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From operational analysis to implementable emergency department throughput interventions: Integrating Theory of Constraints and Design Science Research

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Declarations

Ethics approval and consent to participate

This study was conducted in accordance with relevant Finnish legislation and guidelines and the principles of the Declaration of Helsinki. Formal ethics committee review was not required under the Finnish Medical Research Act (488/1999). Use of the retrospective hospital data was authorised by an administrative decision of the Medical Director of Kanta-Häme Central Hospital. The analysed dataset contained structured clinical and administrative data, including diagnoses, reasons for arrival, disposition, and process timestamps, but no free-text clinical notes or direct personal identifiers. Healthcare professionals participated voluntarily in interviews after providing informed consent. The professional interviews did not meet the criteria requiring prior ethical review under the guidelines of the Finnish National Board on Research Integrity (TENK).

Consent for publication

Not applicable

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to restrictions imposed by the Finnish Act on the Secondary Use of Health and Social Data but are available from the corresponding author on reasonable request, subject to the requirements of the applicable legislation.

The R code used for data processing and statistical analyses is available from the corresponding author on reasonable request.

Competing interests

The authors declare they have no competing interests.

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Authors' contributions

All authors contributed to the study conception and design. Data collection was performed by SS and TL. Analyses were performed by SS and PT. The first draft of the manuscript was written by SS and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Abstract

Background Emergency Department (ED) efficiency is often constrained by crowding, which is driven by non-critical patients and exacerbated by delays in patient transfer to inpatient wards. While numerous studies have identified opportunities to improve ED throughput, fewer have addressed how operational evidence can be systematically translated into implementable interventions. Because indiscriminate acceleration of patient throughput may worsen congestion at the ED–ward interface, this study aimed to develop and operationalise a throughput intervention for dischargeable patients using a combined Theory of Constraints (TOC) and Design Science Research (DSR) approach, providing a systematic framework for translating operational research into healthcare practice.

Methods Using a mixed-methods design, ED visits at a Finnish secondary hospital in 2022 (n = 26,814) were retrospectively analysed. Cumulative ED length of stay (CEDLOS) was calculated for each acute diagnosis among dischargeable patients, and diagnoses were ranked accordingly. The highest-ranking diagnosis whose demand coincided with peak ED crowding was selected as the theoretical target segment, from which an identifiable operational target segment was derived for intervention design. Constraints within the operational target segment were characterised using process mapping, quantitative analyses, and semi-structured interviews with healthcare professionals (n = 8). TOC was used to identify and address operational constraints, while DSR translated these findings into an implementable throughput intervention.

Results Theoretical target segment analysis identified discharged patients with acute atrial fibrillation as the diagnosis contributing the greatest cumulative ED burden during periods of crowding (912 visits, 5,785 hours). An operational target segment suitable for prospective identification was subsequently defined. Key constraints were information flow and laboratory throughput. A fast-track service incorporating rapid assessment, pull-based external electrical cardioversion, point-of-care testing, and patient education was developed.

Conclusions The combined TOC–DSR approach provides a systematic framework for translating operational analyses into implementable ED throughput interventions. By targeting dischargeable patients and requiring no additional resources, the proposed intervention offers a practical pathway for reducing crowding while facilitating the translation of operational research into healthcare practice. Further research is needed to evaluate its effectiveness and generalisability.

Keywords Emergency department, Crowding, Patient throughput, Theory of Constraints, Design Science Research, Healthcare operations

1 Background

Emergency departments (EDs) provide care for patients with a wide range of acuity, from life-threatening emergencies to non-critical conditions requiring complex diagnostic workups. As critical and non-critical patients often compete for shared resources, mismatches between patient demand and ED capacity can lead to crowding and impaired patient flow [1]. ED crowding is commonly characterised by ED length of stay (EDLOS) [2,3], occupancy and patient volume [3]. Crowding adversely affects patient outcomes, staff satisfaction and patient experience [4]. It has been linked with increased mortality [5,6], which has recently been established also among non-critical ED patients [7]. Although the underlying causes of crowding span the wider healthcare system [8–10], EDs can implement operational improvements within their own control to mitigate its effects [11].

ED crowding occurs when patient flow is disrupted in terms of input, throughput or output [8,10]. While input and output factors are often beyond the direct control of the ED, throughput can be influenced through local operational changes, and evidence suggests that throughput factors have a greater impact on ED length of stay than input or output factors [12]. Numerous ED-based throughput interventions have been proposed, including rapid assessment, streaming, fast tracks, physician triage and point-of-care testing (POCT), many of which have demonstrated reductions in EDLOS under appropriate conditions [1,13–16]. However, these studies primarily evaluate specific interventions, offering limited guidance on how healthcare organisations can systematically identify where interventions should be targeted and translate operational analyses into implementable service designs. Multifaceted, context-specific approaches have been suggested to achieve sustainable waiting time reductions [17].

Exit block, along with the related practice of boarding (holding admitted patients in the ED due to lack of inpatient beds) is known to exacerbate crowding [18,19]. Therefore, indiscriminate efforts to increase ED throughput may simply shift congestion from the treatment process to the ED–ward interface, limiting the effectiveness of local process improvements [11]. Targeting patients who are discharged directly from the ED may mitigate this risk by reducing

demand for shared ED resources without increasing downstream congestion. The resulting capacity can then potentially be reallocated to patients requiring time-critical care.

Systematically translating operational analyses into implementable throughput interventions requires both a method for identifying where improvements should be targeted and a process for converting these insights into operational solutions. Theory of Constraints (TOC) [20] is a well-established management methodology that has yielded substantial improvements in healthcare by identifying and addressing system constraints [21]. However, its application in the ED is challenging because of the diversity and time-criticality of emergency care processes [21]. Design Science Research (DSR) provides a structured framework for developing and operationalising artefacts that address [22]. DSR works well in bridging practice and theory [23] and it has been applied in the ED to increase patient flow [24]. To our knowledge, however, TOC and DSR have not previously been integrated to guide the systematic design of ED throughput interventions. By combining these approaches, this study proposes a systematic methodology for translating operational analyses into implementable service interventions while contributing to the methodological integration of TOC and DSR in healthcare operations management.

We demonstrated the proposed methodology through the design of an ED throughput intervention in a Finnish secondary hospital. The research questions guiding this study were:

1. Which dischargeable patient segment should be prioritised for ED throughput interventions?
2. Which operational constraints limit throughput in the identified segment?
3. How can the identified constraints be translated into an implementable ED throughput intervention using a combined TOC-DSR approach?

2 Methods

2.1 Study design

This study employed a problem-driven design, guided by the Theory of Constraints (TOC) and Design Science Research (DSR) frameworks. TOC structured the identification and analysis of operational constraints driving waste in the ED, while DSR guided the focus and translation of these insights into an implementable solution artefact.

The analysis began broadly, considering all ED patients and treatment processes as potential targets for improvement. The study comprised five steps:

1. Identification of the core operational problem.
2. Definition of objectives for addressing the problem.
3. Selection of a specific target patient segment, informed by the problem definition and objectives.
4. Analysis of the target segment and its processes using the first four steps of the TOC Five Focusing Steps (identify, exploit, subordinate, elevate) to generate solution components.
5. Design of a DSR artefact incorporating these components, suitable for implementation in the ED.

Artefact demonstration was outside the scope of this study and therefore, artefact evaluation was based on discussion of potential benefits and risks. The overall study design is presented in Figure 1.

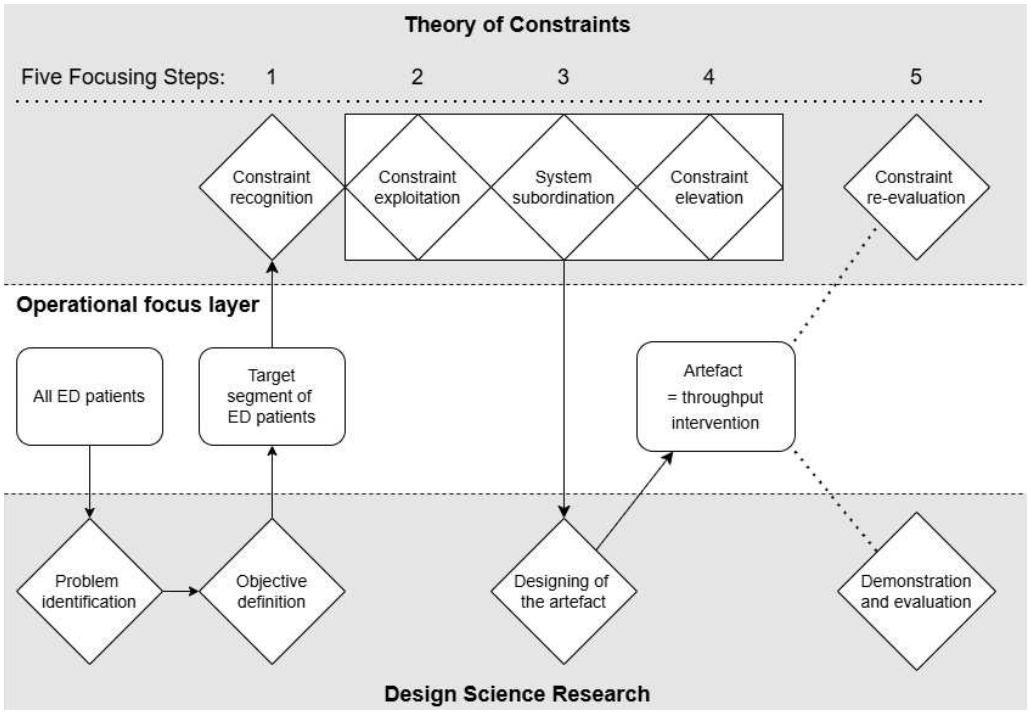


Figure 1 Study design

2.2 Setting

This research was conducted in 2022 in Kanta-Häme Central Hospital (KHCH), a Finnish secondary hospital located in the city of Hämeenlinna, Southern Finland, in the geographical centre of the Finnish population. KHCH serves a population of approximately 171,000 people and handles around 27,000 secondary care ED visits annually. KHCH ED is led by an emergency physician, and it has a bed capacity of 22, of which four are in two resuscitation bays. The adjacent observation unit (i.e. reassessment unit with 24/7 monitoring and treatment capacity) could be used for ED patients if necessary. The secondary care ED services are divided into two streams: Medical Care Stream (MCS) and Surgical Care Stream (SCS). KHCH ED also receives patients categorised as urgent primary care. These were excluded from this study, as the focus was on patients more likely to share resources with critical cases. In this study, critical cases are characterised to have a physician's contact requested as soon as possible, and they are often placed in resuscitation bays. Additionally, KHCH employs the emergency physician-led triage model.

2.3 Problem identification and objective definition

EDs are primarily responsible for managing patient throughput, while its ability to influence patient input (arrivals) or output variables (e.g., ward capacity) is limited. EDs experience crowding, which is associated with delayed care, poorer clinical outcomes, and reduced patient and staff satisfaction. Critical patients are particularly vulnerable to crowding. However, most ED demand comes from non-critical patients. Efforts to increase patient throughput without considering downstream constraints risk exacerbating exit block, thereby reducing the effectiveness of process improvements.

The primary objective of this study was to design a throughput-focused intervention aimed at reducing waste in the ED by liberating capacity in the MCS or the SCS. The released capacity was intended to be available for critical patients. The intervention aimed to reduce waste without compromising medical outcomes, staff satisfaction, or patient experience, and it was required to be implementable using existing resources. The solution specifically targeted dischargeable patients, as improving their flow can mitigate the impact of exit block on throughput improvements.

2.4 Data sources

We conducted a retrospective observational analysis of all KHCH ED visits in 2022 recorded in an institutional dataset exported from the electronic health record system. The central throughput measure in this study was EDLOS, which was estimated as the time from creation of the visit object in the record system to discharge from the ED. Additionally, the quantitative data comprised patient characteristics (age, acute diagnoses, previous diagnoses, urgency based on triage classification) and process characteristics (first and last assigned specialties, total number of specialties, disposition and timestamps) of visits in KHCH ED secondary healthcare units in 2022 (n = 26,814). Acute diagnoses were defined as diagnoses recorded within 48 hours of ED discharge, to account for diagnoses established after initially ambiguous ED presentations. Duplicate diagnostic entries during the same visit were deleted.

Timestamps were also collected for the centralised resources of laboratory and radiology services. The laboratory process was split in two timestamps: “first results available” and “all clinically relevant results available”, where the latter was estimated by finding the moment when results for C-reactive protein and troponin were available, if these tests were requested. These two tests were frequently requested, often had a longer lead time than other tests and their results are often checked before disposition.

Quantitative data were gathered in Excel (Microsoft, San Diego, CA) format, while data preprocessing and quantitative analyses were conducted in R (R Foundation for Statistical Computing, Vienna, Austria). Qualitative data were collected through semi-structured interviews. All willing physicians and nurses of KHCH ED were invited via email. In addition, a medical expert in a relevant field was interviewed. The final interview sample comprised two physicians from KHCH ED, five KHCH ED nurses, and the expert. While the interview sample size was too small to support generalisable conclusions, it was sufficient to generate insights to guide the design of the artefact.

2.5 Target segment selection

The identification of a target segment began with an analysis of when and where crowding occurred in the KHCH ED. This assessment combined demand analyses stratified by weekday and specialty with a separate hourly census analysis (graphed with median lines and interquartile ribbons) to characterise temporal and operational patterns of crowding. For visits involving more than two specialties, the number of potentially unrecorded specialty demands was estimated. Clinical urgency was classified using triage codes. Box plots were used to summarise visit volumes across days of the week. Visits were categorised as critical if either triage or re-triage indicated urgency levels A or B in the KHCH system, and as non-critical if classified as C–E. The purpose of the demand analysis was to identify patient groups that meaningfully contributed to crowding during peak demand.

The aim of segmentation was to identify a patient group that is frequently dischargeable directly from the ED (to any location other than an inpatient ward) and could be readily recognised at presentation. Therefore, a home discharge group (HDG) was formed including all visits that ended in a discharge. While segmentation based on reasons for arrival was clinically preferable, insufficient standardisation in the recording of arrival reasons precluded its use. Consequently, acute diagnoses coded using International Classification of Diseases, Tenth Revision (ICD-10) were selected as the basis for patient grouping.

ED visits with multiple acute diagnoses were split into multiple diagnosis-level records, with all visit-level variables (e.g., timestamps and resource usage) replicated across records. Diagnoses stating the cause of illness or injury (ICD-10 codes with initial V, W, X, Y, and Z) were excluded, because they represent contextual or external factors rather than medical diagnoses relevant to ED care processes. For each diagnosis, a cumulative EDLOS (CEDLOS) was calculated for 2022 by summing EDLOS across all associated visits without aggregating by patient or visit. Diagnoses were then ranked by CEDLOS.

Medians and quartiles of EDLOS, along with the average number of co-occurring acute diagnoses, were recorded for each individual diagnosis. Co-occurring diagnoses were analysed to determine whether a diagnosis with high CEDLOS primarily drove resource use, or more often appeared as a secondary condition alongside others. This analysis was used to mitigate the risk of selecting a target segment in which long CEDLOS was primarily attributable to other co-existing diagnoses rather than to the diagnosis itself. The diagnosis with the highest CEDLOS and a measurable impact on ED crowding, based on demand and census analyses, was selected as the theoretical target segment (TTS).

Because acute diagnoses are typically confirmed after clinical assessment, the TTS may not be fully identifiable at presentation. For practical implementation, a proxy group identifiable early in the ED visit was defined as the operational target segment (OTS). The OTS was defined to maximise overlap with the TTS without relying on disposition information, allowing

real-time application of the intervention while preserving its intended system-level impact. Urgency was analysed as a potential distinguishing characteristic of the OTS.

For OTS visits, specialty demand, CEDLOS, and descriptive statistics of EDLOS (mean, median, and quartiles) were calculated. Hourly OTS presentation patterns were analysed, with visit rates scaled to presentations per 100 days to account for unequal numbers of different day types. This demand analysis supported the expectation that reducing waste within the OTS would meaningfully impact ED crowding.

2.6 Constraint recognition

The OTS was divided into four activity groups based on the presence or absence of laboratory testing and imaging. This distinction was important because activities involving laboratory testing or imaging typically require different resources, coordination, and time, allowing identification of group-specific constraints and bottlenecks. A current-state analysis of the meaningful OTS activity groups was conducted using service blueprinting with swim lane diagrams. These diagrams were created using diagrams.net, a web-based, open-source diagramming tool. For each activity, median lead times were calculated, enabling estimation of total elapsed time, including both queuing and execution. However, queue time could not be isolated from execution time. In Finnish EDs, it is not necessary to wait for a radiologist's formal report on X-rays. Therefore, the interval between image acquisition and reporting was not included in the analysis.

Because processes have multiple paths (e.g. discharge vs admission), bottlenecks may vary, and distributions are typically skewed. Therefore, medians were used to identify the bottlenecks related to common causes instead of specific events. The resulting process maps identified potential bottlenecks and non-value-adding activities. Additional quantitative analyses were conducted as indicated by these findings. However, quantitative data alone were insufficient for reliable constraint recognition.

To complement the quantitative analysis, the qualitative interview data were used to further investigate potential constraints, value-creating activities, and medical risks in the treatment of the OTS. Interviews helped confirm bottlenecks suggested by process metrics, provided insights into unmeasured delays, and generated practical intervention ideas. This triangulation of quantitative and qualitative sources strengthened confidence in the identified constraints. The interview guide is provided as a Supplementary File.

To better understand discrepancies between current practice and value-creating activities, an ideal process was delineated. Value chains were constructed by systematically removing identified waste from the swim lane service blueprints. Inputs for value chain development included interview data, service blueprints, and relevant treatment guidelines. This ideal process informed the design of the intervention.

2.7 Applying the five focusing steps: exploitation, subordination and elevation

Steps 2-4 of the TOC five focusing steps were applied to develop the components of the throughput intervention, which served as inputs for the subsequent DSR artefact formulation. No additional data analyses were conducted during these steps; instead, previously generated analyses and qualitative insights were systematically interpreted through the TOC lens.

Exploitation of the constraint focused on examining processes and decision points associated with the OTS to identify ways to accelerate patient flow without increasing resource utilisation beyond safe limits or compromising care quality. This included assessing whether information or resources required for downstream activities could be made available earlier in the patient journey.

Subordination involved aligning all other processes in the treatment pathway to the pace of the exploited constraint, ensuring that non-constraint activities did not introduce avoidable delays. Elevation then considered the use of existing ED resources, exploring potential reallocation or operational adjustments to increase the effective capacity of the constraint while maintaining safe and effective care.

2.8 Intervention artefact development

The output components generated through TOC were synthesised as design inputs for artefact formulation within the DSR framework, with the aim of improving ED throughput by reducing waste in the treatment of the OTS. These components were combined into a theoretical intervention, which was then adapted to fit the existing workflows and resource constraints of the KHCH ED in collaboration with relevant professionals.

3 Results

3.1 Patterns of ED crowding

The descriptive statistics of the demand data are presented in Table 1.

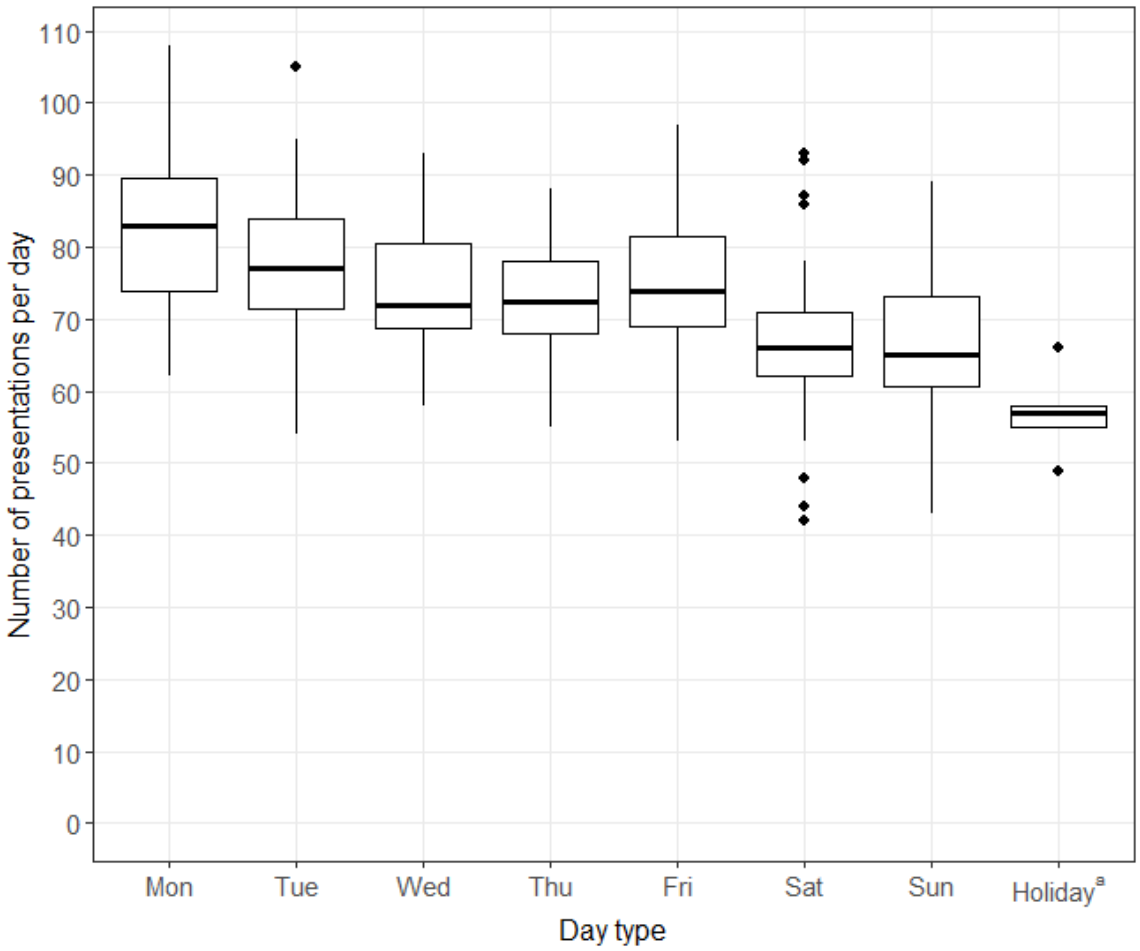
Table 1 Descriptive demand data

Demand data	n (% of visits)
Total number of visits	26,814 (100)
Demand for specialisation[a]	
Medical Care Stream	15,426 (57.5)
Internal Medicine	11,749 (43.8)
Neurology	2,916 (10.9)
Paediatrics	755 (2.8)
Dermatology	6 (0.0)
Surgical Care Stream	12,294 (45.8)
Surgery	11,578 (43.2)
Otorhinolaryngology	374 (1.4)
Gynaecology	317 (1.2)
Ophthalmology	25 (0.1)
Missing specialty observations	316
Urgency	
Critical	2,649 (9.9)
Non-critical	21,849 (81.5)
Urgency not determined	2,316 (8.6)

[a] *If multiple specialties were required, all the respective counts have been incremented. In our emergency physician–led ED, Emergency Medicine was not included in this count.*

Most demand was directed towards the MCS (n = 15,426; 57.5 %), particularly the specialties of Internal Medicine (IM) (n = 11,749; 43.8 %) and Neurology (n = 2,916; 10.9 %). Of all patients, 9.9 % were categorised as critical, while 8.6 % had no assigned urgency rating. Most non-critical patients were discharged directly home from the ED (n = 12,000; 55 % of non-

critical cases), whereas critical patients were more often admitted to an inpatient ward (n = 1,808; 68 % of critical cases). The daily demand distribution presented in Figure 2.



[a] *Holidays on business days (n = 5) which are excluded from other categories Mon–Fri*

Figure 2 Number of ED presentations in 2022 by weekday

Demand was higher on business days (median range = 72–83) than on weekends and holidays (58–73). Hourly medians and interquartile ranges for the total number of patients in the MCS and the SCS combined were plotted for these day groups (Figure 3).

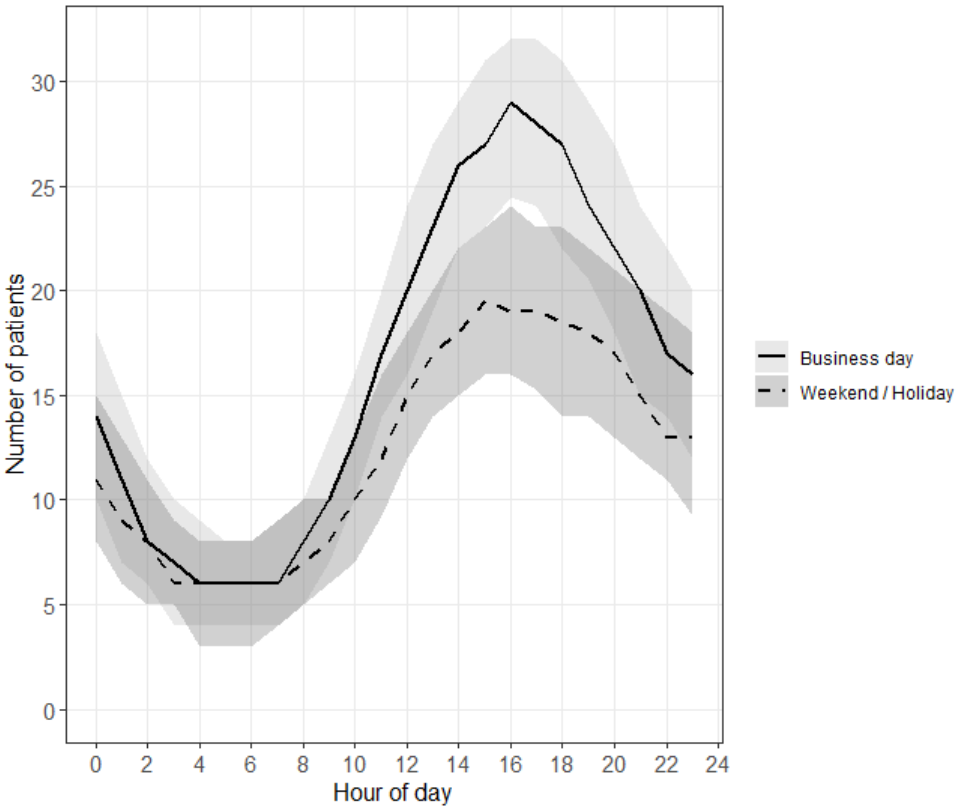


Figure 3 Number of patients in the ED by hour (median and interquartile range)

Across both day groups, the ED was most crowded between 15:00 and 17:00. Taken together, the findings from Table 1 and Figures 2 and 3 suggest that a patient segment assigned to the IM specialty, with demand concentrated in the morning or afternoon, would offer greatest potential impact on ED crowding.

3.2 Identification of the target segment

The HDG comprised 14,057 visits with a total CEDLOS of 63,188 hours. Of these visits, 841 (6.0 %) were categorised as critical. The descriptive statistics for individual acute diagnoses within the HDG, sorted by CEDLOS, are presented in Table 2.

403 **Table 2** Ten most time-consuming acute diagnoses in the home discharge group

404

Diagnosis (ICD-10 code)	Diagnosis (description)	CEDLOS[b] (h)	n	1st quartile EDLOS[a] (h)	Median EDLOS[a] (h)	3rd quartile EDLOS[a] (h)	Mean ACD[c] (n)
I48	**Atrial fibrillation / flutter**	4,428	751	3.7	5.3	7.1	1.4
U07.1	**Confirmed Covid-19**	3,455	609	2.9	4.2	6.2	1.8
R10.4	**Abdominal pain NOS[d]**	2,443	513	2.9	4.2	5.8	1.5
R07.4	**Chest pain NOS[d]**	2,183	459	3.1	4.4	5.8	1.3
R51.80	**Headache**	1,387	271	3.2	4.4	6.3	1.5
R10.1	**Upper abdominal pain**	1,292	256	3.0	4.2	6.0	1.4
R06.0	**Dyspnoea**	1,233	264	3.4	4.6	5.9	1.6
S06.0	**Concussion**	1,213	295	2.4	3.5	5.0	1.8
R10.3	**Lower abdominal pain**	1,181	271	2.8	3.8	5.3	1.5
R55	**Syncope / collapse**	1,158	192	3.2	4.8	6.7	1.6

405

406 [a] *Emergency Department Length of Stay*
407 [b] *Cumulative Emergency Length of Stay throughout 2022*
408 [c] *Acute co-occurring diagnoses*
409 [d] *Not otherwise specified*

410

411 Patients with atrial fibrillation or flutter (AF; ICD-10 code I48) had the highest CEDLOS of
412 4,428 hours, which constitutes approximately 7.0 % of the total CEDLOS in the HDG. AF is a
413 prevalent cardiac arrhythmia characterised by an irregular heart rhythm, leading to a variety
414 of symptoms such as palpitations, dyspnoea, and fatigue, and is associated with an increased

risk of stroke, systemic embolism, and all-cause mortality [25]. Many ED patients with non-critical atrial fibrillation or flutter (NAF) undergo an external electrical cardioversion (ECV) procedure, a treatment in which a direct current electrical shock is delivered to the heart under procedural sedation to restore normal rhythm in patients with AF. ECV is considered safe in the acute setting [26]. The mean number of co-occurring acute diagnoses of AF patients was 1.4, which was comparable to or lower than that of other highly time-consuming patient groups.

Following identification of I48 as the most time-consuming diagnosis within the HDG, a dataset of all AF visits (n = 1,721) was created by filtering the original data to include all observations whose acute diagnoses field included the string “I48”. This approach retained all subtypes of AF, including those not listed in Table 2. Furthermore, the subset of discharged AF patients comprised 846 visits with a total CEDLOS of 4,936 hours, corresponding to 7.8 % of the total CEDLOS in HDG. Based on these findings, discharged AF patients were selected as the TTS, as it represented a patient group with high cumulative throughput impact and discharge potential.

A keyword search of triage records showed that AF was documented as the reason for arrival by the triage nurse in 748 AF-related visits (43%), indicating that AF was frequently recognised at presentation. After excluding visits with missing urgency ratings, the disposition of AF patients was examined by urgency level (Figure 4).

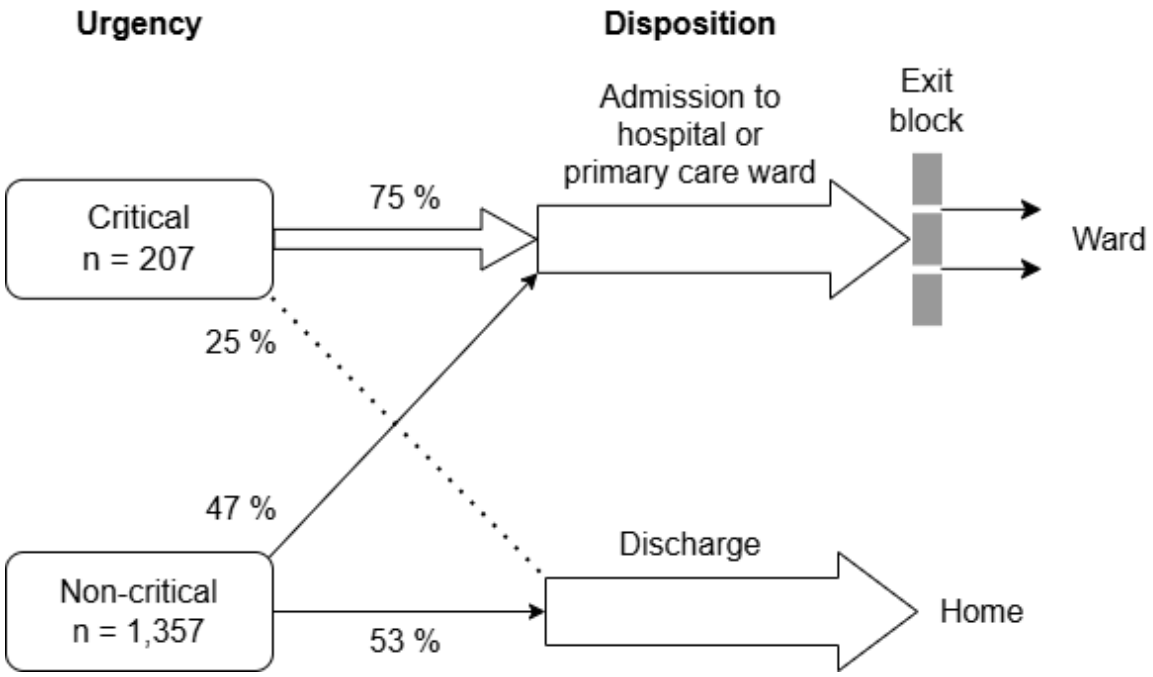


Figure 4 Disposition of AF patients by urgency (data with missing urgency excluded)

Among critical AF patients, 75% were admitted to an inpatient ward, whereas 53% of non-critical AF patients were discharged directly from the ED. Consequently, visits of patients with NAF were selected for further analysis. The NAF group comprised 1,357 visits and is described in Table 3.

Table 3 Descriptive statistics of non-critical atrial fibrillation or flutter (NAF)

Demand data	**n (% of visits)**
Total number of visits	1,357 (100)
Discharged from the Emergency Department	725 (53)
Demand for specialisation[a]	
Medical Care Stream	1,259 (92.8)
Internal Medicine	1,183 (87.2)
Neurology	76 (5.6)
Surgical Care Stream	131 (9.7)
Surgery	131 (9.7)
Emergency Department Length of Stay (EDLOS)	**hours**
Average	6.27
Median (interquartile range)	5.45 (4.02–7.38)
Cumulative EDLOS in 2022	8,511

[a] *If a patient was assigned multiple specialties on the same visit, all the respective counts were incremented. In our emergency physician–led ED, Emergency Medicine was not included in this count.*

The total CEDLOS among NAF visits was 8,511 hours; however, this number is not directly comparable with the CEDLOS of discharged AF patients, as the NAF group included patients affected by exit block. Of the NAF visits, 725 (53.4%) resulted in discharge directly from the ED.

Most NAF visits (87.2%) utilised IM resources, indicating that reductions in waste within this segment would primarily liberate capacity in the MCS. A smaller proportion of visits were assigned to Neurology or Surgery, reflecting cases in which AF was a secondary diagnosis.

Arrival patterns of NAF visits are shown in Figure 5, with hourly arrival counts normalised by the number of days in each day group.

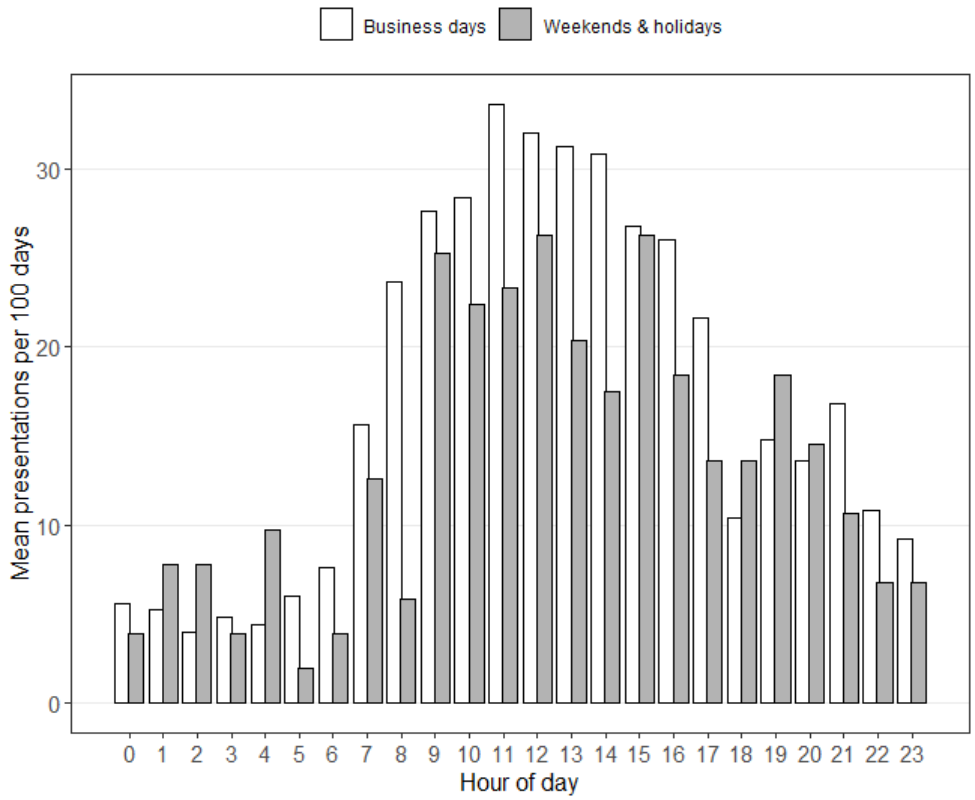


Figure 5 Arrival hours of non-critical atrial fibrillation or flutter on weekends and holidays (mean per 100 days)

On both business days and weekends or holidays, peak NAF presentation hours occurred during the late morning and afternoon, coinciding with periods of peak ED demand (Figure 3). These findings suggest that improving the throughput for NAF patients would have a meaningful impact on ED crowding, particularly within the MCS. Accordingly, NAF was chosen as the OTS.

3.3 Recognised constraints in NAF

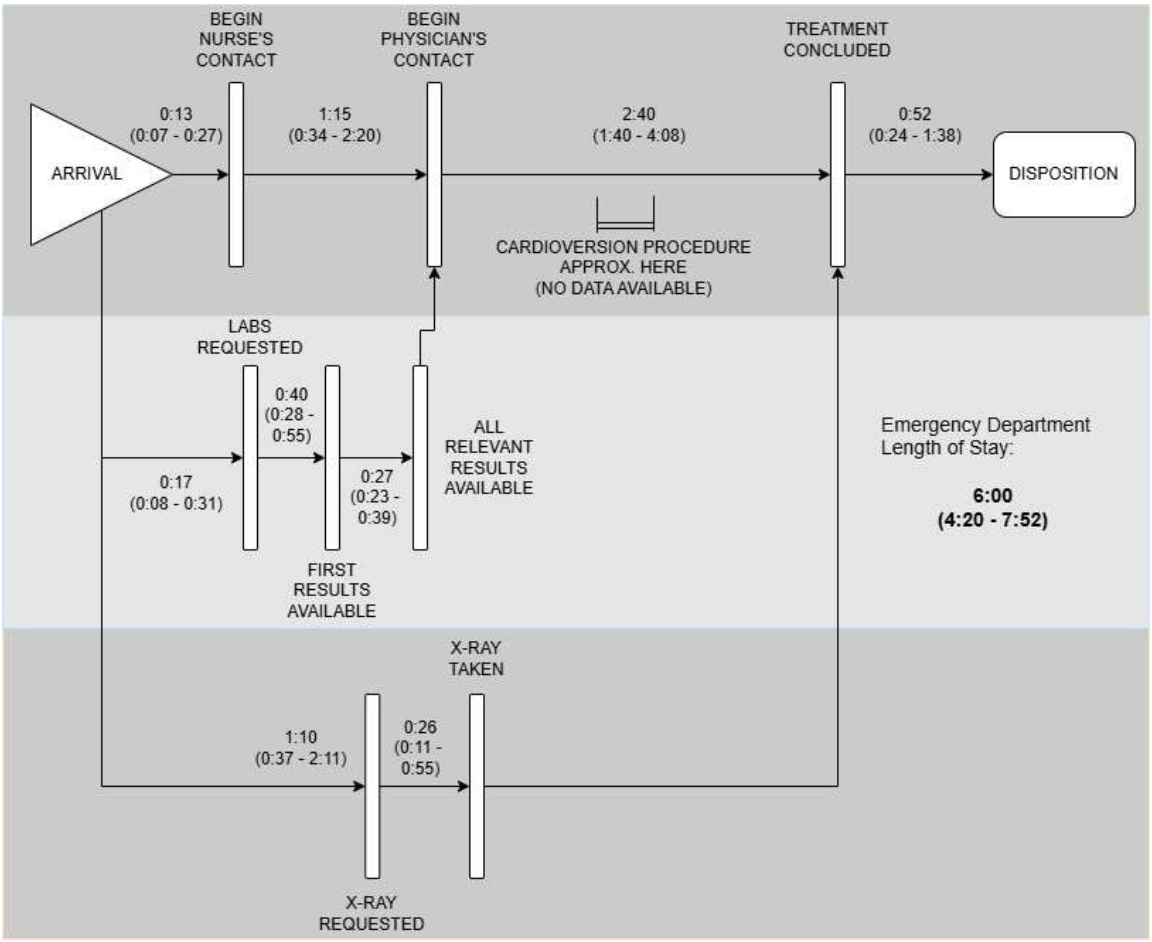
ECV is typically initiated during the physician's contact. However, no structured data were available to explicitly identify ECV procedures. After excluding visits with incomplete

timestamps, 1,061 visits remained for process analysis. These visits were divided into four activity groups based on the use of X-ray and laboratory tests. The sizes of these groups are summarised in Table 4.

Table 4 Cross tabulation of activities in the treatment of non-critical atrial fibrillation or flutter

	At least one X-ray	**No X-ray**
Laboratory tests	n = 549 (51.7 %)	n = 454 (42.8 %)
No laboratory tests	n = 8 (0.8 %)	n = 50 (4.7 %)

Most of the visits included laboratory testing (n = 1,003; 94.5 %) whereas the use of imaging was more evenly distributed. Two process maps were constructed to describe the visits that included laboratory tests, stratified by whether an X-ray was performed (Figure 6) or not (Figure 7).



485

486 **Figure 6** Process map of non-critical atrial fibrillation or flutter visits with laboratory tests and
487 an X-ray (n = 549), showing medians and interquartile ranges

488

489 The process map in Figure 6 shows that laboratory results were frequently available, and
490 imaging was often ordered, before the physician's examination.

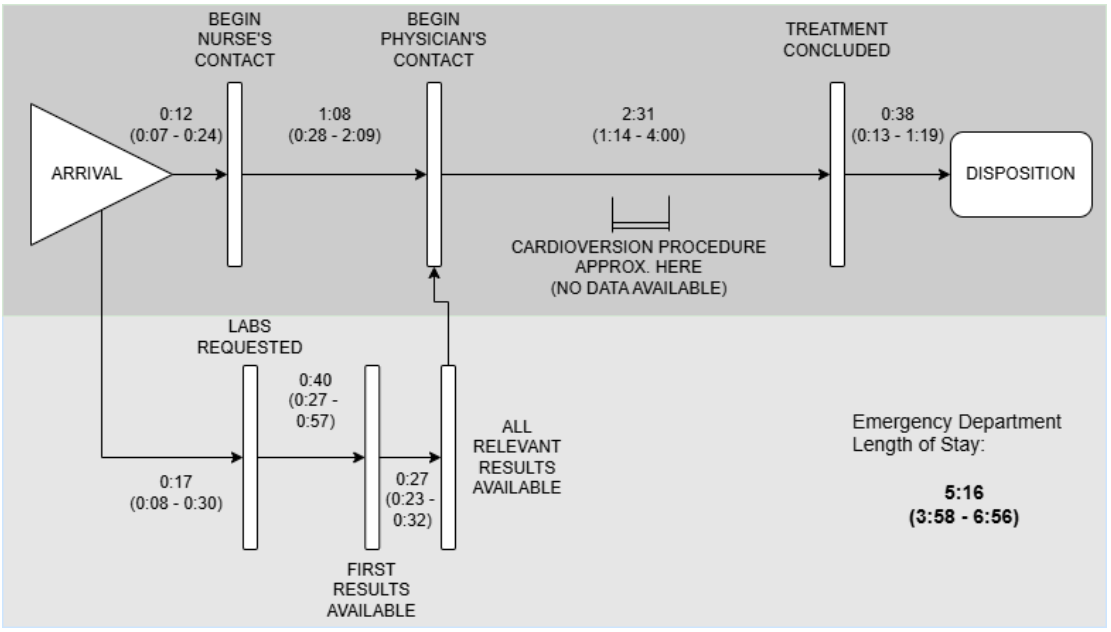


Figure 7 Process map of non-critical atrial fibrillation or flutter visits with laboratory tests but no X-ray (n = 454), showing, medians and interquartile ranges

In 459 visits (43.3 % of NAF with complete timestamps), all relevant laboratory results were available before the physician's contact began. This suggests that physicians may commonly defer examination of non-critical patients until laboratory results are available. Laboratory lead time therefore appears to function as a potential constraint. In median cases, patients who underwent imaging had an EDLOS that was 44 minutes longer than those who did not. This difference may be attributable to queues for imaging resources, patient transport to radiology, and the greater complexity of cases requiring imaging.

A further delay was observed between completion of treatment and disposition. This delay may reflect a combination of exit block for admitted patients and waiting times for transport among discharged patients. To further explore these constraints, semi-structured interviews were conducted. The summarised interview findings are presented in Table 5.

Table 5 Summary of interview findings

Interviewee	Service-defining variables	Successes	Experienced constraints	Improvement ideas
Nurse, 3–5 years of experience	- ECV[a] schedule	- ECV[a] instructions for nurses are comprehensive	- Lab lead-time - Availability of anaesthetists and nurses for ECV[a]	- ECV[a] target time announced upon presentation - POCT[b]
Nurse, 10–15 years of experience	- Fasting period - Severeness of symptoms	- A common patient segment with a lot of routine	- Lacking patient education	- Patient education
Nurse, 15–20 years of experience	- Treating physician	- A common patient segment with a lot of routine	- Lab and radiology lead-times - Availability of anaesthetists for ECV[a]	- Timely imaging orders - POCT[b]
Nurse, 15–20 years of experience	- Fasting period	- A common patient segment with a lot of routine	- POCT[b] is not well known among nurses	- POCT[b] - Patient education
Nurse, 20–25 years of experience	- Is ECV[a] required? - Fasting period	- A common patient segment with a lot of routine	- POCT[b] is not well known - A lot of waiting in the process (e.g. ECV[a])	- Patient education - POCT[b] - A designated AF[c] service model
Physician specialising in Emergency Medicine	- First or recurring AF[c]? - Fasting period	- Patients are often well educated about AF[c]	- Availability of staff for ECV[a] - POCT[b] is not well known	- POCT[b] - Critical evaluation of imaging needs
Emergency Medicine specialist	- Fasting period	- A common patient segment with a lot of routine	- Centralised lab is utilised inefficiently	- POCT[b] - Critical evaluation of imaging needs
Cardiologist	- Should cardioversion be attempted or should AF[c] be permitted?	- Relatively easy to clinically predict whether an AF[c] patient will be discharged	- Centralised lab is utilised inefficiently	- Critical evaluation of imaging needs - Patient education

[a] *External electrical cardioversion*
[b] *Point-of-care testing*
[c] *Atrial fibrillation or flutter*

The interviews indicated that NAF represents a common patient segment in the emergency department, with staff reporting well-established routines for managing these cases. A repeatedly mentioned service-defining variable was the length of the fasting period, which was widely perceived as constraining. Achieving an adequate fasting period at presentation appeared to depend on two main factors: patient awareness of fasting requirements and the severity of AF symptoms. Patients with more severe symptoms were often advised to present soon after symptom onset, irrespective of fasting status.

Patient education therefore emerged as a recurring theme. While some interviewees emphasised that patients were generally well informed, others highlighted a need for additional education. Suggested educational content included guidance on fasting and the appropriateness of waiting before ED presentation, as evidence indicates that it is safe to delay ECV for up to 48 hours from AF onset when there is no haemodynamic compromise and anticoagulation is adequate [27].

Comments regarding the treating physician as a determinant of service, along with suggestions for a designated service design, indicate a perceived need for greater standardisation in NAF management. Decisions regarding whether cardioversion should be attempted were highlighted as critical, underscoring the importance of embedding decision checks into the treatment pathway. Similarly, distinguishing between first and recurring AF was considered important, as first-episode presentations often require more extensive workup, including mandatory use of the centralised laboratory.

Additional constraints were identified in diagnostic processes and staffing. Laboratory and radiology lead times were frequently cited as bottlenecks, with inefficient use of the centralised laboratory attributed in part to unnecessary test ordering. In response, most interviewees proposed wider use of POCT and more critical evaluation of imaging indications. However, some nurses reported limited awareness of POCT, which may have hampered its adoption. Staff availability for ECV was another recurring challenge, as personnel were often mobilised only after all examination activities had been completed. The suggestion to announce an ECV target time at presentation could enable staff to anticipate and better allocate resources in advance.

ECV constitutes a central value-creating activity for symptomatic AF patients in the ED. The interviews identified three relevant service-defining variables for NAF management:

1. Whether ECV is indicated
2. Timing of the required fasting period for ECV
3. Need for imaging or laboratory testing beyond POCT

A value chain for NAF patients eligible for ECV, who had adequately fasted and required no laboratory tests beyond POCT, is presented in Figure 8.

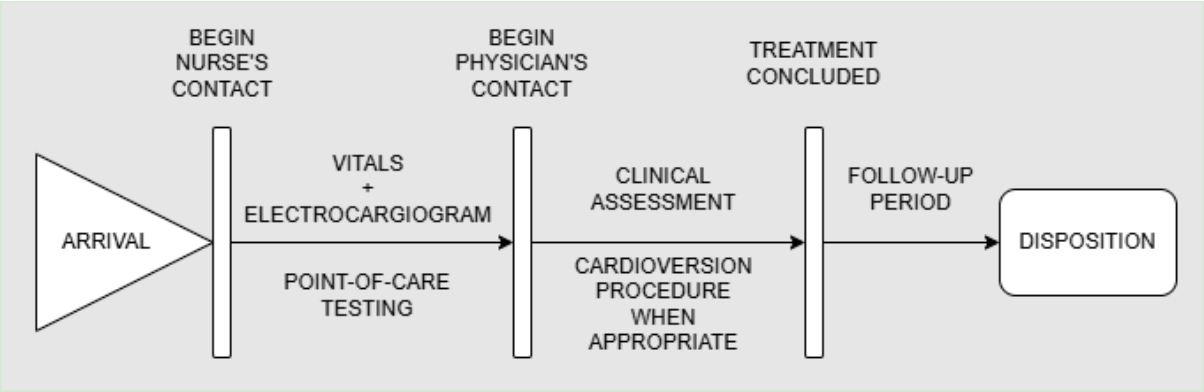


Figure 8 Value chain for non-critical atrial fibrillation or flutter patients requiring cardioversion without laboratory tests beyond point-of-care testing

The interviews revealed that the information required to determine both the need for ECV and its timing was often accessible without laboratory testing or imaging. Consequently, the primary constraint appears not to be resource availability, but rather the timing and flow of information within the process.

3.4 Derived intervention components

The constraint of information flow could be exploited by applying a pull-based production logic to the ECV procedure. In practice, this would mean that when a patient with NAF presents to the ED, the first step is to determine whether ECV is indicated. If the need exists, the first

possible ECV time, typically dictated by completion of the fasting period, is announced to all relevant stakeholders, enabling preparation for the procedure.

Altering the information flow in this way necessitates acceleration of upstream processes prior to ECV. Subordination of earlier process steps was therefore achieved through waste reduction. Interview findings suggested that laboratory-related delays could often be avoided by POCT, while critical evaluation of imaging indications could eliminate unnecessary radiology delays. For AF patients whose earliest feasible ECV timing is earlier than what can be supported using centralised laboratory resources, POCT should be prioritised.

Constraint elevation focused on adjusting work distribution within existing resources to minimise the delay between patient presentation and the ECV decision. At KHCH ED, physician-led triage is employed during peak hours. As triage determines initial resource allocation, the decision to route eligible NAF patients to a fast-track pathway could be embedded within this existing workflow, thereby increasing the effective capacity of the constraint without requiring additional resources.

3.5 Designed throughput intervention

The preceding findings informed the design of the artefact: a POCT-centred fast-track for patients with NAF. The fast-track pathway was designed to employ a pull-based information flow for ECV procedures, system subordination by POCT, and critical assessment of the necessity of imaging. In addition, patient education was incorporated at the end of the service pathway.

Patient education consisted of a pre-written, printable single-page document providing general information on AF and its management in the ED. The aim of this educational component was to facilitate value co-creation by enhancing patients' understanding of their condition and by supporting behaviours that enable better preparation for ED treatment.

Integration of the fast-track service into existing KHCH ED operations was planned collaboratively with the managing physicians of the ED and KHCH Cardiology. Patients eligible for the fast track require careful selection, as they are not expected to need centralised laboratory

services or imaging. However, decision checkpoints were embedded within the pathway to allow clinicians to reassess patient suitability for the fast track and to determine whether additional diagnostic tests are required as the process progresses. The inclusion criteria for the non-critical atrial fibrillation fast track are presented in Table 6.

Table 6 The inclusion criteria for non-critical atrial fibrillation fast-track

Medical history	- Pre-existing diagnosis of atrial fibrillation or flutter - Rhythm control treatment strategy - No need to measure blood clotting parameters or serum digoxin
Symptoms	- Patient recognises symptoms as atrial fibrillation or flutter - No alarming symptoms (e.g. chest pain) - No fever or other signs of infection - Patient is clinically stable and expected to be discharged following treatment

The fast-track service design is illustrated as a flow chart in Figure 9.

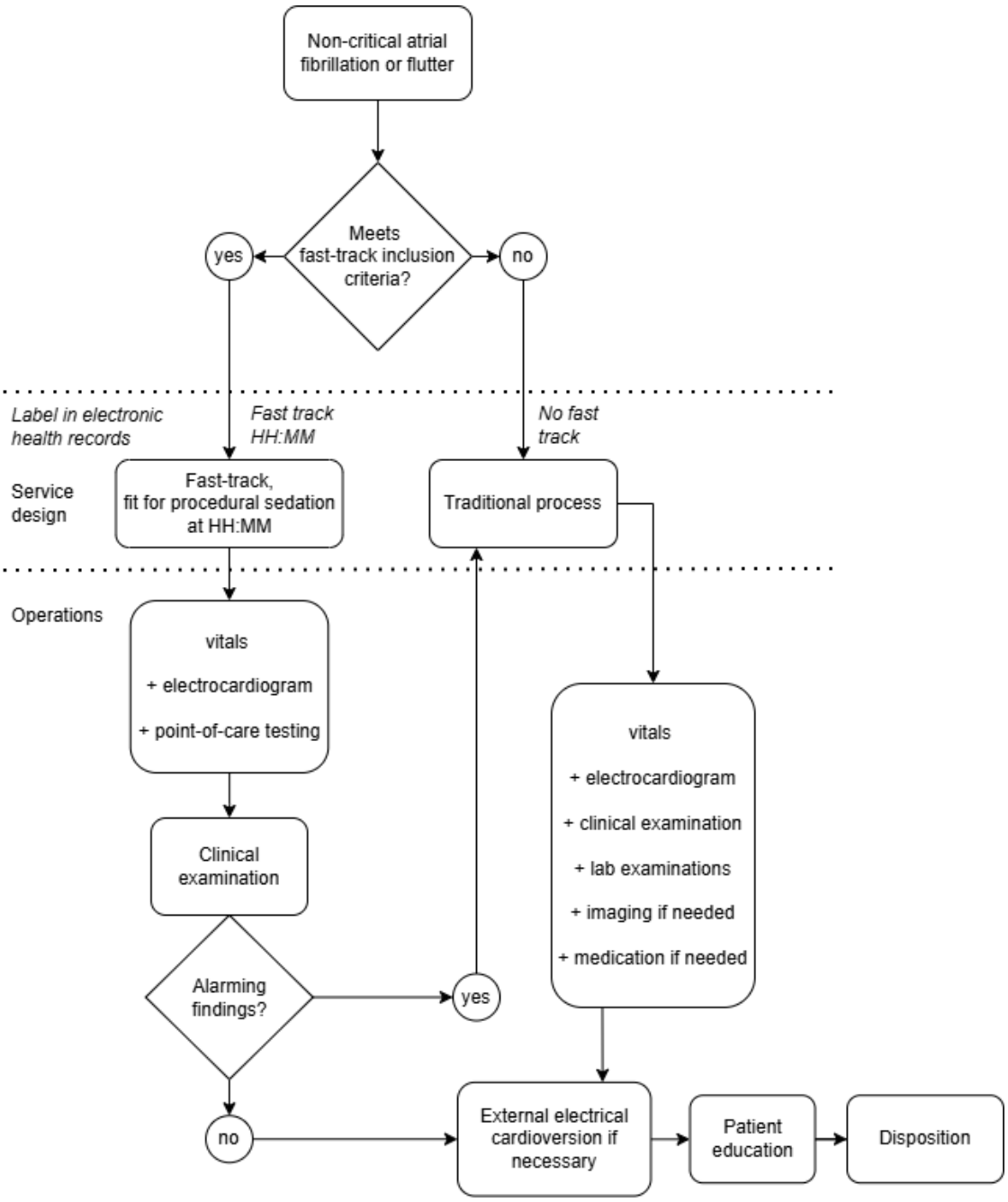


Figure 9 Non-critical atrial fibrillation fast track service design

4 Discussion

This study demonstrates a systematic methodology for translating operational analyses into implementable ED throughput interventions by integrating TOC and DSR. Applied in a Finnish secondary hospital, the methodology identified NAF as a high-impact dischargeable patient segment and guided the design of a targeted fast-track intervention.

In the studied ED, the management of NAF had previously followed an exploratory and largely ad hoc process, particularly in its reliance on external diagnostic services. More broadly, quantitative analyses alone often provide an incomplete representation of operational inefficiencies in complex healthcare systems.

In this study, quantitative analyses identified a high-impact patient segment and operational constraints, while qualitative interviews provided contextual understanding of clinical workflows and operational feasibility. TOC then prioritised the constraints with the greatest potential impact on ED throughput, and DSR translated these findings into an implementable service intervention. Together, the integrated TOC-DSR methodology enabled a systematic progression from operational analysis to intervention design. Unlike improvement approaches that pursue incremental gains across multiple processes, the TOC–DSR methodology explicitly prioritises interventions addressing the dominant operational constraint.

While TOC has previously been applied in healthcare operations, its use in emergency care remains limited [21]. By integrating TOC with DSR, this study extends the literature beyond constraint identification to the operationalisation of implementable service interventions. In doing so, it demonstrates a practical methodology for translating operational analyses into implementable service interventions while illustrating the value of integrating complementary approaches to healthcare improvement. The use of hybrid approaches has already been highlighted as a promising path of improving ED operations in its complex and ever-changing environment [28].

4.1 Operational insights informing intervention design

The selection of NAF as the target segment illustrates the value of combining quantitative and qualitative analyses within the proposed methodology. Although AF patients frequently presented with multiple acute diagnoses, prolonged EDLOS appeared to be driven primarily by process characteristics rather than clinical complexity. Laboratory lead time emerged as a key operational constraint, consistent with previous studies identifying diagnostic delays as an important contributor to prolonged EDLOS [12]. Previous research has also shown that fast-track models [14] and POCT [10] can improve ED throughput, particularly when applied selectively to patient groups most likely to benefit. Likewise, international practice demonstrates that ECV can often be performed without extensive laboratory evaluation [29].

Qualitative findings complemented these operational analyses by confirming that NAF represented a common, low-variability presentation with opportunities to simplify the care pathway. Staff consistently described many clinical decisions as being possible without routine reliance on centralised laboratory or imaging services. Together, these findings justified the proposed intervention, in which POCT and early decision-making were introduced not as generic throughput measures but as targeted responses to the identified operational constraints.

4.2 Estimated throughput impact

The proposed fast track is a type of clinical pathway, which have been shown to improve ED efficiency among other benefits [10,30]. Grouping low-variability patients into dedicated pathways has been shown to improve throughput [31], and the proposed NAF pathway follows this principle. The intervention also incorporates early physician involvement through physician-led triage, a practice previously associated with cost-neutral improvements in patient flow [1,13]. By shifting key clinical decisions to the earliest feasible stage of the ED visit, the intervention aims to reduce waiting, overprocessing, and unnecessary queuing, which are central forms of operational waste in the ED.

The projected reductions in CEDLOS illustrate how modest improvements within a carefully selected dischargeable patient segment may yield meaningful operational benefits at the system level. Under conservative assumptions, the intervention could reduce CEDLOS among discharged AF patients by approximately 2,398 hours annually, corresponding to an average reduction of 2.8 hours per visit. A more realistic estimate for non-critical AF patients discharged from the ED was 2,030 hours, representing 41% of CEDLOS within the segment and 3.2% of CEDLOS for all patients discharged home. Although these estimates are theoretical, they demonstrate the potential value of targeting interventions at patient groups with a high cumulative operational burden rather than pursuing broadly applied throughput measures.

4.3 Implementation considerations

The proposed intervention was intentionally designed to fit existing clinical workflows and resources within the studied ED rather than to introduce additional capacity. This reflects the DSR principle that successful artefacts must be operationally feasible within their intended context. Consequently, organisational factors such as staffing models, physician triage, diagnostic infrastructure, and local care pathways are likely to influence implementation and should be considered when adapting the intervention to other settings.

More broadly, the intervention itself should not be viewed as universally transferable. Instead, the principal contribution of this study is the TOC–DSR methodology used to derive it. While the resulting fast-track pathway is context-specific, the methodology provides a systematic process for identifying high-impact patient segments, recognising operational constraints, and translating these into implementable service interventions. This distinction between a transferable methodology and a context-dependent intervention may facilitate wider adoption across diverse ED settings.

4.4 Limitations and future research

Several limitations should be acknowledged. First, CEDLOS based on acute diagnoses does not fully account for comorbidities or clinical overlap between patient groups. As a result, some segments with similar care needs but different diagnostic codes may have been overlooked. More granular and standardised recording of reasons for arrival would enable more clinically intuitive segmentation. Second, variability in timestamp recording introduces measurement uncertainty. Although timestamps were routinely recorded, differences in documentation practices may have affected the precision of individual process measurements.

Third, acute diagnoses were identified by extracting all diagnoses recorded within 48 hours of ED discharge. This approach may have captured redundant diagnoses or diagnoses associated with return visits. However, among AF patients, repeat visits within 48 hours were rare, suggesting limited impact on the primary findings. Finally, the proposed intervention represents a design artefact that has not yet undergone implementation or evaluation. Accordingly, the estimated throughput improvements remain theoretical and should be interpreted as hypotheses to be tested in practice.

Future research should focus on implementing and evaluating the proposed TOC–DSR methodology across different patient segments and emergency care settings to establish its effectiveness, transferability, and broader applicability. The NAF fast-track intervention developed in this study represents an artefact derived using the methodology and should be evaluated with respect to both process and treatment outcomes. More broadly, this study provides a systematic methodology for translating identified constraints into implementable service interventions, enabling healthcare organisations to identify where throughput interventions are likely to have the greatest impact while minimising unintended downstream consequences.

5 Conclusion

This study presents a systematic methodology for translating identified operational constraints into implementable emergency department (ED) throughput interventions by integrating Theory of Constraints (TOC) and Design Science Research (DSR). Applied in a Finnish secondary hospital, the methodology identified non-critical atrial fibrillation as a high-impact dischargeable patient segment, recognised laboratory delays and information flow as key operational constraints and guided the design of a targeted fast-track intervention. While the resulting artefact is tailored to the study hospital, the proposed TOC–DSR methodology offers a transferable framework for translating identified constraints into implementable service interventions that can be adapted and evaluated in other ED settings.

6 List of abbreviations

AF	Atrial fibrillation or flutter
CEDLOS	Cumulative emergency department length of stay
DSR	Design Science Research
ECV	External electrical cardioversion
ED	Emergency department
EDLOS	Emergency department length of stay
HDG	Home discharge group
ICD-10	International Classification of Diseases, Tenth Revision
KHCH	Kanta-Häme Central Hospital
MCS	Medical care stream
NAF	Non-critical atrial fibrillation or flutter
OTS	Operational target segment
POCT	Point-of-care testing
SCS	Surgical care stream
TOC	Theory of Constraints
TTS	Theoretical target segment

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