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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.

INTRODUCTION

Health care 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) have been promoted [2], [3]; these highlight health as a public good with social and economic impact, which requires the collaboration of multiple actors in the system (health systems, business system, community, government) [4], in order to strengthen the capacities of the medical value chain.

In this scenario, Marqués León [5] states that, to improve efficiency, various studies show the need to overcome functional barriers and move towards process management, through the integration of clinical and administrative departments in a collaborative model. In the literature [6], [7], two main visions are distinguished in the management of the different processes: the clinical one, focused on patient care, and the administrative one, 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]. To this end, tools have been developed that range from resource planning to the management of patient pathways and capacity optimization[5],[10],[11]. However, achieving a synergy between care and administrative processes that allows adaptation to variations in demand is crucial[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 being virtually infinite, volatile and unpredictable[16], which makes it necessary to adopt forecast methods that allow anticipating its behavior[10]. These methods include qualitative ones (expert judgment), quantitative ones (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 treatment stages with the aim of receiving care[10]; efficient coordination of these pathways also ensures more effective care.

Installed capacity, in turn, depends on the demand for care; once demand exceeds capacity, patients must wait to receive treatment, so managing capacity in turn implies managing demand with the different 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, and that they are not operationally integrated into daily capacity management[19],[21]. This gap is accentuated in specialized services such as urology, where fluctuation 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 Hospital Clínico Quirúrgico Docente “Faustino Pérez” in Matanzas, Cuba, specific problems have been observed, such as poor scheduling of beds and rooms, extensive waiting lists, deficient information and computer systems to support demand monitoring, and insufficient planning of limited resources. These aspects reveal a gap in the capacity 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 the fact that it combines 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 more resilient and efficient management of hospital urology services.

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

LITERATURE REVIEW

Optimizing limited resources to meet the needs of patients becomes a necessity for hospital 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 health managers[22].

Jiménez Paneque [24] states some of the criteria for the analysis of hospital capacity, including: quality, safety, efficiency or effectiveness; from the perspective of operations management (OM), it is one of the tools that allow determining the quantity of resources (operating rooms, care staff, beds, material resources, furniture and diagnostic means) per unit of time available to meet demand [25], [26].

The optimization of resources in hospital environments has evolved from traditional approaches, such as planning through heuristic methods [27], toward 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 the strategic levels (long term) to the operational level (short term), an element that, according to Sánchez Suárez et al.[30], allows improvement of the utilization percentages of hospital capacity (Fig. 1); furthermore, it favors the control and organization of work.

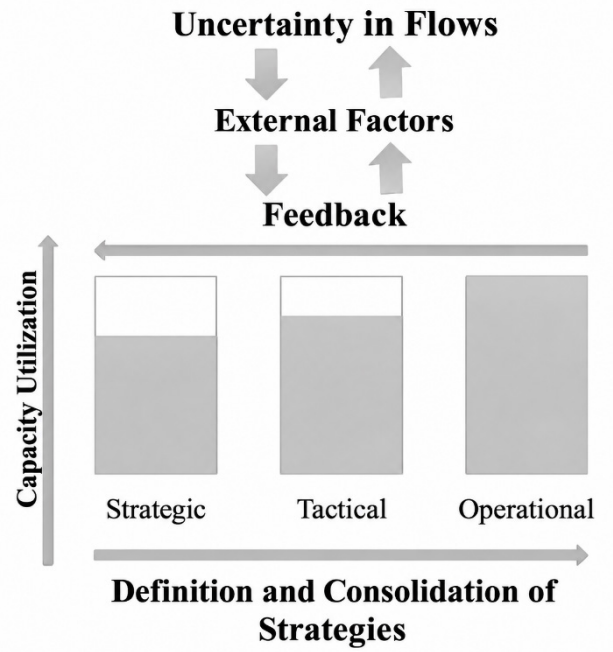

Fig. 1. Strategy for hospital capacity planning. Source: Sánchez Suárez et al. [30].

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
Queuing 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.

The study of procedures analyzes their gaps and identifies possibilities for improvement 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 information technologies to support decision-making and (4) strengthening comprehensive 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 a deeper, more adaptive analysis of health systems[39].

Heuristic methods and planning based on proportional criteria rest on practical rules, previous experience or historical ratios[30]. Their main advantage is simple implementation and low computational requirements, which makes them useful when decisions must be made quickly or data are limited. However, they have significant limitations[40]: they do not guarantee optimal solutions, they adapt poorly to dynamic changes and they do not explicitly handle the variability and uncertainty of the system, which can lead to underutilization of resources or saturation of services.

In contrast, discrete event simulation emerges as a powerful tool for modeling the complexity of hospital flows. This approach can dynamically reproduce processes such as patient admission, operating room utilization and hospital discharge, which facilitates 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 address uncertainty directly, stochastic models incorporate probability distributions for key variables, such as service times or patient arrivals. This allows risks to be quantified and performance metrics to be calculated 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, in particular, 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, which yields solutions that are feasible and perform well under a range of future conditions, without relying 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 approaches analyzed.

MATERIALS AND METHODS

A quantitative research study[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 conducted during 2024 (January – December), and patients with urinary obstructive syndrome were selected for study, with 143 discharges representing 52.5 % of the total (Fig. 2).

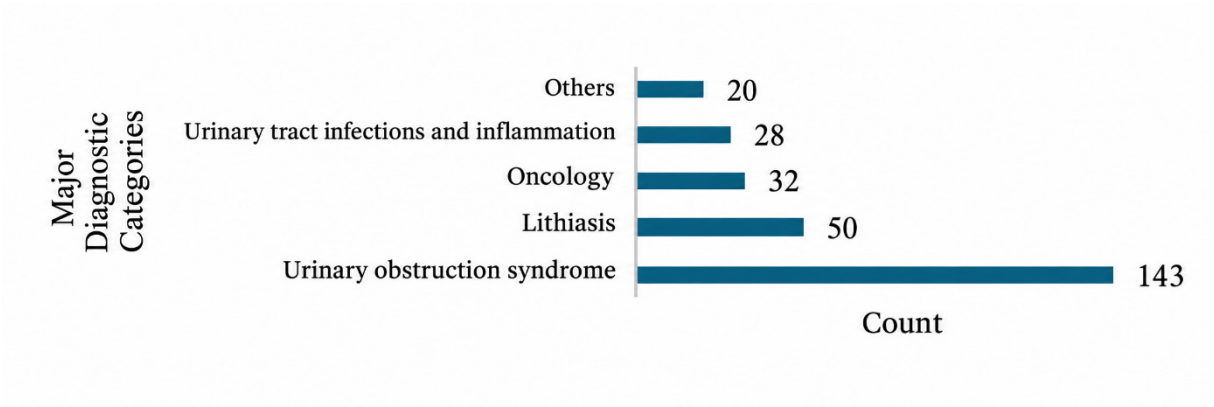

Fig. 2. *Analysis of the number of discharges from the urology service.*
Source: own elaboration.

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

Description of the procedure

Stage 1. Description of the selected service

For the description of the selected service, As – Is[10]or cross-functional flowcharts can be used, which allow the sequence of activities by treatment stages to be observed, an element that enables 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 the preparation.

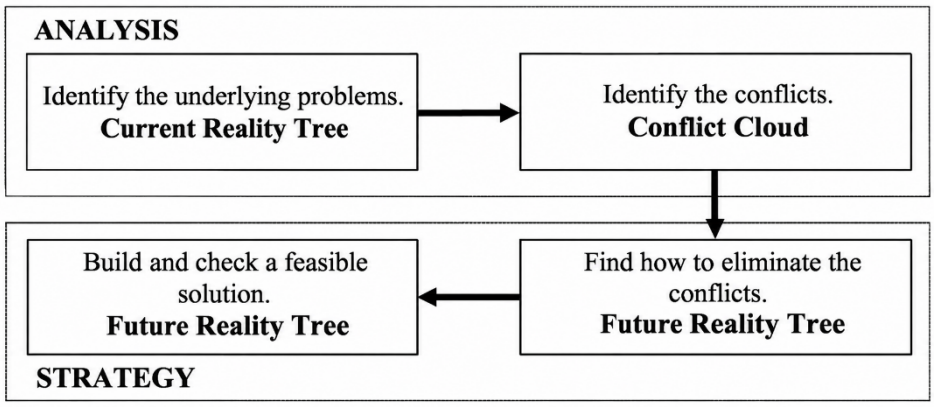

Fig. 3. *Analysis of the service through TOC thinking.*
Source: Sánchez Suárez [10].

Stage 2. Determination of the demand for care

Initially, the forecast objectives were identified and patient grouping was performed based on the procedure proposed by Marqués León, et al.[5]. Data collection related to the demand for care of the diagnosis-related groups (GRD) defined was carried out by the 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 its capabilities with the expert modeler, which supports the process of selecting the forecast model that best fits each of the GRDs; the expert criterion is incorporated through the survey proposed by Sánchez-Suárez, et al.[27], with the support of(1).

$$Previsión = Pronóstico \pm O_e \quad (1)$$

Where:

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

Stage 3. Calculation of service capacity

To calculate service capacity, the limiting resources of the system were identified with the support of table 2.

Table 2: Identification and prioritization of limiting resources

Limiting resource	Treatment stage	Priority level
Resource 1	X1	1 or 2
Resource 2	X2	1 or 2
Resource z	Xn	1 or 2

Source: own elaboration.

The priority level for managing limiting resource capacity is interpreted as: [1] Highest priority, represented by the resources essential for assistance at treatment stage x and [2] Medium–low priority, represented by resources complementary to assistance. The delimitation and classification of resources was the responsibility of the head of services.

To determine the service capacity (C_s), that is, the demand for care that the service can assume in a period of time (equation 2), the demands for care resulting from the demand forecasting must be compiled, and the time funds (F_j) of each limiting resource with maximum priority must be calculated by means of equation 3, which is expressed as the number of available hours of the resources per year (hours/year).

Equation 4 shows the actual load of the limiting resource throughout all care (Q_j)which is expressed as the consumption of the resources per year (hours/year). The capacity coefficient (W_j) relates the time fund available per year to its consumption (equation 5), and the utilization rate (P_j), expressed as a percentage (%), supports the development of improvement strategies (equation 6).

$$C_s = \text{Attention demand} * W_j$$

$$Fj = \text{amount of resources} * \frac{\text{hours}}{\text{days}} * \frac{\text{days}}{\text{week}} * \frac{\text{weeks}}{\text{month}} * \frac{\text{months}}{\text{year}} * (1 - P_s)$$

$$Q_j \sum_{i=1}^{n} = \text{Attention demand} * \text{attention time}$$

$$W_j = \frac{Fj}{Qj}$$

$$P_j = \frac{1}{Wi} * 100$$

Where:

• P_s: Percentage of stoppages due to maintenance or other causes.

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

For the criteria for selecting the stage of treatment that limits care and the fundamental point, the criteria of[27]and[30]were used.

Stage 4. Proposal of strategies

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

RESULTS

The results of applying the proposed procedure are presented.

Stage 1. Description of the selected service

Fig. 4 shows the representation of the urology service.

A brainstorming session was held with the work team in an unstructured manner, admitting all types of criteria and focused on the situations that prevent aggregate capacity planning under uncertainty in the service. Based on the results of the brainstorming, the Current and Future Reality Tree technique was applied, which makes it possible to detail the patient flow problem in this process and to show the desirable states to be achieved (Fig. 5).

When analyzing the results, it can be seen that, in the experts' judgment, the most important problem is the one related to aggregate capacity planning under uncertainty in the service, associated with causes such as underutilization of operating rooms, insufficient room capacity, poor planning of activities and shortages of medical supplies.

The main GRDs in the service according to the major diagnostic category (MDC) defined were identified as: 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), Prostatic adenocarcinoma with medical treatment (ICD 10 C61.1), Prostatic adenocarcinoma with endoscopic treatment (ICD 10 C61.2), Prostatic adenocarcinoma with laparoscopic treatment (ICD 10 C61.3) and Prostatic adenocarcinoma with open surgery (ICD 10 N35).

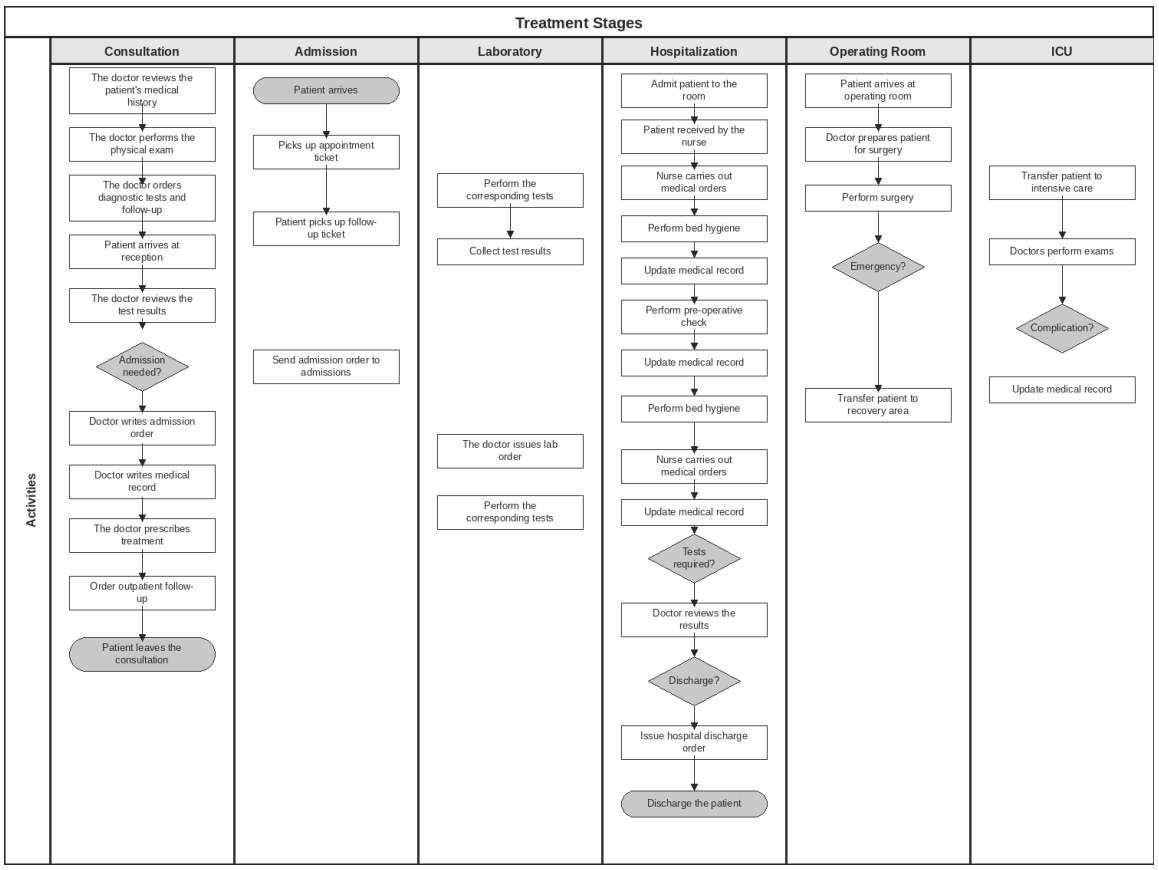

Fig. 4. *Cross-functional diagram of the urology service.*
Source: own elaboration.

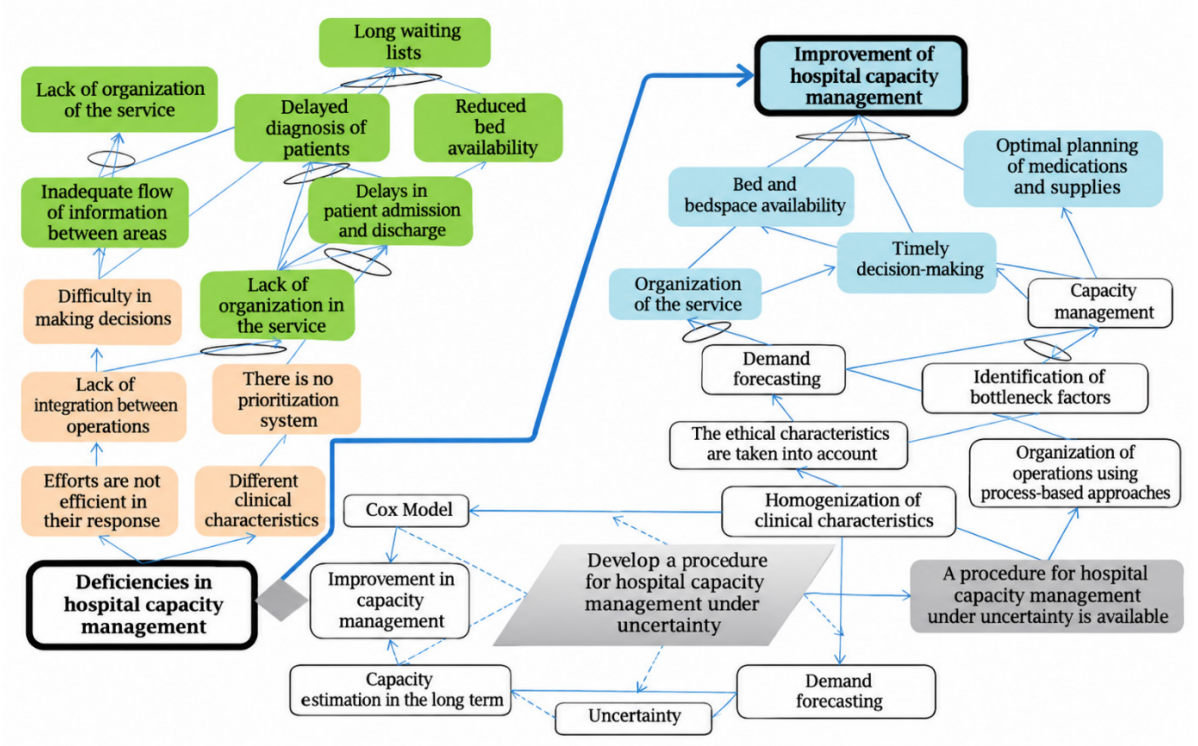

Fig. 5. *Analysis of the current situation of the urology service.*
Source: own elaboration.

Stage 2. Determination of care demand

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

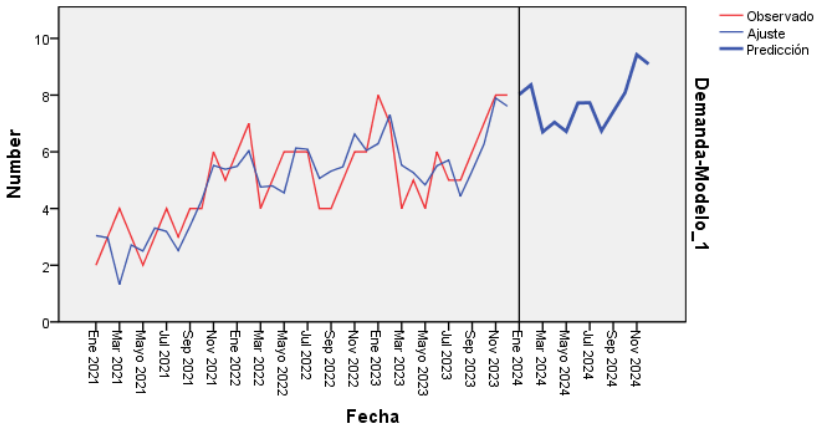

Fig. 6. *Forecast for model_1 ICD 10 N35.2.*
Source: own elaboration.

The demand for care forecast is shown in table 3.

Table 3: Demand for care forecast

ICD	Jan 2023	Feb 2023	Mar 2023	…	Nov 2023	Dec 2023	Total
ICD 10 N35.2	8	8	8	…	9	9	96
ICD 10 N40	7	6	8	…	7	8	88
ICD 10 C61	9	9	9	…	9	10	110
ICD 10 C61.2	9	7	7	…	8	10	96
ICD 10 C61.3	9	8	9	…	7	8	94
ICD 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	Inpatient 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 GRDs and the average hospitalization time (time the patient spends in the hospital occupying a bed) are shown in table 5.

From the application of the method for calculating the 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 GRDs: 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 identified as the fundamental point, on the criterion that this is where the greatest use of consumable resources occurs and that these are the most costly and currently the scarcest, given the difficult situation the country is in. 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.

Table 5: Information on the GRDs

GRDs	Surgery duration (minutes)	Time in operating room (minutes)	Average length of stay (unit/days = bed)
ICD 10 N35.2	75	105	2
ICD 10 N40	60	90	4
ICD 10 C61	60	90	3
ICD 10 C61.2	60	90	2
ICD 10 C61.3	60	90	2
ICD 10 N65	70	100	2

Source: own elaboration.

Stage 4. Proposal of strategies

Among the strategies for improving the service, the team of experts proposes:

1. To study the number and organization of beds in the wards in order to detect reserves in their distribution, and to assess the possibility of increasing their number.
2. Continue implementing innovative techniques that allow non-invasive surgeries to be performed. This increases the performance of outpatient surgeries, reduces the hospital stay and therefore reduces the use of beds in the wards.
3. To increase by eight beds the admission ward of the urology service, which do not affect any hygiene protocol.
4. To carry out medication planning based on care needs at the strategic, tactical and operational levels.
5. To carry out the allocation of medical and non-medical materials based on the demand of the service.
6. Continue with the audit process and the review of the medical record (MR) evaluation carried out to improve the quality of the methodological documents, especially the MR.
7. Systematically verify by sampling that the cases operated on come from the registry and act accordingly if cases outside the established criteria are detected.
8. Control the registry book of pending patients and guarantee its completion and systematic use.

DISCUSSION

Capacity management is a topic of interest in recent research[27],[29], and it gained greater relevance after the COVID-19 pandemic, when the demand for care increased sharply[44]. In this scenario, the organization of services and their description make it essential to identify all activities and their precedence relationships in order to guarantee continuity of care with a focus on the patient journey. This process can be optimized through the use of flow coordinators, which is in line with what was 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 such as the one shown in Figure 4 allows the connections between activities to be visualized and facilitates the identification of bottlenecks.

The identification of capacity constraints, in turn, was carried out through a collaborative approach among experts, guided by an experienced researcher, which made it possible to integrate multiple perspectives and prioritize limiting resources by consensus. This practice is consistent with what was suggested by Loorbach and Wittmayer[46], who emphasize the importance of interdisciplinary work in hospital capacity planning.

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

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

Service capacity is calculated using the proportionality coefficient (W_j), which relates the available time fund to the load imposed by the limiting resources. When$W_j < 1$, the service lacks the capacity to meet the forecast 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 to validate and demonstrate the robustness of the proposed procedure. Four scenarios (S) were created for this purpose:

- E_1: Demand increases by 5 patients and scheduled interruptions decrease by 5%.
- E_2: Reduce demand by 5 patients and eliminate interruptions.
- E_3: Care time is increased to 5 days a week (reference 3 days) and interruptions remain at 10%.
- E_4: Care time is increased to 4 days a week (reference 3 days) and scheduled interruptions decrease by 5%.

Table 6: Sensitivity analysis

Scenario	^{r}j	^{q}j	^{w}j	Analysis
E_1	41040	52464	0,78	$W_j < 1$
E_2	38880	49575	0,78	$W_j < 1$
E_3	64800	52400	1,24	$W_j > 1$
E_4	54720	52400	1,04	$W_j > 1$

Source: own elaboration.

With an increase in demand of 5 patients but a 5% decrease in scheduled interruptions, the capacity coefficient increases

from 0.74 to 0.78. Likewise, when care times increase from 3 to 5 days a week with scheduled interruptions of 10%, the capacity coefficient increases to 1.24 ($W_j > 1$), which means that the service has capacity and reserves of 24%. These scenarios underscore the importance of continuously monitoring the key factors that influence uncertainty in process management in order to establish safety margins, an element that would make it possible to build a risk profile and define thresholds for activating 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. In addition, the method depends critically on data quality and on the periodic recalibration of forecasts.

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

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 make it possible to observe how it operates and the systematic identification of limiting resources, which translates into building risk profiles and defining thresholds for activating corrective measures.

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

Regarding the demand analysis, 11 GRDs were defined within the service and a sample of 273 patients attended during 2024 was studied. Of these, only six surgical-type GRDs were analyzed in depth for the monthly forecast for 2025. It should be noted that the validity of the forecast is conditioned by the temporal stability of demand patterns and by 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 service studied is the operating room, with a utilization rate of 135 %. The available capacity calculated for 2024 varied between 55 and 81 care episodes depending on the GRD. However, these values depend critically on the assumptions of care time, available time funds and uncertainty factors considered. The proportionality coefficient (W_j) proved to be a useful indicator for identifying gaps, but its precision is tied to the rigor of the input estimates.

The study has limitations for its long-term applicability, which reduces precision in planning. On the other hand, there is a lack of formal mechanisms to identify other sources of uncertainty, dependence on historical data and specialized personnel, and a restrictive focus on a single service and hospital. Future lines of research propose developing calibration protocols, an integrated decision tool, incorporating risk management, complementing the procedure with simulations, and evaluating reproducibility in other health systems.

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