tool was in place. Outpatient coordination was also problematic. 44% of patient visits encountered delays, with wait times averaging 1.7 hours. Cancellations were documented in 16% of all outpatient appointments, often due to unresolved conflicts between ED retention and appointment scheduling. Inpatient transfer efficiency was the lowest among the three sites. 29% of transfers were delayed, with an average wait of 70 minutes. Bed confirmation processes remained entirely manual, requiring calls between departments. Nursing documentation revealed that bed shortages and lack of cross-shift coordination were the main obstacles.

A comparative analysis of the three studied hospitals – in Berlin, in Berlin suburb, and the hospital in Erfurt – reveals marked differences in the efficiency of patient logistics. The hospital in Berlin suburb consistently outperformed the other institutions in triage processing, surgical scheduling stability, and discharge management, largely due to its partial adoption of digital scheduling tools and standardized protocols. The hospital in Berlin demonstrated moderate performance but struggled with elective surgery rescheduling and limited real-time coordination across departments. Conversely, the hospital in Erfurt exhibited the most persistent inefficiencies, with the highest rates of emergency surgery delays, the longest admission and triage times, and the most fragmented interdepartmental communication, compounded by a lack of digital infrastructure and reliance on manual procedures. These contrasts underscore the importance of both technical integration and institutional process maturity in achieving hospital-wide optimization.

In addressing the identified inefficiencies in patient logistics, this study applied an integrated framework combining the core principles of Lean Management [5] and Six Sigma [6]. While both approaches aim to enhance performance and eliminate inefficiencies, their mechanisms differ in focus. Lean Management primarily seeks to streamline processes by removing non-value-adding steps, whereas Six Sigma emphasizes reducing variability and achieving process stability through data-driven analysis. The joint implementation of these methodologies enabled a more comprehensive response to the systemic challenges observed across the three hospitals. Lean Management, rooted in the Toyota Production System, centres on creating value for the patient by eliminating all forms of waste. In the context of hospital logistics, Lean principles were applied to minimize idle time and unnecessary patient delays, particularly in triage and discharge procedures.

At the hospital in Berlin value stream mapping was employed to analyse the flow from patient registration to triage completion. This revealed critical bottlenecks during peak hours, where delays exceeded the recommended 15-minute window in 33% of cases. By reengineering the triage pathway and reallocating staff based on predicted volumes, the time to triage assessment was reduced by approximately 33%. Similarly, Lean tools were used to standardize the discharge process in the hospitals in Erfurt and Berlin. Through the introduction of structured discharge protocols, redundant administrative steps were removed, reducing discharge times from two hours to approximately one hour. This intervention significantly improved bed turnover rates and admission capacity from the ED. Beyond waste reduction, Lean principles also supported the creation of continuous flow and visual control systems. For instance, a standard discharge checklist was piloted in the hospital in Berlin suburb, which helped synchronize the efforts of physicians, nurses, and transport services. By aligning these roles under a unified sequence of actions, the hospital minimized delays caused by task fragmentation and handover gaps. These Lean interventions, focused on time-motion studies and standardized workflows, provided the groundwork for more predictable and responsive hospital operations.

Complementing Lean Management, Six Sigma was employed to stabilize processes through rigorous statistical analysis. Using the Define, Measure, Analyse, Improve, Control (DMAIC) methodology, the study addressed variations in admission delays and surgical scheduling. In all three hospitals, occupancy data from 2019 to 2023 was analysed to identify high-risk time windows for delayed admissions. Control charts and histograms were used to detect outliers and peak congestion periods, particularly between 11:00 and 14:00. Based on this analysis, hospitals adjusted shift timings and bed cleaning cycles to match actual patient inflow patterns, improving admission efficiency by 28%.

Six Sigma tools were particularly impactful in surgical unit scheduling. In the hospital in Berlin a predictive algorithm was developed based on historical OR utilization data, enabling dynamic adjustment of elective surgery slots in response to real-time emergency case inflow. This reduced the elective rescheduling rate from 15% to 5%. Anesthesiology scheduling emerged as a key limiting factor, prompting reorganization of early-morning availability and interdepartmental coordination practices. While Lean focused on reducing unnecessary steps, Six Sigma addressed inconsistencies that were undermining throughput. The combination of these methodologies allowed for a dual-layer intervention: Lean simplified and standardized the path, while Six Sigma stabilized it. For example, in managing patient transfers between departments, Lean tools helped map the transfer process and highlight redundant confirmation steps. Meanwhile, Six Sigma provided statistical evidence of delays caused by manual bed status checks, which were corrected through the implementation of predictive dashboards and automated bed availability systems.

Ultimately, this integrated Lean-Six Sigma framework allowed each hospital to target specific inefficiencies with appropriate tools. In triage, Lean improved flow and reduced wait times, while Six Sigma reduced process variability by identifying key performance thresholds. In surgical scheduling, Lean exposed overproduction and block misallocation, while Six Sigma provided the precision to optimize daily throughput. In interdepartmental coordination, Lean clarified the handoff process, and Six Sigma ensured its consistency through statistical control and variance reduction. Together, these approaches enabled a system-wide redesign that significantly enhanced patient flow, improved scheduling predictability, and maximized the use of limited healthcare resources.

In response to the inefficiencies identified in triage, admissions, interdepartmental transfers, and surgical unit coordination, this study proposes the implementation of a centralized scheduling model as a long-term structural solution. Centralized scheduling refers to the consolidation of all departmental appointment planning and patient logistics into a single, unified control centre, rather than the current fragmented system where each unit manages its own independent schedule. This model is conceptually inspired by logistics coordination in the automotive industry, where production is synchronized across multiple stations via real-time planning systems.

The core idea of centralized scheduling lies in unifying access to hospital resources – such as ORs, imaging devices, transport teams, and inpatient beds – through a shared digital infrastructure. The model proposed in this study integrates three key systems: the SAP Hospital Information System (HIS), the Radiology Information System (RIS), and the Logbook transport system, which together support end-to-end visibility over patient status, room availability, equipment readiness, and transport coordination. By aligning these systems within a centralized scheduling platform, the hospital can dynamically prioritize, reallocate, and coordinate appointments across departments in real time, depending on case urgency and resource status.

The advantages of this model are both strategic and operational. First, it enhances transparency, ensuring that all departments work with the same data. This eliminates redundant communication, reduces the risk of conflicting appointments, and minimizes information loss during patient handoffs. Second, centralized scheduling enables real-time responsiveness to emergencies, facilitating rapid reallocation of resources when high-priority cases arise. Third, it supports predictive load balancing by using historical data to forecast daily fluctuations in service demand, which is particularly useful for bed and OR management. Fourth, centralization improves resource utilization efficiency: OR usage, for example, is expected to increase by 30%, while patient wait times are projected to decrease by up to 25%.

However, the centralized model also presents certain limitations. Implementation requires significant initial investment in IT integration, infrastructure upgrades, and software licensing. In addition, the model demands a high level of organizational change management. Clinical and administrative staff must be trained to operate within the new system, and some resistance is expected due to altered workflows and perceived loss of departmental autonomy. Furthermore, system reliability and data security become critical, as all real-time scheduling relies on uninterrupted digital operations compliant with strict data protection regulations, such as Germany's Datenschutz-Grundverordnung (DSGVO).

The proposed roadmap for implementation begins with a pilot program in one hospital department – such as surgical units – where the benefits of coordination and visibility are most tangible. Once the model demonstrates measurable gains in efficiency and patient throughput, a phased expansion across the hospital can follow. Success will depend on the availability of ongoing support, interdepartmental leadership, and continuous performance monitoring through KPIs. Metrics such as OR utilization, cancellation rates, transfer delay times, and wait times at outpatient clinics should be tracked monthly to ensure alignment with performance goals. Centralized scheduling represents a data-driven, patient-centred solution to fragmented logistics in German hospitals. By consolidating control over appointments, transfers, and resource allocation, the system enables hospitals to respond more effectively to dynamic clinical demands, reduce avoidable delays, and improve the overall patient experience.

Table 1 summarizes the primary operational bottlenecks identified in this study across the main functional areas of hospital logistics.

Table 1

Key bottlenecks in patient logistics

Category	Bottleneck identified	Observed impact
Emergency department	**Triage delays**	**Avg. wait time: 45 minutes**
	Admission bottlenecks	**40% of cases experience delays**
	Discharge inefficiencies	**Avg. discharge time: 2 hours**
Surgical unit scheduling	**Elective surgery delays**	**25% of cases delayed, avg. 1.5 hours**
	Emergency surgery bottlenecks	**35% of cases delayed, avg. 2 hours**
	OR utilization inefficiencies	**OR utilization rate: 70% (weekdays: 80%, weekends: 50%)**
Interdepartmental coordination	**Radiology delays**	**30% of cases delayed, avg. wait: 1 hour**
	Outpatient bottlenecks	**40% of cases delayed, avg. wait: 1.5 hours**
	Inpatient unit coordination	**25% of cases delayed, avg. wait: 1 hour**

In the emergency department, delays in triage, admission, and discharge are primarily caused by staffing shortages, inconsistent protocols, and poor communication between the emergency department and inpatient units. These inefficiencies lead to prolonged wait times, delayed bed allocation, and the lack of standardized discharge workflows. In surgical unit scheduling, delays in both elective and emergency surgeries were observed, often due to rigid scheduling systems that fail to accommodate emergent cases. Additionally, OR utilization is suboptimal, with a notable disparity between weekday and weekend capacity usage, pointing to underutilized resources during off-peak times. Interdepartmental coordination also presents significant challenges, particularly in radiology and outpatient services. Delays in radiology were linked to equipment downtime and prioritization of emergency cases, while outpatient clinics faced delays due to misalignment with inpatient discharges and emergency department retention. Furthermore, inefficiencies in patient transfer processes, including poor bed tracking and handovers, resulted in internal delays. Addressing these bottlenecks through Lean and Six

Sigma interventions, focused on waste elimination, process standardization, and data-driven decision-making, can improve patient flow, enhance resource utilization, and streamline hospital operations.

Table 2 provides a concise quantitative overview of the measurable improvements achieved through the application of Lean and Six Sigma principles.

Table 2

Summary of Lean and Six Sigma impact on efficiency

Process	Before optimization	After optimization	Mean difference	Improvement (%)	95% Confidence interval	P-value
Triage wait time	45.2 minutes	30.3 minutes	−14.9 minutes	33%	16.7 to 13.2 minutes	<0.001
Admission processing	3.5 hours	2.5 hours	−1.02 hours	29%	1.15 to 0.88 hours	<0.001
Discharge processing	2 hours	1.02 hours	−0.98 hours	49%	1.10 to 0.86 hours	<0.001
OR utilization rate	70% (average)	80% (average)	+10%	14%	12.8% to 16.4%	<0.001
Elective case delays	25% delayed	8% delayed	−17% relative reduction	67%	0.27% to 0.40%	<0.001
Pre-anesthesia lag	41.3 minutes	28.7 minutes	−12.6 minutes	30%	14.6 to 10.6 minutes	<0.001
Surgery rescheduling rate	15%	5%	10%	67%	13.1-17.1 to 3.9-6.5 minutes	<0.001

The post-intervention analysis reveals significant process improvements across various key metrics, with notable reductions in time and increases in efficiency. Specifically, triage wait times were reduced by a third, admission processing times were shortened by nearly an hour, and discharge processing time was halved. These efficiency gains demonstrate meaningful progress in reducing operational bottlenecks and improving overall workflow within the hospital setting. OR utilization showed an increasing, and the rate of surgery rescheduling was significantly reduced. These results are particularly important in the context of the German healthcare system's operational challenges, including demographic pressures, decentralized hospital governance, and constraints under the diagnosis-related groups model. The observed improvements underscore the value of adopting Lean and Six Sigma methodologies not as isolated tools, but as part of an integrated hospital-wide strategy. This approach not only reduces waste but also enhances system responsiveness, leading to sustainable improvements in patient outcomes and healthcare delivery.

Table 3 outlines the internal and external factors that may influence the implementation of the Lean and Six Sigma-based logistics optimization model in German hospitals.

Table 3

SWOT analysis of the Lean/Six Sigma framework for optimizing patient logistics

Strengths	Weaknesses
Reduces inefficiencies in ED workflows	Requires staff retraining
Improves OR utilization rates	High implementation costs
Opportunities	Threats
Integration with AI-based tools	Resistance to organizational change
Support for digital health policies	Compliance with data privacy regulations

As shown in Table 3, the strengths of the proposed framework lie in its proven ability to reduce inefficiencies in ED workflows and to substantially improve OR utilization. These improvements are not theoretical but are supported by empirical data gathered during the six-month observational study across three German hospitals. They reflect the model's capacity to streamline patient flow, enhance coordination between departments, and increase overall efficiency in resource allocation. However, Table 3 also highlights several important weaknesses that could impede the practical implementation of the framework. Chief among them is the necessity of extensive staff retraining, which requires both time and institutional commitment. Additionally, the financial burden associated with integrating hospital IT systems – particularly in decentralized structures – presents a significant barrier for institutions operating under constrained budgets or rigid procurement processes.

On the opportunity side, the framework's emphasis on real-time responsiveness and predictive analytics positions it well within the current trajectory of Germany's healthcare reforms. The ongoing push for digital transformation in healthcare and policy-level incentives for adopting AI-driven solutions offer a favourable environment for pilot implementation and scaling. The centralized scheduling model, in particular, complements national strategies aimed at hospital modernization and efficiency gains.

At the same time, as illustrated in the threats quadrant of Table 3, the model faces systemic and cultural challenges. Resistance to change among clinical staff, who may be wary of increased automation or loss of departmental autonomy, could undermine early-stage implementation. Furthermore, Germany's strict data protection regulations, especially under the DSGVO framework, may limit the full potential of real-time interoperability between hospital departments. These external threats suggest that even a technically sound framework will require robust change management, clear communication, and compliance-oriented design to succeed in the complex regulatory and cultural environment of German public healthcare.

To illustrate the practical application and cross-departmental impact of the centralized scheduling model proposed in this study, Table 4 outlines how key logistical issues within individual hospital departments can be addressed through integrated coordination mechanisms. Each department – emergency, surgical, radiological, outpatient, and inpatient – faces its own distinct scheduling and communication challenges, many of which stem from fragmented planning systems and asynchronous decision-making. Table 4 juxtaposes these current inefficiencies with the projected improvements made possible by centralized scheduling, based on empirical outcomes and predictive modelling. By integrating patient flows and resource allocation through a unified digital platform, hospitals can reduce delays, optimize prioritization, and improve bed and staff management across units. Table 4 thus demonstrates how centralized scheduling functions not merely as a technical upgrade, but as a systemic solution with tangible operational benefits across the hospital ecosystem.

Table 4

Centralized scheduling solution

Department	Current issues	Impact of centralized scheduling
Emergency department	Long triage and admission delays (avg. 3.5 hrs)	Faster coordination, reducing triage time by 30%
Surgical unit	Frequent scheduling conflicts, 25% surgery delays	Optimized OR allocation, reducing delays by 20%
Radiology	30% imaging delays, equipment downtime issues	Prioritized scheduling, reducing wait times by 25%
Outpatient clinics	40% appointment delays, overbooking problems	Real-time coordination, reducing cancellations by 15%
Inpatient units	Bed shortages, slow transfer processes	Improved bed management, reducing wait times by 10%

Table 4 highlights the systemic benefits of centralized scheduling by quantifying its anticipated impact across five core hospital departments. The improvements are not uniform but tailored to the specific logistical challenges of each unit. In the ED, where triage and admission delays often exceed 3.5 hours, centralized scheduling facilitates faster cross-departmental coordination, reducing triage time by approximately 30%. In the surgical unit, where unanticipated emergencies frequently disrupt elective procedures, real-time scheduling integration enables dynamic OR reallocation, reducing delay rates by

20%. Radiology departments, often affected by equipment downtime and ad hoc prioritization, benefit from automated queue management and case-level urgency scoring, which help lower average wait times by 25%. Outpatient clinics – traditionally vulnerable to overbooking and missed handoffs – experience a projected 15% reduction in appointment cancellations due to tighter synchronization with inpatient and ED schedules. In inpatient units, where bed shortages and manual confirmation of transfers result in prolonged patient holds, centralized oversight allows for improved capacity planning, yielding a 10% decrease in wait times for room assignment.

Collectively, these results underscore the adaptability and system-wide applicability of the centralized scheduling model. Rather than treating coordination as an isolated administrative task, the model repositions scheduling as a strategic function embedded in daily clinical operations. This shift is particularly relevant in the German healthcare context, where fragmented hospital structures and decentralized decision-making often hinder real-time responsiveness. By facilitating unified oversight of clinical resources and patient movement, centralized scheduling addresses one of the root causes of logistical inefficiency in public hospitals – disconnected planning across interdependent departments. As such, the table not only quantifies local improvements but also points to a scalable operational paradigm for hospital modernization.

This study shows that patient flow optimization in German hospitals benefits from explicit coupling of Lean waste elimination and Six Sigma variance control with real time and historical data. By grounding interventions in control chart evidence, regression modeling, and value stream mapping, measurable gains were achieved across emergency intake, surgical scheduling, and interdepartmental coordination. The analysis therefore advances beyond descriptive mapping of inefficiencies toward mechanism-based improvements that are sustainable in routine operations.

Interdisciplinary coordination remains a key determinant of performance. In agreement with A. Bendowska and B. Baum [17], who report that collaborative practice is central to effective care, our data demonstrate that weak synchronization between emergency, radiology, and inpatient units produces quantifiable congestion, including a 40 percent delay rate in outpatient appointments that is explained by upstream mismatches. The present findings extend this evidence by indicating where coordination fails in practice and by linking corrections to standard work for handoffs, shared queues, and automated bed ready signals. Predictive technologies support patient flow decisions when embedded in operational workflows. Consistent with A.R. Sharafat and M. Bayati [18], who developed PatientFlowNet for forecasting emergency department congestion, retrospective logs from 2019 to 2023 informed a bed allocation model that reduced average admission delays by 28 percent. Whereas the cited study focuses on model architecture and predictive accuracy, the contribution here lies in cross departmental deployment and monitoring with capability indices and suppression of out-of-control signals.

Operating room scheduling illustrates the trade-off between emergency readiness and elective throughput that G. Rao et al. [19] synthesize in their review of operations research methods. In our cohort, 35 percent of emergency surgeries were delayed by about two hours under rigid blocks. Dynamic scheduling that reassigned blocks in response to real time emergency inflow narrowed this gap and cut elective rescheduling, which links theoretical optimization to bedside practice. Hospital wide orchestration is necessary to consolidate these gains. In line with D. Bertsimas and J. Pauphilet [20], who show that integrated predictive flow management reduces length of stay and raises throughput, centralized scheduling in our setting connected emergency, operating rooms, radiology, and inpatient movement on one platform, which increased operating room utilization by about 30 percent and raised bed turnover by 10 percent. These effects indicate that local improvements scale when they are coordinated within a single control architecture.

Incremental improvement can contribute to efficiency, although it is often insufficient on its own in complex environments. A.C. Zeferino et al. [21] report moderate gains from Kaizen events in emergency units. In our study, standardized admission and discharge steps accelerated flow, yet the largest effects, including a 50 percent reduction in discharge processing time, emerged when Kaizen activity was embedded in a broader Lean and Six Sigma program that also addressed variability and capacity alignment. Centralization extends beyond staffing to logistics. L. Morse et al. [22] find that centralized nursing staff scheduling improves efficiency and reduces overtime. The present results generalize this logic to patient movement and operating room block assignments, with a 25 percent decrease in waits when a unified appointment system was piloted, which indicates that centralization of information and decision rights is a lever for hospital wide optimization.

Digital readiness is the enabling substrate for these changes. A.I. Stoumpos et al. [23] emphasize that successful digital health implementation requires alignment between technology and human factors. The hospitals studied possessed core systems such as hospital and radiology information platforms, yet limited cross platform compatibility and uneven training constrained benefits. The opportunity and risk dualism described by Y. Karrouk et al. [24] for smart hospital and artificial intelligence transformation, including efficiency gains alongside governance and cost burdens, was also evident here, and the SWOT analysis reflects this balance within the constraints of DSGVO. Change management and skills development are therefore pivotal. P.S. Ferreira [25] shows that resilience during digitalization is cultural and organizational as well as technical. Staff reservations about central scheduling and standard work in our cohort are consistent with this view, and they underscore the need for structured training and leadership sponsored adoption. Complementarily, Y.A. Picón Jaimes [26] documents gaps in digital preparedness within professional education. Limited uptake of dashboards and scheduling tools observed in this study suggests that workforce programs should embed data literacy and operations management before clinical deployment.

The implications for safety and efficiency in emergency departments align with the synthesis by S. Pearce et al. [27], who detail the harms associated with crowding in international systems. Prolonged admission and triage intervals in our study are consistent with their analysis. A related multicenter survey by J.G. Guerrero et al. [28] identifies communication failures, diagnostic delays, and bed shortages as drivers of crowding, patterns that were mirrored in the sites examined. The adoption of dynamic scheduling and standardized handoffs in the present study reduced these pressures, thereby translating recommendations in the literature into tested managerial responses. Finally, the review by J. Pereira et al. [29] on surgical planning optimization underscores the need for flexible and adaptive models. The dynamic allocation used here, which adjusted elective blocks to real time emergency inflow and reduced surgery rescheduling by 67 percent, represents an empirical confirmation of the frameworks that the review advances.

The findings confirm and extend prior work by showing that capability level improvements in patient logistics arise when predictive analytics and central coordination are explicitly tied to Lean and Six Sigma controls. The practical implication is that hospitals should prioritize integrated scheduling infrastructures, continuous monitoring with control charts and capability indices, and structured change management and training so that analytic insight is translated into sustained operational performance.

CONCLUSIONS

1. The study identified significant inefficiencies in patient logistics across three German university hospitals, with notable performance disparities. The hospital in Berlin suburb showed higher efficiency due to partial digital integration and standardized procedures, while the Erfurt hospital faced persistent delays and manual bottlenecks across various operations.
2. Key findings highlighted the impact of triage delays, extended admission processing, and overbooked operating rooms on patient care and throughput. For instance, triage delays in Erfurt exceeded the recommended time in 38% of cases, while Berlin faced a 26% elective surgery delay rate, often due to poor real-time coordination with emergency cases.
3. Inefficiencies were further exacerbated by inadequate interdepartmental communication, with up to 29% of internal patient transfers delayed due to manual bed confirmation and unsynchronized discharge planning.
4. The application of Lean Management and Six Sigma principles provided an effective optimization framework to address these inefficiencies. Lean principles reduced non-value-adding activities, especially in triage and discharge workflows, while Six Sigma's data-driven tools addressed process variability and scheduling inconsistencies.
5. The combined Lean and Six Sigma methodology resulted in measurable improvements, including a 33% reduction in triage times, a 28% improvement in admission efficiency, and a 67% decrease in elective surgery rescheduling.
6. The study introduced a centralized scheduling model as a key solution, inspired by industrial logistics practices. This model integrated hospital information systems, radiology information systems, and transport platforms into a real-time coordination centre, improving operating room utilization by up to 30% and enhancing interdepartmental communication.
7. Challenges to implementing this model include the need for significant staff retraining, IT investment, and strict data protection compliance under Germany's regulations.
8. The study contributes to healthcare logistics by providing empirical evidence from real-world hospital settings and emphasizes the importance of predictive scheduling, algorithm-based planning, and digital coordination platforms tailored to the constraints of Germany's decentralized healthcare system.
9. Limitations of the study include its focus on three urban hospitals, which may not be applicable to smaller or rural facilities, and the six-month observational period, which may not fully capture seasonal trends. Data access constraints due to

privacy compliance also limited the granularity of patient-level analysis.

10. Future research should explore diverse hospital settings, examine the impact of financing models like the diagnosis-related groups system on logistical performance, and investigate AI-based patient flow prediction tools, particularly for real-time emergency department management. Longitudinal studies assessing the long-term impact of Lean and Six Sigma interventions would also provide valuable insights for scalable implementation.

11. In conclusion, the study demonstrates that process redesign, underpinned by Lean and Six Sigma principles, can substantially improve hospital logistics. Smarter scheduling, standardized coordination, and digital transformation can enhance operational efficiency, reduce patient wait times, and improve care outcomes in an increasingly strained healthcare system.

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