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Capacity management under uncertainty in a specialized medical service

Gestión de la capacidad en condiciones de incertidumbre en un servicio médico especializado

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Abstract: Medical care requires an organized response from health care managers, in this sense, planning and managing capacity will allow meeting the demand for care. The objective of the research is to management capacity under uncertainty in a Urology service. Quantitative research was carried out on the basis of a descriptive and retrospective case study, developed during the year 2024 (January - December). A four-stage structured procedure was designed to allow the proposal of strategies for capacity improvement. The demand for care of the groups related to the defined diagnosis was determined and the capacity of the service was calculated considering uncertainty factors. It was determined that the limiting resource is the operating room with a utilization rate of 135 %. The application of the proposed procedure in the entity under study allowed demonstrating its usefulness for the improvement of capacity management under uncertainty.

Keywords: capacity, demand forecasting, patient flow, urology service, proportional method.

Resumen: La asistencia médica exige una respuesta organizada de los gestores sanitarios, en este sentido, planificar y gestionar la capacidad permitirá satisfacer la demanda de atención. El objetivo de la investigación es gestionar la capacidad en condiciones de incertidumbre en un servicio de Urología. Se llevó a cabo una investigación cuantitativa a partir de un estudio de caso de tipo descriptivo y retrospectivo, se desarrolló durante el año 2024 (enero – diciembre). Se diseñó un procedimiento estructurado en cuatro etapas que permite la propuesta de estrategias de mejora de la capacidad. Se determinó la demanda de atención de los grupos relacionados por el diagnóstico definidos y se calculó la capacidad del servicio considerando factores de incertidumbre. Se determinó que el recurso limitante es el salón de operaciones con un porcentaje de utilización de 135 %. La aplicación del procedimiento propuesto en la entidad objeto de estudio, permitió demostrar la utilidad del mismo para la mejora de la gestión de la capacidad bajo incertidumbre.

Palabras clave: capacidad, previsión de la demanda, flujo de pacientes, servicio de urología, método proporcional.

1. INTRODUCCIÓN

Healthcare management requires organized responses aimed at maximizing hospital performance and patient satisfaction [1]. Within this framework, policies aligned with Sustainable Development Goal 3 (health and well-being) [2], [3], have been promoted, highlighting health as a public good with social and economic impact, which demands collaboration from multiple actors in the system (health systems, business system, community, government) [4], to enhance the capabilities of the medical value chain.

In this scenario, Marqués León [5] argues that, to improve efficiency, various studies show the need to overcome functional barriers and move towards process management by integrating clinical and administrative departments in a collaborative model. In the literature [6], [7], two main visions in the management of different processes are distinguished: the clinical, focused on patient care, and the administrative, oriented towards the governance and support of health services [8].

Hospitals, as essential components of the health system, must be managed through adequate planning, organization, and control [9]. For this, tools have been developed that address everything from resource planning to patient pathway management and capacity optimization [5], [10], [11]. However, it is crucial to achieve synergy between care and administrative processes that allows adaptation to demand variations [8], [12].

Hospital demand management is a complex process, influenced by the design of care pathways [13], installed capacity [14] and uncertainty in arrivals [15]. Demand is characterized as virtually infinite, volatile, and unpredictable [16], which makes it necessary to adopt forecasting methods that anticipate its behavior [10]. Among these methods are qualitative (expert judgment), quantitative (mathematical models), and those based on artificial intelligence [17].

The design of care pathways is closely related to the management of patient pathways [13], considered in the literature as the movement of patients through the different stages of treatment with the goal of receiving care [10], furthermore, their efficient coordination guarantees more effective care pathways.

On the other hand, installed capacity depends on the demand for care. Once demand exceeds capacity, patients must wait to receive treatment; therefore, managing capacity also involves managing demand with its various fluctuations or uncertainties in arrivals [18].

The correct application and structuring of information for deployment enhances sound capacity decision-making, recognized as one of the main functions of Operations Management (OM) [19], and measures, in the context of health services, the amount of care that can be provided in a period of time.

However, in high-uncertainty scenarios such as hospital systems especially in contexts with limited resources, traditional forecasting and planning approaches are often insufficient [20]. Recent studies indicate that most existing models fail to adequately capture the variability and unpredictability of demand, nor are they operationally integrated into the daily management of capacity [19], [21]. This gap is accentuated in specialized services such as Urology, where fluctuations in demand and resource limitations can generate prolonged waiting lists, underutilization of beds and rooms, and deficiencies in information systems for patient follow-up [22].

In the Urology Service of the "Faustino Pérez" Clinical Surgical Teaching Hospital in Matanzas, Cuba, concrete problems have been observed, such as poor scheduling of beds and rooms, extensive waiting lists, deficient information and computer systems supporting demand tracking, and insufficient planning of limited resources. These aspects evidence a gap in the ability to plan under conditions of uncertainty, where current methods do not offer adaptive and proactive solutions.

In this context, the specific contribution of this methodological proposal lies in combining quantitative modeling with adjustment based on demand studies under conditions of uncertainty, designed for environments with resource constraints and high demand variability, thus contributing to a more resilient and efficient management of hospital urology services.

Consequently, the research objective is to manage capacity under conditions of uncertainty in a Urology service.

2. LITERATURE REVIEW

The optimization of limited resources to meet patient needs becomes a necessity for hospital

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institutions, in order to fulfill their social purpose [23], in this scenario, the planning and coordination of medical and non-medical resources becomes a challenge for healthcare managers [22].

Jiménez Paneque [24] lists some of the criteria for analyzing hospital capacity, among them: quality, safety, efficiency, or effectiveness; from the perspective of OM, it is one of the tools that allows determining the amount of resources (operating rooms, care personnel, beds, material resources, furniture, and diagnostic means) available per unit of time to face demand [25], [26].

The optimization of resources in hospital environments has evolved from traditional approaches, such as planning using heuristic methods [27], towards more sophisticated analytical methodologies [28], [29]. This transition responds to the need to manage the inherent uncertainty in the demand for health services and to improve operational efficiency.

Capacity planning based on uncertainty must be carried out from strategic levels (long term) to operational (short term), an element that according to Sánchez Suárez, et al. [30] allows for improvement in hospital capacity utilization percentages (Fig. 1); furthermore, it favors the control and organization of work.

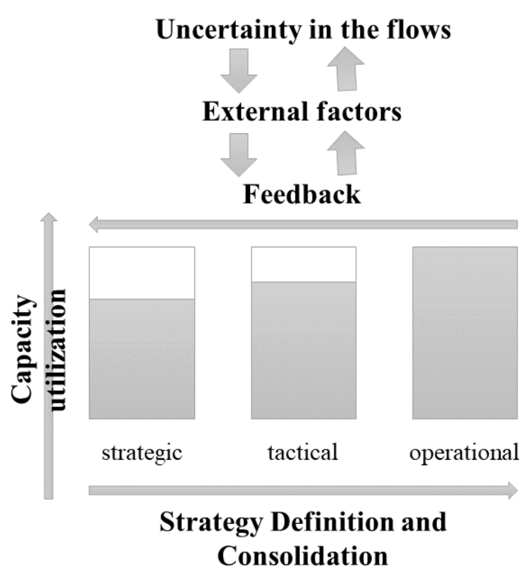

***Fig. 1**. Strategy for hospital capacity planning.*
***Fuente:** Sánchez Suárez, et al. [30].*

Table 1 shows an analysis of procedures for capacity planning in hospital institutions.

***Table 1:** Analysis of procedures for capacity planning in hospital institutions*

Approach / Reference	[31]	[32]	[33]	[34]	[35]	[36]	[11]	[37]	[30]	[38]
year	2011	2016	2019	2020	2020	2021	2022	2023	2023	2023
Queueing theory			X							
Indicators	X									
System dynamics				X	X					
Simulation		X			X		X			
Data Envelopment Analysis (DEA)						X				
Heuristic methods								X	X	X

***Source:** own elaboration.*

From the study of procedures, their gaps are analyzed and possibilities for improvement are identified regarding: (1) the identification of constraints in capacity planning, (2) the identification of uncertainty factors and their use in calculating demand forecasting, (3) the deployment of computer technologies to support decision-making, and (4) enhancement of integral solutions through the use of coordinators.

While traditional or heuristic methods offer simplicity and speed [30], advanced approaches such as discrete simulation, stochastic models, mathematical optimization, and robust programming allow for a deeper and more adaptive analysis of health systems [39].

Heuristic methods and planning based on proportional criteria are based on practical rules, previous experiences, or historical ratios [30]. Their main advantage lies in their simple implementation and low computational requirement, making them useful in contexts of quick decision-making or with data limitations. However, they present significant limitations [40]: they do not guarantee optimal solutions, are usually poorly adaptive to dynamic changes, and do not explicitly handle system variability and uncertainty, which can lead to underutilization of resources or service saturation.

In contrast, discrete event simulation emerges as a powerful tool for modeling the complexity of hospital flows. This approach allows for the dynamic reproduction of processes such as patient admission, operating room utilization, and hospital discharge, facilitating the identification of bottlenecks and the evaluation of "what-if" scenarios without altering the real system [41]. Its strength lies in incorporating stochastic behaviors and variability, although it does not by itself provide optimized solutions, but rather a detailed diagnosis of the system.

To directly address uncertainty, stochastic models incorporate probability distributions for key variables, such as service times or patient arrivals. This allows for risk quantification and performance metric calculation under variable conditions, offering a more solid basis for demand forecasting [42]. However, they require statistical assumptions and can become mathematically complex.

The search for optimal resource allocations finds its natural framework in mathematical optimization and, particularly, in robust programming. These methodologies formulate the planning problem with a set of constraints and an objective function (such as minimizing costs or waiting times) [43]. Robust programming extends this approach to consider multiple uncertainty scenarios, generating solutions that are feasible and perform well across a range of future conditions, without depending on a complete probability distribution. Although their computational cost and data requirements are higher, they offer the greatest rigor and potential for optimality among the analyzed approaches.

3. MATERIALS AND METHODS

Quantitative research [9] was carried out, based on a descriptive and retrospective case study with the purpose of planning capacity in a Urology service under conditions of uncertainty. It was developed during the year 2024 (January - December). Patients with urinary obstructive syndrome were selected for study, with 143 discharges representing 52,5 % of the total (Fig. 2).

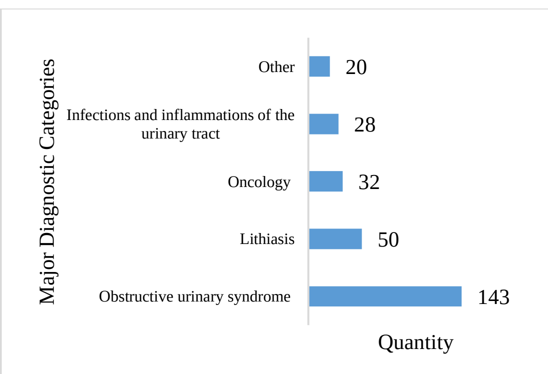

Fig. 2*. Analysis of the number of discharges from the Urology service.*
Source: *own elaboration.*

Based on the gaps found and the suggested improvement opportunities, a procedure for capacity planning in hospital services under conditions of uncertainty was developed, structured in four stages.

3.1. Procedure Description

Stage 1. Description of the selected service

For the description of the selected service, As-Is flowcharts [10] or cross-functional diagrams can be used, which allow observing the sequence of activities by treatment stages, an element that allows managers to locate available resources more quickly. To support the preparation process, the following questions are recommended: What does this step produce? Who receives this result? and What happens next? Microsoft Visio 2016 was used for its preparation.

For the analysis of capacity-related problems in the service, the Theory of Constraints (TOC) was used with the preparation of the current and future reality tree (Fig. 3), structured in three steps [10]: Step 1. Construction of the current value stream map, Step 2. Construction of the cloud or conflict diagram, and Step 3. Construction of the future value stream map.

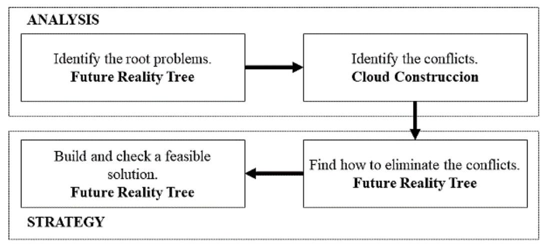

Fig. 3*. Service analysis using TOC thinking.*
Source: *Sánchez Suárez [10].*

Stage 2. Determination of care demand

Initially, the forecasting objectives were identified and patient grouping was performed based on the procedure proposed by Marqués León, et al. [5]. Data collection related to the care demand of the defined Diagnosis-Related Groups (DRGs) was carried out by vertical students in the service.

This process was organized into three groups with different schedules: the first from 8:00 am - 4:00 pm, the second from 4:01 pm - 12:00 am, and the third from 12:01 am - 7:59 am, supervised by the flow coordinator (head of the service's nursing team).

For the forecast calculation, IBM SPSS Statistics 22 software was used due to the capabilities it shows with the expert modeler, which supports the process of selecting the most suitable forecasting model for each of the DRGs. Expert criteria were incorporated using the survey proposed by Sánchez-Suárez, et al. [27], with the support of (1).

$$\text{Forecast} = \text{Prediction} \pm O_e \qquad (1)$$

Donde:

- O_e: Represents the subjective criterion of the expert with a margin of error.

Stage 3. Calculation of service capacity

For the calculation of service capacity, the system's limiting resources were identified with the support of Table 2.

***Table 2:** Identification and prioritization of limiting resources*

Limiting Resource	Treatment Stage	Priority Level
Resource 1	X_1	1 o 2
Resource 2	X_2	1 o 2
Resource z	X_n	1 o 2

***Source:** own elaboration.*

The priority level for managing the capacity of limiting resources is interpreted as: 11 Maximum priority, represented by resources indispensable for care in treatment stage x, and 22 Medium -- low priority, represented by resources complementary to care. The delimitation and classification of resources was the responsibility of the service manager.

To determine the service capacity (C_s) which is the demand for care that the service can assume in a period of time (equation 2), it is necessary to collect the care demands resulting from the demand forecast, calculate the time funds (F_j) of each limiting resource with maximum priority, using equation 3, which is expressed as the number of hours available from the resources per year (hours/year).

Equation 4 shows the real load of the limiting resource during the entire care process (Q_j) expressed as resource consumption per year (hours/year). The capacity coefficient (W_j) relates the annual available time fund to its consumption (equation 5), and the utilization percentage (P_j), expressed in percent (%), which supports the development of improvement strategies (equation 6).

$$C_s = \text{Care demand} * W_j \qquad (2)$$

$$F_j = \text{quantity of resources} * \frac{\text{hours}}{\text{days}} * \frac{\text{days}}{\text{week}} * \frac{\text{weeks}}{\text{month}} * \frac{\text{months}}{year} * (1 - P_s) \qquad (3)$$

$$Q_j = \sum_{i=1}^{n} \text{Care demand} * \text{care time} \qquad (4)$$

$$W_j = \frac{F_j}{Q_j} \qquad (5)$$

$$P_j = \frac{1}{W_j} * 100 \qquad (6)$$

Donde:

- P_s: Percentage of stops due to maintenance or other causes.

In an interview with the deputy medical director, it was identified that the service has the operating room active 5 hours a day, 3 days a week, 4 weeks a month, for 12 months a year, and that according to historical data, scheduled interruptions are at 10%.

The criteria for selecting the treatment stage that limits care and the fundamental point used the criteria from [27] and [30].

Stage 4. Proposal of strategies

For the proposal of strategies to improve service capacity, the causes and sub-causes identified during the TOC thinking process must be taken into account. These strategies were agreed upon in the service's morning meeting among all participating students, residents, specialists, and managers.

4. RESULTS

The results of the application of the proposed procedure are presented.

Stage 1. Description of the selected service

Fig. 4 shows the representation of the Urology service.

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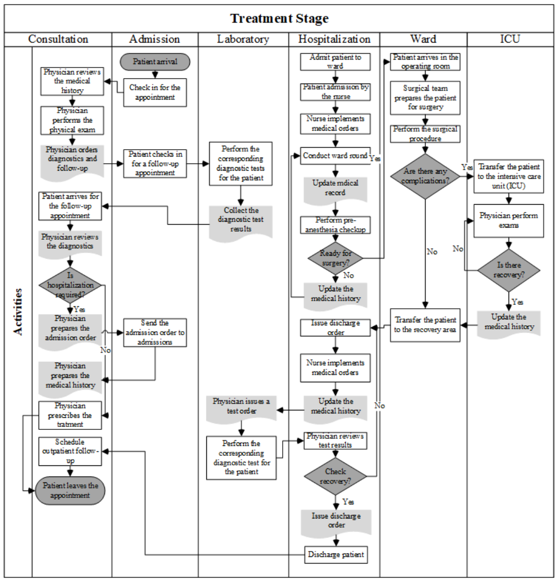

Fig. 4*. Cross-functional diagram of the Urology service.*
Source: *own elaboration.*

A brainstorming session was conducted with the work team, in an unstructured manner, accepting all types of opinions, focused on situations that prevent aggregate capacity planning under uncertainty in the service. Based on the brainstorming results, the Current and Future Reality Tree technique was applied, which allows detailing the patient flow problem in this process and showing the desirable states to be achieved (Fig. 5).

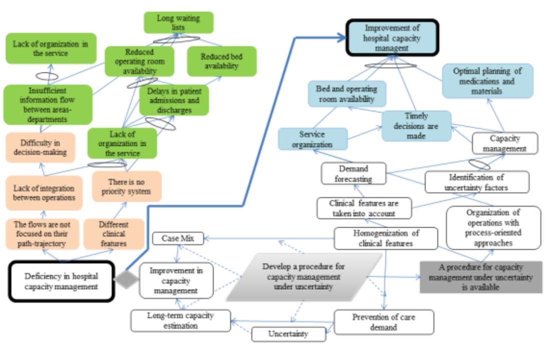

Fig. 5*. Analysis of the current situation of the Urology service.*
Source: *own elaboration.*

Analyzing the results, it is observed that the most important problem, according to the experts, is related to aggregate capacity planning under uncertainty in the service, associated with causes such as underutilization of operating rooms, insufficient room capacity, deficient activity planning, and scarcity of medical supplies.

Stage 2. Determination of care demand

The main DRGs in the service were identified according to the defined Major Diagnostic Category (MDC): Urethral stricture with medical treatment (ICD-10 N35), Urethral stricture with instrumental treatment (ICD-10 N35.1), Urethral stricture with endoscopic treatment (ICD-10 N35.2), Urethral stricture with open surgery (ICD-10 N40), Benign Prostatic Hyperplasia with medical treatment (ICD-10 N40.1), Benign Prostatic Hyperplasia with endoscopic treatment (ICD-10 N40.2), Benign Prostatic Hyperplasia with open surgery (ICD-10 C61), Prostate adenocarcinoma with medical treatment (ICD-10 C61.1), Prostate adenocarcinoma with endoscopic treatment (ICD-10 C61.2), Prostate adenocarcinoma with laparoscopic treatment (ICD-10 C61.3), and Prostate adenocarcinoma with open surgery (ICD-10 N35).

Fig. 6 shows the time series with the forecast for model_1 ICD-10 N35.2.

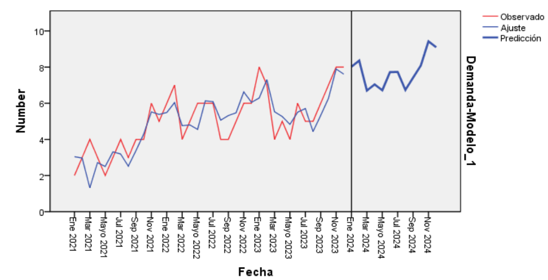

Fig. 6*. Forecast for model_1 ICD-10 N35.2.*
Source: *own elaboration.*

The care demand forecast is shown in Table 3.

Table 3: *Care demand forecast*

CIE	Jan 2023	Feb 2023	Mar 2023	…	Nov 2023	Dec 2023	Total
CIE 10 N35.2	8	8	8	…	9	9	96
CIE 10 N40	7	6	8	…	7	8	88
CIE 10 C61	9	9	9	…	9	10	110
CIE 10 C61.2	9	7	7	…	8	10	96
CIE 10 C61.3	9	8	9	…	7	8	94
CIE 10 N65	6	6	7	…	7	7	74

Source: *own elaboration.*

Stage 3. Calculation of service capacity

Table 4 shows the summary of limiting resources in the service.

Table 4: *Identification of limiting resources*

Limiting Resource	Treatment Stage	Priority Level

Beds	Hospitalization	1
Diagnostic means	Internal consultation	2
Operating Rooms	Surgical stage	1
Human Resources	All	2

Source: *own elaboration.*

The values related to the duration of surgeries and time in the operating room for the defined DRGs and the average hospitalization time (time the patient spends in the hospital occupying a bed) are shown in Table 5.

Table 5: *Information on the DRGs*

DRGs	Surgery Duration (minutes)	Time in Operating Room (minutes)	Average Length of Stay (unit/days = bed)
CIE 10 N35.2	75	105	2
CIE 10 N40	60	90	4
CIE 10 C61	60	90	3
CIE 10 C61.2	60	90	2
CIE 10 C61.3	60	90	2
CIE 10 N65	70	100	2

Source: *own elaboration.*

From the application of the method for calculating service capacity, the following results were obtained: The available capacity of the urology service for the year 2024 is 71, 65, 81, 71, 69, and 55 for the DRGs: ICD-10 N35.2, ICD-10 N40, ICD-10 C61, ICD-10 C61.2, ICD-10 C61.3, and ICD-10 N65, respectively.

The operating room resource was determined as the fundamental point under the criterion that it is there where the greatest use of consumable resources occurs, being the most expensive and currently the most scarce due to the difficult situation in the country. The application of this method showed that operating rooms are the resource that most limits capacity in this service with a value of $W_j = 0{,}74$.

Stage 4. Proposal of strategies

Among the service improvement strategies, the expert team proposes:

1. Study the quantity and organization of beds in the rooms to detect reserves in their distribution. Assess the possibility of increasing their number.
2. Continue implementing innovative techniques that allow for non-invasive surgeries. This increases the performance of outpatient surgeries, reduces hospital stay, and therefore decreases the use of beds in the rooms.
3. Add eight beds to the admission room of the Urology service, which do not affect any hygiene protocol.
4. Perform medication planning based on care needs at the strategic, tactical, and operational levels.
5. Allocate medical and non-medical use materials based on service demand.
6. Continue with the audit process, review of Medical Record (M.R.) evaluation that is carried out to improve the quality of methodological documents, especially the M.R.
7. Systematically verify through sampling that the cases operated on come from the registry and act accordingly if cases outside what is established are detected.
8. Control the registry book of pending patients and ensure its completion and systematic use.

5. DISCUSSION

Capacity management is a topic of interest in recent research [27], [29], and gained greater relevance after the COVID-19 pandemic where care demand increased sharply [44]. In this scenario, the organization of services and their description is fundamental to identify all activities and their precedence relationships to guarantee continuity of care with a focus on the patient pathway. This process can be optimized through the use of flow coordinators, which aligns with what is reported by Subramony, et al. [45], who highlight the role of these coordinators in managing patient pathways, especially in contexts of high demand and variability. The graphical representation of the flow through cross-functional diagrams as shown in Figure 4 allows visualizing connections between activities and facilitates the identification of bottlenecks.

On the other hand, the identification of capacity constraints was carried out through a collaborative approach among experts, guided by an experienced researcher, which allowed integrating multiple perspectives and prioritizing limiting resources in a consensual manner. This practice is consistent with what is suggested by Loorbach and Wittmayer [46], who emphasize the importance of interdisciplinary work in hospital capacity planning.

Regarding demand estimation, the proposed procedure incorporates expert opinion to adjust quantitative forecasts, as recommended by Ackermann and Sellitto [17]. This hybrid approach allows correcting possible biases in statistical models and adapting projections to local conditions or contextual changes. It is crucial that these values are continuously updated and monitored, given the inherent dynamics of hospital systems and the influence of unforeseen external factors.

The analysis of DRG behavior is essential for selecting the appropriate forecasting method. As noted by Rodríguez Jáuregui, et al. [16], hospital demand is volatile and unpredictable, so not all DRGs can be modeled solely with time series; in some cases, qualitative methods or artificial intelligence may be required. The choice of method directly influences the accuracy of the forecast and, consequently, capacity planning.

Service capacity is calculated through the proportionality coefficient (W_j), which relates the available time fund to the load imposed by limiting resources. When $W_j < 1$, the service lacks the capacity to meet the forecasted demand, which requires immediate adjustment decisions by managers. Conversely, a $W_j > 1$ indicates that the service has sufficient capacity.

Table 6 shows a sensitivity analysis with the purpose of validating and demonstrating the robustness of the proposed procedure. For this, four scenarios (S) were created:

- S_1: Demand increases by 5 patients and scheduled interruptions decrease by 5 %.
- S_2: Demand decreases by 5 patients and interruptions are eliminated.
- S_3: Care time is increased to 5 days a week (reference 3 days) and interruptions remain at 10 %.
- S_4: Care time is increased to 4 days a week (reference 3 days) and scheduled interruptions decrease by 5 %.

Table 6: *Sensitivity analysis*

Scenario	F_j	Q_j	W_j	Analysis
S_1	41040	52464	0,78	$W_j < 1$
S_2	38880	49575	0,78	$W_j < 1$
S_3	64800	52400	1,24	$W_j > 1$
S_4	54720	52400	1,04	$W_j > 1$

Fuente: *elaboración propia.*

An increase in demand of 5 patients, but with a 5 % decrease in scheduled interruptions, the capacity coefficient increases from 0,74 to 0,78. Similarly, an increase in care times from 3 to 5 days a week with scheduled interruptions of 10 %, the capacity coefficient increases to 1,24 ($W_j > 1$) which represents that the service has capacity and reserves of 24 %. These scenarios underline the importance of continuously monitoring key factors that influence uncertainty in process management to thus establish safety margins, an element that would allow building a risk profile and defining thresholds to activate corrective measures.

Among the limitations of the procedure, in agreement with Marrero Otero, et al. [14], are the challenges in the accuracy of long-term planning and the lack of a formal instrument to identify and link uncertainty factors with hospital risk prevention plans. Furthermore, the method critically depends on data quality and the periodic recalibration of forecasts.

An internal simulation showed that, without continuous updating with expert criteria, the forecast error could increase between 25% and 40% after six months, compromising the validity of W_j [47]. Therefore, successful implementation requires an institutional commitment to the continuous improvement of information systems and the periodic review of model assumptions.

6. CONCLUSIONS

The application of the proposed procedure in the entity under study suggests its possible usefulness for improving aggregate capacity planning in contexts of uncertainty. The results obtained in this specific case allow observing its operation and the systematic identification of limiting resources, which translates into building risk profiles and defining thresholds to activate corrective measures.

The service process was graphically represented through cross-functional diagrams, a tool that facilitates the description of connections between activities and allows for an integrated analysis of the patient pathway, from admission to discharge. However, the generalization of this representation to other services or hospitals with different structures or flows requires contextual adaptations.

Regarding demand analysis, 11 DRGs were defined within the service, and a sample of 273 patients treated during 2024 was studied. Of these, only six surgical DRGs were analyzed in depth for the monthly forecast of 2025. It should be noted that the validity of the forecast is conditioned by the temporal stability of demand patterns and the quality of historical records. The inclusion of expert opinion, although enriching, introduces a subjective component that must be managed with methodological transparency.

The results indicated that the most limiting resource in the studied service is the operating room, with a utilization percentage of 135 %. The available capacity calculated for 2024 varied between 55 and 81 attendances depending on the DRG. However, these values critically depend on the assumptions of care time, available time funds, and considered uncertainty factors. The proportionality coefficient (W_j) proved to be a useful indicator to point out gaps, but its precision is linked to the rigor of the input estimates.

The study presents limitations in its long-term applicability, which decreases accuracy in planning; on the other hand, the lack of formal mechanisms to identify other sources of uncertainty, dependence on historical data and specialized personnel, a restrictive focus on one service and hospital. In future lines of research, it is proposed to develop calibration protocols, an integrated decision tool, incorporate risk management, complement the procedure with simulations, and evaluate reproducibility in other health systems.

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