Specialization: Transport Engineering and Logistics

Report number: 2016.TEL.8058

Title: Hospital planning process redesign from a customer-centric perspective

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Assignment: Research

Confidential: no

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Date: 26-08-2016

Title (in Dutch) Herontwerp van een ziekenhuis planning proces, vanuit een klant-gericht perspectief.

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Hospital planning process redesign from a customer-centric perspective

by

M. Spekreijse

to obtain the degree of Master of Science at the Delft University of Technology,
Preface

This report is the result of a combination of a literature review, empirical research and data analysis on hospital planning and scheduling. The focus lies on how to improve the current processes, while also increasing the customer satisfaction. For this research I would like to thank Enrike van der Linden for her support and connections within the LUMC Hospital, Jan Schoones for setting up my literature review and Sander van Buren for sharing patient data. Also I would like to thank Jan Bink, Maarten Veldstra, Egbert Krug, Suzanne van der Kraan from the LUMC for their time to let me interview them, the same goes for Lizette Berkx and Jeanne Bezstarosti from the Erasmuc Medical University Centre of Rotterdam. Finally I would like to thank my teacher and mentor Wouter Beelaerts van Blokland for the supervision, the interesting insights and help on the subject.

M. Spekreijse
Delft, June 2016
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## Abbreviations

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<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
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<tr>
<td>ACT</td>
<td>Anaesthesia controlled time</td>
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<tr>
<td>CFT</td>
<td>Cross-functional teams</td>
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<tr>
<td>DC</td>
<td>Daycare ward</td>
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<tr>
<td>DMAIC</td>
<td>Define, Measure, Analyse, Improve and Control (Six Sigma)</td>
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<tr>
<td>FTE</td>
<td>Full Time Equivalent</td>
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<tr>
<td>KPI</td>
<td>Key performance indicator</td>
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<td>LoS</td>
<td>Length of Stay</td>
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<td>LP</td>
<td>Linear programming</td>
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<tr>
<td>LS</td>
<td>Long stay ward</td>
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<tr>
<td>LUMC</td>
<td>Leids Universitair Medisch Centrum</td>
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<tr>
<td>MSS</td>
<td>Master Surgical Schedule</td>
</tr>
<tr>
<td>OR</td>
<td>Operating Room</td>
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<td>ORDS</td>
<td>Operating Room Day Schedules</td>
</tr>
<tr>
<td>OT</td>
<td>Overtime</td>
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<tr>
<td>PT</td>
<td>Performance team</td>
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<tr>
<td>SCT</td>
<td>Surgery controlled time</td>
</tr>
<tr>
<td>SLD</td>
<td>Swimlane Diagram</td>
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<td>SS</td>
<td>Short stay ward</td>
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</table>
As this research is conducted from a technical perspective, a lot of medical terms are considered unfamiliar for researchers and readers who possibly have no former experience in medicine. Therefore the definitions for medical terms which are used in this report will be explained in this section in tabular form, table 1, the explained terms are deemed necessary and fundamental for understanding this research. Every first time a term is used in this report, and found in table 1, it is made **bold**.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>Ambulatory care</td>
<td>Health care services provided to patients on an ambulatory basis, rather than by admission to a hospital or other health care facility. The services may be a part of a hospital, augmenting its inpatient services, or may be provided at a free-standing facility.</td>
</tr>
<tr>
<td>Elective patient</td>
<td>Patients for whom the hospital visit can be planned in advance</td>
</tr>
<tr>
<td>Hospitalization</td>
<td>The confinement of a patient in a hospital.</td>
</tr>
<tr>
<td>Inpatient</td>
<td>Persons admitted to health facilities which provide board and room, for the purpose of observation, care, diagnosis or treatment.</td>
</tr>
<tr>
<td>Master Surgical</td>
<td>Fabricated time table for a specific cyclic period which defines the allocation of OR hours per sub-specialism</td>
</tr>
<tr>
<td>Schedule</td>
<td>Patient sequencing per subspecialism to fill in the granted OR time</td>
</tr>
<tr>
<td>Operational planning</td>
<td></td>
</tr>
<tr>
<td>Outpatient</td>
<td>Persons who receive ambulatory care at an outpatient department or clinic without room and board being provided.</td>
</tr>
<tr>
<td>Patient case mix</td>
<td>Type, composition or mix of patients treated by the hospital</td>
</tr>
<tr>
<td>Planning</td>
<td>The process of reconciling supply and demand</td>
</tr>
<tr>
<td>Scheduling</td>
<td>Sequence and time allocation to procedures</td>
</tr>
<tr>
<td>Strategic planning</td>
<td>Long term planning which defines the patient case mix for the coming period.</td>
</tr>
<tr>
<td>Tactical planning</td>
<td>Medium term planning which divides OR time between subspecialisms</td>
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Introduction

This report is the result of research done on the process performance of hospital planning and scheduling. The information needed for this research was gathered via literature, interviews held with professionals, theories learned via the MSc. curriculum of Transportation, Engineering and Logistics at the Delft University of Technology, observations made within the "Leids Universitair Medisch Centrum"\(^1\) (LUMC) and the analysis thereof. The foundation of this research will be established in this chapter, the research's background and methodology will be discussed in the following sections.

1.1. Background

Hospitals and university medical centres are the largest healthcare institutions with an organized medical staff serving multiple core activities like patient care, research and education\(^2\). Patients can either be categorized as \text{inpatients}, patients which are being \text{hospitalized} and therefore requiring care for multiple days, and \text{outpatients}, requiring care for less than 24 hours and thus receiving \text{ambulatory care}. Hospital data found at CBS [8] show a shift in hospitalization to ambulatory care, this is illustrated in figure 1.2. These trends will continue, putting more pressure in volumes on the outpatient department of hospitals. This increased pressure results in the need for a critical review on the hospital planning and scheduling processes, as the effect on the resources in the wards should be considered.

1.2. Scope

During this research theories, literature and analyses will be applied to the planning and scheduling practices of hospitals, the LUMC will be used as a benchmark hospital to learn how the current practice works. The focus will lie on the planning process design of planning and scheduling patients, personnel and resources. Also the influence of planning and scheduling on the outpatient department of the LUMC will be considered. This specific department was chosen due to time limitations of the research, the outpatient department is relatively easy to isolate and it can be assumed that all patients administered here are \text{elective patients}. Still these patients interact with other departments and therefore the system

\(^1\)University Medical Centre in Leiden, The Netherlands
\(^2\)Unless specified otherwise, definitions are retrieved from the PubMed MeSH database [15]
boundary equals the physical boundary of the hospital. External instances like the general practitioner and the physiotherapist will be left out the scope.

1.3. Research methodology
The philosophies of Lean Production and Six Sigma will be used as a tool and roadmap to defining the target areas [9]. Lean has a focus on identifying and reducing unnecessary wastes, which are increasing costs without adding value, and increasing customer satisfaction. Six Sigma envisions to reduce variation to the minimum, increasing the quality of your processes. Chapter 2 will go further into detail on these tools, but during this research it will be tried to highlight:

- Wastes according to the Lean principles
- Variation in product, process or performance
- Factors relating to customer satisfaction
Keeping these philosophies in mind, the research should answer the following research question:

How can a hospital planning and scheduling process be further enhanced, by keeping in mind the complex multi-actor organization and increasing patient service level?

This research question is driven by the following sub-questions, these sub-questions are answered in the following chapters:

1. What is the established opinion on hospital planning and scheduling improvements, according to literature?
2. What are the current processes in the benchmark hospital and what are the relevant information flows?
3. What is the production of the isolated department, what are the quantifiable problem area's?
4. How can the found solutions complement the found problem area's, resulting in a improved process design?

1.4. Organization of Research

The research is structured in four steps, the first stage consists of a literature study. This survey will highlight trends in planning and scheduling as well as other relevant topics, which is found in Chapter 2. The processes on planning and scheduling, found through empirical research, will be visualized in chapter 3. Chapter 4 holds an analysis of the outpatient clinic patient flows to highlight the problem areas, which should correlate with found literature. These insights on the core patient flows are retrieved from the LUMC's patient data of 2015. These findings from both a literature study, empirical research and data analysis should give insights on a future process design, which will be the deliverable in the 5th and final chapter.
Literature review

A literature survey has been conducted to create a better understanding on the processes around hospital planning and scheduling. First the topic of Lean Six Sigma will introduce and discuss tools which can be used to improve the planning processes. Thereafter a discussion is held on the different subjects within Operating room planning and scheduling, such as the planning decision levels, sources of variation, estimation of surgery duration and proposed frameworks. Thirdly, Hospital bed management considers practices which increase the efficiency of the hospital bed utilization.

2.1. Lean Six sigma

Lean Six Sigma is a methodology where the two improvement philosophies Lean and Six Sigma are combined as one quality- and efficiency improvement programme. The contributions of the two methodologies are as follows: Lean has the standardized principles, practices, tools and techniques; Six Sigma gives structure to the whole project with it’s quantitative analyses. The following sections introduce both philosophies and discuss their value towards hospital planning processes.

2.1.1. Six Sigma

Six sigma is a quality improvement programme which aims to both minimize process variation and -defects. The ‘sigma rating’ of the systems indicates the maturity regarding Six Sigma, a higher rating resembles less defects per million opportunities. The iterative approach is shown in figure 2.1.

Six Sigma is split in five steps: Define, Measure, Analyse, Improve and Control (DMAIC). During each iteration problem areas are highlighted by quantifying the process variation, bottlenecks and wastes; action should be taken to permanently improve the system. The DMAIC approach is suggested to be used as a tool for hospitals to track and improve the status of the future (or current) process [5].

2.1.2. Lean

Lean is a customer driven philosophy of principles, practices, tools and techniques; it has three focus areas: the elimination of waste, identification of bottlenecks and managing variation. Lean has a large set of customer-centric standards and solutions for common pro-
cess problems. The tools relevant to this research will be discussed in this section.

Muda

Lean identifies eight types of waste (Muda), these wastes are: Transport, Inventory, Motion, Waiting, Overproduction, Over processing, Defects and Skills.

- **Transport**: Diminish the amount of distance travelled for patients, personnel and resources during the complete patient journey, transport creates chaos and variation.

- **Inventory**: Too much inventory means that there is unused expensive product. While stock should be reduced with the Just in Time principle, inventory can be seen as a 'necessary evil' as stock-outs are unacceptable in healthcare.

- **Motion**: To prevent unnecessary checks and rework, planning personnel should have real-time access to all the patient-, surgeon and OR information and unnecessary steps in the planning process should be removed.

- **Waiting**: Waiting occurs either by natural- (overtime due to complexity during surgery) and fabricated variation (overtime due to underestimated surgery duration). The latter is preventable by transparency, real-time access to patient data and computer supported decision making.

- **Overproduction**: Rework of planning due to cancelled or delayed surgery.

- **Over processing**: Patient or process data is that decided on by multiple departments, but lacks a transparent platform to share this. The same data is processed multiple times throughout the process.

- **Defects**: Defects in the planning process are related to overproduction, as a defect leads automatically to rework.

- **Skills**: It is important to keep the personnel up-to-date with the state-of-the-art technology and innovations in the hospital.
Mura and Muri
Process unevenness is described with Mura: this creates inventory, waiting times and other types of waste. Solutions are found in balancing the horizontal processes in supply and demand. With the detection of bottlenecks overburden (Muri) is made visible. An effective methodology is the Theory of Constraints, it sees systems as a chain of multiple activities and one of the links constraints the whole process. To increase the output of the system, and reduce the unevenness, these bottlenecks should be identified and improved to release the constraint. The easiest way to identify these constraints, is to look for accumulation of inventory or highlight the processes with the longest throughput time. If the constraint is lifted the whole process starts again, Lean promotes continuous improvement.

Examples of found bottlenecks:

- Waiting room before first consult in clinic
- Waiting in clinic between different steps
- Waiting list for surgery
- Discharge rounds of wards

A future planning model should level both in- and outgoing patient flows.

Error proofing
The Jidoka and Poka-Yoke principles both involve stopping the process for the sake of error proofing. Whilst stopping the process may seem unproductive, this has resulted in better process performance on the long run[13]. The most important change is that every staff member involved in the process should has the power to stop if defects are observed, without any blame.

One working implementation is the one shown in figure 2.2, each patient receives during admissions a patient care plan. The care plan has multiple toll gates and at each gate the progress of care should be critically reviewed for errors. Decision authority lies at the staff member with the most expertise in that situation, rank or status is irrelevant. This methodology is proofed to work in Grout and Toussaint [13] and resulted in a rise in customer satisfaction, reduction in costs, defects and LoS.
2.2. Hospital planning and scheduling

The Operation Room (OR) is defined in literature as the core function of the hospital, it must be run efficiently because it is the largest cost and revenue centre[24]. One of the hospital’s main goals is to increase patient volumes, this can be achieved by increasing the OR capacity, allowing more flexibility in the surgeons schedules or improving current patient planning and scheduling practices [17]. To prevent any misinterpretations during this research **planning** refers to the process of reconciling supply and demand, where **scheduling** defines the exact sequence and time allocation to procedures.

2.2.1. Decision levels

No hospital is the same in size, composition and strategy, still three decision levels can be recognized: the Strategic, Tactical and Operational level[7][17][27]. The strategic level concerns on long term planning of the **patient case mix**, tactical planning focusses on the **Master Surgical Schedule** (MSS) and the operational level represents the short term planning and sequencing of patients.

![Decision levels in OR planning and scheduling](image)

With **Strategic Planning**, hospitals have to decide how to distribute the valuable OR hours between the different sub-specialisms. These choices are made depending on strategic objectives, to pursue a specific philosophy[2], economic- or financial motivators. During this research it was concluded that strategic planning is a very sensitive and delicate matter for hospitals, the governing mechanisms will not be challenged as these also consider politics.

During **Tactical planning** the MSS is created, this is a 1, 2 or 4 week cyclic schedule in which sub-specialisms have dedicated time blocks in the OR[27], this is called **block scheduling**. Also an **open-scheduling** strategy could be used [17], which allows disciplines and surgeons to be scheduled in infrequent patterns. While this increases the flexibility of the schedule, this is a more practical approach for specialised clinics as surgeons there are fully dedicated to surgery.

In the final phase, **Operational planning**, decisions are made on the sequence of patients in the upcoming cyclic period. The tools used for the decisions to be made, according to literature [1][2][7][17][20][27], vary from simple (most urgent case first, longest case first) to advanced (mathematical models). Surgeons use their expertise to determine the length of the procedure, but this is prone to bias [21]. Also it is challenged that only through mathematical models the most optimal solution can be found, this objective function will be set up according to the hospital needs (minimize bed demand peaks, minimize nurse workload, smooth outgoing flow of patients, level resource occupancy).
2.2.2. Stakeholder analysis

Figure 2.4 shows a stakeholder analysis, with the relevance of the different hospital actors to the power and interest on patient scheduling. Before mentioned hierarchical decision levels hold multiple actors, which all contribute to the process, their needs and roles are explained in this section.

![Stakeholder Analysis Diagram]

**Hospital board**
*The hospital board* has the goal of maximizing the amount of successful procedures, treated patients, revenue and minimizing hospital costs. Their focus is completely strategic.

**Surgeons**
*Surgeons* have both the tactical and operational focus on the problem and their prime interest is to help as many patients as possible, overtime (OT) is therefore only paid for a limited amount of time by the hospital to discourage surgeons. They do not easily accept changes in their schedules, as they have other responsibilities like giving consult, education and conducting scientific research.

**Ward management**
*The ward management* also cares about the surgeons objectives, but they also prefer an effective and transparent way of planning and scheduling, to prevent OT and excessive workloads for the nurses and resources as they fear this will diminish the quality of care.

**Patients**
*The patient* has little influence on the schedule and their preference lies in being helped as soon as possible, in the least amount of time at the moment of their preference.
2. Literature review

All the remaining hospital personnel who have (in)direct responsibilities to the patients, like the planners, admissions office and the OR centre, have troubles with transparency; communication up- or downstream in the healthcare supply chain is sometimes incomplete and non-standardized and therefore decisions of these actors are not always optimal.

2.2.3. Sources of variation

Variation disturbs the hospital planning process, because in a system it is amplified along the care pathway [3]. Distinction should be made between natural- (hard to avoid) and fabricated variation (non-random and thus preventable). This subsection will explain sources of variation in in the healthcare planning process, to create an understanding of the difficulties in healthcare systems.

Patients
The patient arrival patterns show natural variation, this is dependent on whether the patient is late or cancels on the day itself, patients may get lost in the hospital or are delayed at the previous department. Also abnormal medical conditions like complications or infections may cause uncertainty in the schedules, when these arise the probably causes should be found to increase the quality of care. The patient length of stay (LoS) is linked with the former as there is no standard recovery time (apart from a set minimum after surgery). Surgery is also sometimes cancelled due to patients who do not follow the strict diet- and medicinal guidelines.

Surgeons
Like patients, surgeons and surgery staffing also show variation in their arrival patterns1. The estimated surgery duration by surgeons shows bias if there is no feedback system. In Gomes et al. [12] it is stated that surgeons tend to estimate on round numbers (figure2.5) and underestimate these durations: some surgeons have the incentive to squeeze more patients in the timeslot, others do not take steps like anaesthesia into account.

Surgery
The uncertainty in surgery planning is whether the predicted duration holds, which either results in either OT, which can be natural (emergency patient) or fabricated (wrongly estimated), or slack OR time. Also the surgery changeover is prone to variation in the set-up, cleaning and change of shift in the OR. There are also uncertainties which can be dedicated to human error and mechanical failure. First an inaccurate reservation of resources disrupts the whole process. Secondly, an inaccurate or inaccessible patient file can even lead to dangerous situations; this happens when forms are filled in manually during multiple steps by multiple persons.

2.2.4. Surgery duration

The complete surgery procedure in the OR can be divided in two phases: the Surgery Controlled Time (SCT) and the Anaesthesia Controlled Time (ACT). The SCT is the duration of all the actions the surgeon and staff takes on operating the patient and the ACT presents the time needed for patient induction and emergence.

1Hospitals normally have backup staffing for extreme cases.
The estimation of the SCT is one which can be forecast accurately. The studies of Eijkemans [10], Gomes et al. [12] and Vargas et al. [24] focus on increasing the accuracy, which automatically improves the quality of the OR schedule. Data-mining is promoted as a underlying algorithm to increase the effectiveness of the present data. Studies do show that the surgeon’s estimate is a very important factor, but inaccurate estimations are made when they do not distinguish patient characteristics like age, sex or BMI. Also it was stated that they tend to underestimate the surgery, trying to squeeze extra patients in the timeslot.

A supporting tool could be beneficial for the surgeon, which presents their personal (and colleagues) historical data on their procedures. It should take the following factors into account:

- Type of procedure
- Amount of steps in procedure
- Surgery team composition and experience level
- Patient age, sex, BMI and amount of previous admissions

In van Veen-Berkx et al. [23] it is stated that the ACT holds for 20-30% of the total surgery duration. Whilst some hospitals use scorecards to determine the ACT duration or try to use historical data analysis, they argue that the multiplication of the SCT by 1.33 is sufficient, and reduces complexity, for a accurate estimation.

### 2.2.5. Proposed planning- and scheduling frameworks

Multiple solutions to the problems in hospital planning and scheduling can be found in literature. In this section three different proposals will be highlighted.

- In Van Houdenhoven et al. [20] it is found out that a longer cyclic period reduces peaks in demand if operational planning is supported by Linear Programming (LP). Also, according to systems theory, when subsystems are optimized the total system
is only sub-optimally used. The MSS should be implemented as a flexible, inter-department communication tool between dedicated planners and clinicians, surgeons and other services should only be consulted to confirm the made choices.

The prime interest was to fill the OR as efficiently as possible: sets of OR day schedules are created after the MSS has been launched, these schedules were not assigned to a date. By using LP patients were rescheduled until the unused OR time was minimized, this resulted in the ideal set of Operating Day Schedules. Thereafter a second LP calculated assigned these day schedules to specific days in the MSS until the second objective, levelled bed occupancy, was satisfied (figure 2.6).

- The findings of Adan et al. [2] promotes the use of Multiple Integer Linear Programming (MILP) for a combination of Tactical and Operational planning, to find and plan the ideal mix of patients for the upcoming cyclic period. The governing system should consider both bed- and OR capacity, as currently admission scheduling systems only consider the first and surgery planning systems the latter; this results in sub-optimal use of resources. The tool is not destined to be the best mathematical solution that can be found, but should act as a flexible and fast supporting tool.

- The Radboud University Medical Centre's OR performance has been significantly improved by implementing cross-functional teams (CFT) [22]. These teams consist of representatives from all departments who work directly with the OR: an anaesthesiologist, a scheduler, an OR/recovery/ward nurse and a surgeon. The CFT reviews every week the proposed OR schedule and the performance of the past week; they have

Figure 2.6: Simple representation of optimising the ORDS by iteration [20]
2.3. Hospital bed management

received operational decision power to alter the upcoming schedule (they consult the surgeon responsible). This approach has increased awareness over all departments, reduced OT and cancelled surgeries.

- The work of Samudra et al. [17] does not present a new framework, but an interesting note on rescheduling is made. It is stated that surgeries tend to take longer than planned due to natural variation; OT is restricted by the Hospital to prevent excessive costs. The system stays stable only when only the today part of the schedule can be rescheduled, this is backed by [7].

2.2.6. Planning and scheduling KPI’s

The status of a planning and scheduling system can be easily tracked via KPI’s, these are summed in the following list:

- Waiting time (patient / surgeon)
- OR throughput / utilization
- Ward throughput / utilization
- Defects (rework, cancellation)
- Overtime (hours)

2.3. Hospital bed management

There are considerable defects in the OR planning, hospital asset management and -design when there is a lack of bed availability [3]. According to Bekker and Koeleman [4] and Berg and Denton [6], the hospital wards can be seen as an Erlang B queue with patients as customers and beds as servers; arrivals occur when a patient is admitted and depart when they are discharged. The system constipates when arrival- and discharge patterns are not synchronized and/or have a random element [26]. To improve the flow of patients either an increase of discharge rate or -capacity or a reduction of the process variation at each step in the process is needed.

Figure 2.7 visualises the different arrival- and discharge flows during admission. The arrival rate into the OR is dependent on the OR schedule, is therefore controlled and is only vulnerable to natural variation. The ward arrival rate is dependent on the accuracy of the estimated surgery duration, complications during surgery or if an emergency patient
went before the elective patient. The discharge rate can be easily controlled, but it is now dependent on the availability of the surgeon responsible; as currently he is the one with the authorization to discharge.

In Scott [18] it is stated that hospital beds are used more efficiently if OR hours are extended, but at the same time it is argued that the required changes in professional culture and funding is too complex to implement on a short term basis. It is also proposed to outsource elective patients to the private sector when patient volumes become too large to handle, allowing the private sector to act as a temporary buffer and prevent high investment costs.

2.3.1. Accelerating discharges

The bed occupancy of the ward can be levelled by accelerating the discharge rate. It is subjected to the availability of authorized personnel, the discharge frequency and the patient recovery time. In Scott [18] and El-Eid et al. [11] three solutions to accelerate the discharge rate are proposed:

- By increasing the level of transparency on the digital patient file, allowing access to nurses or other doctors who are available. could check if the patient could be discharged early.

- Spread the authorization for discharging patients, by introducing the nurse-led discharge. This would increase the discharge frequency and allow specialists to fulfil their other responsibilities. Nurses should be trained into recognizing when the specialists consult is needed and when not.

- Moving after-care activities to a post-discharge time line, allowing patients who have had less critical treatment to recover at home whilst being surveyed via e.g. the internet.

2.3.2. Reduction of variation

According to Bekker and Koeleman [4] the reduction in the variation of LoS is only beneficial for the system variation if the arrival process has been stabilized. This could be solved by creating standardized focus areas for the largest specialist procedures. Small focus pools should however be prevented, because these tend to have a high variability. As optimized subsystems only brings a suboptimal solution, it should be investigated to see if clinical, technical or physical boundaries can be broken to merge certain positions within the hospital.

An example of process standardization and redesign can be found in Walley [26], where a hospital has created a separate stream in the hospital for outpatients having minor injuries. First, patients had to wait before they were admitted and also between every step in the process: Triage, Assessment, Treatment and Discharge. Personnel was trained in performing all of these steps, creating multi-skilled personnel which could process patients via this fast track up to 70% faster.
2.3.3. Bed management KPI's
When the bed demand problem is quantified, one should consider several Key Performance Indicators (KPI) to track the status of the system. In the case of bed management, two KPI's could be taken into account. The first is the bed throughput, which should be maximized via minimizing the bed cycle, the time between two patients. The bed cycle can be optimized via eliminating, combining or improving single steps in the cycle process like changing sheets, patient transport or discharge. Secondly the bed waiting time and LoS should be minimized via controllable arrival rates and scheduling.

2.4. Conclusion and Discussion
In this chapter a literature survey was done to create the foundation for this research. Subjects for this study were ‘Lean Six Sigma’, ‘Hospital Planning and Scheduling’, ‘Estimation of Surgery Duration’, ‘Bed Management’ and an actor analysis was carried out. The philosophy of Lean Six Sigma will be a solid foundation for the redesigned hospital planning and scheduling process. The DMAIC approach could be used as a tool for future improvements and tracking performance. Also the Lean tools to identify wastes within the processes will be used in the following chapter.

The focus for the future planning and scheduling process will be on operational planning and partly on tactical planning. The higher decision levels consider complex mechanisms like hospital politics and these will remain outside of the research’s scope. The patient case mix, the division of OR time between specialisms, will be respected. The multi-actor analysis gave insight on how a future process should work out for everyone, it also shows that decision levels are sometimes spread out. By taking a customer-centric approach to the future process design, there is want for transparency: the patient should be able to have a solid communication line with the hospital.

Furthermore, the different sources of process variation were listed. As there are multiple ways for the patient to cause deviation in the schedule, communication should be clear and efficient to prevent any misunderstandings during the procedure. The sources of fabricated variation during surgery planning should also be handled to prevent a bull-whip effect in the complete patient care chain, like increasing the accuracy of the SCT estimate. Literature has shown that the SCT can be predicted through data-mining algorithms and the surgeon should be supported in making his forecast.

The multiple frameworks and improvements which were found in literature show potential, these should be combined with the learnings from the other subjects. It is interesting to have insights on both the mathematical foundation on planning and on how to create awareness by allowing teams to criticize performance and planning. The problem with implementing tools or mathematical models to increase the accuracy of these predictions is that this requires a change of management: the decision making power of doctors will be reduced and this is prone to resistance.

Finally the theories which correlate with bed management were discussed. The ward can be simulated with an Erlang B Queueing model and this will create enhanced insights by implementing this in the overlapping planning tool. There is need for a visualisation of the impact on the wards, because the link between these two departments, the OR and the wards, is not always present and a future process should take both into account. Also improvements around discharging patients should be considered, as unstable patterns constipate the wards; this leads to high unwanted utilization peaks.
This chapters discusses the planning and scheduling departments and processes within the benchmark hospital. All information is retrieved by empirical research. First the Delft System Approach is applied to the hospital, to create a basic understanding of the different flows, functions and stages of the planning process. This basic understanding will be extended by the discussion and visualisation of the different flows of information within the hospital, which should give insights on the current standing of communication. Finally the operational part of the planning process will be discussed and the process will be visualised in two Swim-lane diagrams, these will be evaluated. To clarify the terminology on patient classifications used in this and the upcoming sections:

Patients can normally be classified in three categories: internal-, surgery patients and ‘other’. Internal patients are patients who will be admitted for minor procedures and do not require an OR. Surgery patients will undergo surgery in the OR and other are all patients who do not fall under the previous two.

The biggest difference is that internal patients have more freedom of planning and scheduling, they are not dependent on the complex decision making around OR utilization.

### 3.1. Delft Systems Approach

The Delft Systems Approach is an instrument to decompose complex systems in a simplified overview [25]. The Process-Performance or PROPER model presents an industrial system as a subsystem of the organisation, containing both the process transformation and -control. The governing processes are simplified to the aspects Order, Product and Resource; the transformation and control of these functions is visualised in the PROPER model. In figure 3.1 the PROPER model is applied to healthcare institution and the core functions are abstracted to Perform the Patient File, Operate Patients and Use Resources:

- The **patient file** holds all information of the patient, his diagnosis and needed treatment. The file is administered by the specialist responsible for the patient’s treatment and nurses fill in small diagnoses during the patient’s stay in the ward.

- **Patients** can be classified into **elective, non-elective** or emergency patients [7]. The first group surgery can be planned up front, the second group has a increased urgency level and has to be planned in a relative short time-frame and the latter require immediate treatment.
• Hospital *resources* which are needed for the planning process are personnel, beds, OR’s, medical equipment and consumables.

• All operations are controlled by the *hospital board*, who supervise the strategic goals of the hospital whilst also managing external parties like the Government, Insurance companies and the public.

![Hospital PROPER Model](image)

The black box is opened in figure 3.2 and the patient’s journey can be divided into three phases: diagnosis, planning and treatment. During the first admissions, the specialist’s consult and treatment the patient file is updated. After the patient has been discharged the info could be abstracted and added to the patient meta data, adding to the hospital’s learning curve. Resources are assigned or reserved during each phase and released afterwards, since resources have to be planned up front there is need for efficient information sharing.

The PROPER model shows that intelligence is distributed in the hospital and that different departments are dependent on efficient information sharing. The patient file is evolving from a hard-copy bundle to a digital file, giving accessibility troubles to the nurses in the wards when supervising their patients. Also with increasing patient volumes, resources are becoming scarce and defects can be disastrous. To achieve optimal use of resources, these information streams need to be visualised and simplified in a future process design.
3.2. Information flow diagram

The DSA showed that on multiple moments information is to be shared between different hospital departments, this section will explain and visualise the communication activities between different actors and departments. The information flow diagram will be added to the discussion on the current station of information sharing, at the end of this chapter. Research has showed that the different departments who work within the planning process can be abstracted to the Clinic, the OR and the Ward. In each department there are multiple actors who work on the planning, these different positions will be discussed in their responsibilities, decision power and authorization.

Clinic
Each (sub)specialism has its own clinic\(^1\), patients are admitted here for consult and minor treatment. There are multiple actors active in a sub-specialism clinic and it is assumed that each sub-specialism works the same:

- The *secretariat* is responsible for the basic communication within the hospital and have no decision power. They register patients and settle non-specialized appointments like infusion therapy for them.

- The *specialist* or *surgeon* consults patients and determines the needed procedures for further treatment. These specifications are admitted to the waiting list for surgery or the patients are referred for internal treatment to the secretariat.

- The *sub-specialism Planner* controls the waiting list for surgery and makes sure that patients are treated according to their urgency. For each MSS period a OR planning is created with patients from the waiting list, this list is passed on to the clinic admissions office. In the benchmark hospital the planner is one of the sub-specialism’s specialists.

- The *Admissions office* files the upcoming OR planning in the electronic environment and adds it to the patient file. Also they make sure that demanded resources are available.

\(^1\)In the Netherlands this department is referred to as the ‘Polikliniek’.
OR Centre
The OR centre manages the multiple OR’s of the hospital, their prime interest lies in preventing or minimizing OT. Together with the surgeon and planner they approve the upcoming OR schedule, making sure the patients are sequenced in the right order and empty spaces are filled up. A letter of confirmation, with the forecast day and time, is sent to the patient when the OR schedule is confirmed.

Ward
Wards are organized differently per hospital, some divide it on specialism and other on LoS. Still these wards all have the same operational character:

- Patients are registered during their stay by the secretariat and for internal procedures the secretariat is able to schedule an appointment. Also patients undergoing surgery have to call one day up front to the secretariat, to inform for the exact time of admission.

- The ward nurses supervise patients, they prepare them for their treatment and are the patient’s spokesperson. Also their responsibility is that patients undergo their treatment according to the strict medical guidelines (e.g. diet).

- The ward supervisor governs the daily operations of the ward, the nurses and secretariat. For surgery they have to plan the assets according to the made planning of the surgeon, which is shared via the electronic patient file. Sometimes the system lacks the exact procedural code and assets have to be reserved for the whole day.

Patient E-file
The patient electronic file is created during the first admission in the clinic and all information concerning the patient, received diagnoses and treatments will be filed in here. The e-file’s accuracy depends on the discipline of the one responsible for completing this information. The file is open to personnel with the right authorization.

Hospital ICT platform
The hospital has an overlapping ICT platform, in which the OR and ward planning and scheduling is managed. The ICT platform also has access to the patient files.

Information flow diagram
The different information streams during the patient journey are mapped in figure 3.3, the figure should be read from left to right. The figure does not present all the steps taken during the planning process, but refers only to inter-department information sharing. The diagram shows that tasks are segregated and decision power is divided over multiple departments. Solutions are to be sought in process simplification through integration of tasks and authorization. In the final subsection remarks on this diagram will be shared, after the planning process has been analysed more thoroughly.

---

2 There is no OR needed
3 Treatments in The Netherlands are filed as declaration codes and are uniform.
Figure 3.3: Overview of the current information streams within the hospital
3.3. Swimlane diagrams

The planning process has been observed and analysis via empirical research within the benchmark hospital and conducting interviews with professionals. These findings have led to the construction of the Swim-lane diagrams (SLD), which give clear insights on the different tasks and the division of authorization within the process. These diagrams can be found on pages 48 to 27. The following sections will discuss the procedures per process phase.

3.3.1. Internal treatment planning

The internal treatment SLD concerns only patients receiving care without making use of the OR. There are five actors active in the internal planning process: the patient, sub-specialism specialist and -secretariat, ward nurses and -secretariat.

Clinic visit
The patient is admitted in the hospital clinic by making an appointment by phone with the clinic’s secretariat. During the visit the patient receives consult from the specialist, which results in a diagnosis on whether the patient is in need of surgery or internal treatment.

Create appointment
After consult the patient returns to the clinic secretariat and starts the appointment making process. The secretariat contacts the ward secretariat and together they negotiate an appointment date and time, which is fed back the patient if this is according to their preferences. When the patient has agreed, the appointment is registered by the clinic secretariat in the patient e-file and resources are booked by the ward secretariat.

Treatment
The ward secretariat admits the patient at the scheduled date and time, the nurse takes supervision over the patient. The nurse places the patient in the ward, starts the treatment preparations and checks if the patient is ready to undergo treatment. Treatment can be cancelled if the patient did not follow the strict diet rules or if there are other potential health risks. After treatment the patient enters the after-care stage, which lasts until the patient is recovered and is ready to go home. If the patient is not discharged before 19:00h, he is transit to the short-stay department.

3.3.2. Surgery planning

The surgery planning process SLD is for patients who visit the OR during treatment. During the process eight actors are present: the patient, sub-specialism specialist, -planner and secretariat, the OR centre, ward nurse, -secretariat and -supervisor.

Clinic visit
The clinic visit is equal for both internal and surgery patients.

Create appointment
After consult the specialist files the patient on the waiting list, which holds the procedure declaration code, estimated duration, required patient LoS and the urgency level. This will be further discussed in the next chapter.

---

4Will be further discussed in the next chapter
waiting list is not a standardized form in the hospital ICT platform, specialists list these to their own preferences. The planner plans the upcoming OR sessions for his sub-specialism, picking patients from the waiting lists; this results in an expected OR schedule and this is send, non-standardized, toward the specialism's admissions office.

The admissions office has the administrative task to file the OR planning in the ICT platform and check if the resource demand can actually be fulfilled, but nothing is definitive until the schedule has been approved. One week before the OR planning a meeting between specialists, planners, admissions office and the OR Centre will decide on the complete schedule for that sub-specialism; if all is confirmed the OR Centre will inform the patient, which is the first notification the patient receives, and activates the procedure on the ICT platform.

Surgery
One day before surgery the patient calls the secretariat for confirmation of the exact time of admission and is admitted the next day\(^5\). The nurse takes over and the patient is placed in his bed, prepared for surgery and checked if all conditions are fulfilled (diet, health). After surgery the patient enters after-care for at least three hours, which is needed for the anaesthesia to work out and to check for any complications, and lasts until the patient is recovered. If the patient is not discharged before 19:00h, he is transit to the short-stay department\(^6\).

### 3.3.3. Swim-lane diagrams

The following pages hold the SLD’s for both internal treatment planning (figure 5.7 and 3.5) and surgery planning (figure 5.8 and 3.7), each SLD is split in two to increase the readability. SLD’s show how delays, mistakes and unnecessary steps occur by organizing tasks for one department in one lane, tasks to the right occur later in the process. Due to differences in procedures, SLD’s for internal treatment and surgery are split up; each will be discussed separately.

---

\(^5\)If surgery was not cancelled or re-planned.

\(^6\)Will be further discussed in the next chapter
### Swimlane Planning Process Internal Patients

<table>
<thead>
<tr>
<th>Clinic visit</th>
<th>Create appointment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient</strong></td>
<td></td>
</tr>
<tr>
<td>GP referral to hospital</td>
<td>Make appointment at clinic</td>
</tr>
<tr>
<td>Make appointment at clinic</td>
<td>Visit clinic</td>
</tr>
<tr>
<td><strong>Subspecialism - specialist</strong></td>
<td>Make appointment internal treatment</td>
</tr>
<tr>
<td>Appointment surgery</td>
<td>Surgery?</td>
</tr>
<tr>
<td><strong>Subspecialism - secretariat</strong></td>
<td>Negotiate appointment</td>
</tr>
<tr>
<td>Register patient / appointment</td>
<td>Negotiate appointment</td>
</tr>
<tr>
<td><strong>Ward secretariat</strong></td>
<td>Register appointment in digital environment</td>
</tr>
<tr>
<td><strong>Ward nurses</strong></td>
<td>Book resources</td>
</tr>
<tr>
<td><strong>Negotiate appointment</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Book resources</strong></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.4: Swimlane internal treatment planning: Clinic Visit and Create Appointment.
Figure 3.5: Swimlane internal treatment planning: Treatment
Figure 3.6: Swimlane surgery planning
3.3. Swimlane diagrams

Figure 3.7: Swimlane surgery planning
3.4. Analysis and remarks

Both the information- and the SLD give a structured overview of the processes around hospital planning. With the lessons learned from the literature review and by focussing on the research methodology, the following remarks are made on the planning process:

- **The surgery planning process shows more complexity.** As was stated in this chapter's introduction, internal treatment is not subjected to the OR and therefore it is easier to plan patients for these procedures. Surgery planning requires five departments to finalize and approve the schedule, book resources and inform the patient.

- **The Internal treatment planning is not under control.** The secretariat is free to schedule the patients to their preference, this is definitive and there is no feedback on the made schedule. Therefore gaps arise in the internal treatment schedule, because every treatment is scheduled independently.

- **There is no dedicated planning personnel.** Current planners are either specialists or secretariat personnel assigned to this part time task, who have not been trained or educated in planning efficiency and managing a supply chain.

- **The OR planning is overcomplicated due to multi-actor interests.** The specialist, planner, admissions office and OR centre have their say in the definitive schedule, the OR planning is not ‘first time right’. The interests are not quantified and there is a unclear procedure for defining the definitive schedule.

- **There is rework in the OR planning preparation.** The patient file and OR planning is worked by the specialist, planner and admissions office; only the latter registers this on-line.

- **There is segregation in resource planning.** The Admissions Office, Sub-specialism Planner, OR Centre and the Ward Supervisor have a say in the reservation of resources. This leads to a conflict of interests, slow decision making and potential rework.

- **The OR planning process is segregated and lacks a holistic view.** Each department fills his own timeslots, not knowing the consequences of their planning to the OR and Ward utilization for the whole hospital. Each department has part-time non-specialized planning personnel.

- **The OR planning and Ward resource planning are isolated from each other.** This leads to exposure on the risk of overbooking, which eventually leads to rework. While the admissions office checks for resource availability, the ward supervisor and secretariat do the definitive booking of resources.

- **There is risk for rework and defects in ward resource planning.** While the admissions office checks for resource availability whilst the planning is not definitive and the ward supervisor books the resource reservations later in the chain.

- For surgery planning, **the patient receives all information on a short notice.** This leads to customer dissatisfaction and potential rework when the patient is unavailable or he is lacking information.
3.5. Conclusion

This chapter opened the planning process from a top down approach. First the Delft Systems Approach was used to decompose the hospital in three aspects Patient status, Patient and Resources and three phases Diagnosis, Planning and Treatment have been identified. The PROPER Model gave basic insights on these streams and the interaction between them, that enhanced information sharing abilities would improve a future design. Still the findings from the PROPER model were insufficient and a more in-depth analysis of the different departments and their roles in the process was held. These findings resulted in a Information Flow Diagram, which showed for each actor/department the information they shared and received during the planning process. This showed that solutions are to be sought in standardizing, simplifying and integrating tasks and decision power.

To have more knowledge on the exact procedure and the division of tasks between department, a Swim-lane Diagram was constructed for both the internal treatment and surgery planning process. An analysis showed that there is potency for department and task integration, changes in planning professionalism should diminish the risk on rework and defects. Also a horizontal supply chain integration is missing, where planners have insights on the effects of their planning choices later on in the chain.
Data analysis

Apart from a literature survey and empirical research, patient data from 2015 was shared by the LUMC to give insights on the production of their outpatient clinic. The effect of the internal treatment and surgery planning process can be quantified and visualised through data analysis. The outpatient ward was chosen for this research, because the department is easy to isolate: all patients receive elective care and they do not stay overnight. The chapter is structured as follows, first key figures quantifying the magnitude of the LUMC and the outpatient clinic will be listed. Thereafter arrival patterns, sub-specialism composition and resource utilization will be presented with figures and numbers. Finally a conclusion on these findings will be made in relation to improving the planning process.

4.1. Introduction

The outpatient ward, or daycare (DC), is a subsystem of the LUMC were patients are admitted and discharged on the same day. This section will introduce both the LUMC and the outpatient department with some key figures, which gives an idea of the system's magnitude, these are listed in table 4.1. The table shows that the DC has a relative high ratio admissions to beds when compared to the hospital. The mean LoS implicates too that the DC has a relative high turnover environment.

Table 4.1: Key figures

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinic admissions 95198</td>
<td>Admissions 10068</td>
</tr>
<tr>
<td>Inpatients 22618</td>
<td>Capacity 32</td>
</tr>
<tr>
<td>Beds 882</td>
<td>Beds 22</td>
</tr>
<tr>
<td>Patient days 145044 days</td>
<td>Chairs 10</td>
</tr>
<tr>
<td>Mean LoS excl. outpatients 6.4 days</td>
<td>Mean LoS 3.9 hours</td>
</tr>
</tbody>
</table>

Depending on the forecast LoS, elective patients are admitted over three different wards for treatment. These are the Long Stay- (LS), Short Stay(SS) and Daycare Wards (DC), these wards have been split of in order to be able to close off departments during nights (DC) and
during the weekends (DC and SS). Also patients receiving care for several days are not faced with a high turnover environment like the DC and are placed in rooms with other patients facing comparable care.

Table 4.2: Different wards of the LUMC

<table>
<thead>
<tr>
<th>Ward</th>
<th>Length of stay</th>
<th>Opening hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daycare ward</td>
<td>Ambulatory care</td>
<td>07:00h - 19:00h Monday - Friday</td>
</tr>
<tr>
<td>Short stay ward</td>
<td>1 to 5 days</td>
<td>Weekdays 24hrs Monday - Friday</td>
</tr>
<tr>
<td>Long stay ward</td>
<td>5 days or more</td>
<td>24/7</td>
</tr>
</tbody>
</table>

The DC has a capacity of 32 patients, see figure 4.1, there are 22 beds and 10 seats; the procedure of assigning patients to these is as follows: if the patient LoS is predicted to stay under 3 hours the patient is given a seat\(^3\), else a bed will be booked. When asset utilization is discussed in this chapter, it will be divided between patients receiving care in a seat or bed; this will contribute to the discussion of current division of beds and chairs in the DC.

Some of these assets are equipped for a specific type of procedure or sub-specialism, see figure 4.1. Of the 10 seats, four (blue area) are equipped for infusion therapy and the other

\(^3\)Exceptions to physical limitations of patients.
six (red area) are employed for non-narcotic surgery that is carried out on the specialized OR on the DC floor. Of the 22 beds, six (green area) are in the lock area; these are single bed rooms for patients who are in need of isolation against e.g. risk of contagion.

4.2. Ward production

A basic understanding of the outpatient clinic has been sketched in the previous section. This section will zoom into the ward production: the distribution of different sub-specialisms under patients, admissions and resource turnover.

4.2.1. Sub-specialism division

During 2015, 26 sub-specialisms have been treated in the DC; the distribution of these sub-specialisms is shown in figures 4.2(a) and 4.2(b). The figures show that for two angles, amount of patients or total LoS\(^4\), five specialisms easily cover for over 50% of the complete production. This shows potential for the ward to specialize in these procedures and create standardized environments.

There are differences in top sub-specialisms if data is filtered on type of resource (bed vs seat). Figure 4.2(c) shows that for beds the most treated sub-specialisms are MDL, END, REU, INT and OOG. This is interesting as INT normally has no need for the OR, but patients sometimes undergo a colonoscopy\(^5\) which is a lengthy procedure. For seats patients mostly originate from OOG, CHI, MDL, KNO and END, see figure 4.2(d). Whilst OOG has a designated area, a large part of the procedures are longer than 3 hours and therefore patients are still placed in beds.

4.2.2. Admissions

In 2015 the clinic patient volume was 10069 admissions and with 253 operative days for 2015 the clinic turnover was 39.8 patients per day. See table 4.3. In figures 4.3(a) and 4.3(b) the turnover during the year is visible. Seats have a higher turnover\(^6\) than beds (1.9 vs 0.9), meaning that all beds on average used less than once a day throughout the year. It is interesting to note that seats turnover remains stables throughout the year, but beds have a strong seasonal influence.

Table 4.3: Patient volumes of the outpatient ward [19].

<table>
<thead>
<tr>
<th>Daycare</th>
<th>Quantity</th>
<th>Seats</th>
<th>Quantity</th>
<th>Beds</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Admissions per day</td>
<td>10069</td>
<td>Admissions per day</td>
<td>4883</td>
<td>Admissions per day</td>
<td>5186</td>
</tr>
<tr>
<td>Patients returning (%)</td>
<td>5132</td>
<td>Patients returning (%)</td>
<td>1502</td>
<td>Patients returning (%)</td>
<td>3630</td>
</tr>
<tr>
<td>Turnover</td>
<td>1.2</td>
<td>Turnover</td>
<td>1.9</td>
<td>Turnover</td>
<td>0.9</td>
</tr>
</tbody>
</table>

\(^4\)From now on the ‘amount of patients’ angle will be used for further analysis, since total LoS may give a wrong representation due to the influence of waiting between procedures.

\(^5\)Internal examination of the intestines.

\(^6\)How many times a resource is used during operation.
4. Data analysis

(a) Top sub-specialisms in amount of patients.

(b) Top sub-specialisms in total length of stay

(c) Patients per specialism (%) - beds

(d) Patients per specialisms (%) - seats

Figure 4.2: Distribution of specialisms in the LUMC DC[19].
The 10069 admissions are from 5132 patients and figure 4.3(d) shows that 73.7% of these patients are one time visitors. The second and third table in table 4.3 show that seats have a relative higher rate of returning patients (42% to 20%). For returning patients it is assumed that these patients undergo one treatment for which multiple returning moments is needed and thus there is room for standardization.

Figure 4.4(a) shows the distribution of the admissions per day during 2015. The projected curve is asymmetrical, showing that the bulk of the admissions are around 35 to 49 patients per day; meaning that a small positive error is more likely than a small negative error. In figures 4.4(c) and 4.4(d) the curve is filtered on resource type, showing that the distribution on seats is more symmetrical and that volumes for beds a spread out.

Interesting is the amount of admissions per day of the week, figure 4.4(b), which shows that there is a peak on Wednesday. On this day the DC treats 10% more patients than on the other days. This is explained when the division of specialisms per day is analysed, which
shows that the OOG specialism has a 200% increase over the average amount of patients on Wednesdays. Also this overview shows that the irregularities during the week, which is dependent on the OR schedule.

**4.3. Arrivals and utilization**

It was clear from literature that the ward needs a stable arrival and discharge rate, because random elements and sudden peaks lead to chaos. This section covers the findings on the arrival-, discharge pattern and resource utilization during operation. Figures 4.4(e) and 4.4(f) show the arrival patterns of the clinic, each figure shows the mean value, 95th percentile and the maximum. This was chosen such that the figure gives both insights in normal- and extreme cases. The figures 4.4(h) and 4.4(g) consist of two graphs: a histogram, amount of patients versus time, and a line diagram, resource utilization as a percentage versus time. The first corresponds with the left vertical axis and the latter with the right, also these graphs show the mean value, 95th percentile and the maximum.

Approximately 50% of the patient volume arrives before 10:00h and during peak hours the ward can expect 6 to 10 patients per hour. Figure 4.4(f) shows normal behaviour, that peaks are between the 20 to 25 patients and that the clinic was never full in 2015. Seats have a mean utilization of 27%, it fluctuates between the 20% and 40% during the day, and only the top 5% cases reach utilizations of 70 to 90%. The average bed utilization is 42% and during peaks this reaches 70%, even some cases show that the ward was overbooked. Both graphs show that there is room for more efficient planning or a reduction of resources. The ward has only patients receiving elective care and therefore occupation should be higher than current levels.

**4.4. Patient length of stay**

Figures 4.5(a) and 4.5(b) share insights on the LoS distribution for both seats and beds. Seated procedures take 2 hours on average and 50% of the patient volume takes between 1.75 to 2.25 hours. Procedures for bedded patients take on average 5.7 hours and due to the lower limit the curve is asymmetrical. About 55% of the patients stay under 5 hours and 80% under 8 hours, this shows that a higher turnover on beds is possible as in the 12 hour time frame multiple patients could be serviced.

The predicted patient LoS is influenced by it’s spread, figures 4.5(c) and 4.5(d) visualise the LoS for the five largest specialisms, on total LoS, in a boxplot. Whilst each specialism has numerous procedures, the figures show that the CHI, OOG (2x) and KNO specialisms have relative large variability in their LoS. Still a dedicated research on the exact procedures and their process quality could give better indications on improvements.
4.4. Patient length of stay

Figure 4.4: Graphs on ward arrival and utilization patterns, 2015[19]
4. Data analysis

(a) Length of stay - seats

(b) Length of stay - beds

(c) Boxplot - duration five largest specialisms: seats

(d) Boxplot - duration five largest specialisms: beds

Figure 4.5: Graphs on patient LoS, 2015[19]

4.5. Conclusion

The DC ward is a relatively small department in the LUMC, which is characterised by handling large patient volumes with a mean LoS of a few hours. In the department distinction is made between two patient groups: patients who are spending their time seated or in bed. Patients who spend more than 3 hours in the ward are required to stay within beds.

An analysis of the ward production showed that about five specialisms cover for 50% of the procedures and that these differ per patient group. This means that areas of the ward could be specialized when there is a stable inflow of patients from a specific sub-specialism. Also the figures showed that there are relatively more returning patients in seated procedures, which gives potential to standardization as well. Furthermore, it was found that beds have a turnover below 1 during the year.

The arrival patterns and clinic utilization lead to the understanding that the clinic has a relative low utilization while it has only elective patients. While occupancy levels should not be too high, literature indicates that there is a lot of variability in healthcare, current levels of 27% and 40% for respectively seats and beds show that resources are not planned optimally. Patients LoS for seats is concentrated around 2 hours and beds around 5 hours, this indicates that a higher turnover is possible for both seats and beds.
Future process design

This chapter holds a proposal for a future process design for hospital planning and scheduling. By using the information and lessons learned during the literature review, interviews, the process- and data analysis, a new process design is visualised by two swimlane diagrams, figures 5.7 and 5.8. These diagrams show the change in tasks and functions of several departments, also some departments have been removed. The following sections discuss the proposed changes.

5.1. Tracking performance

The planning process performance will be reviewed by the 'Performance Team' (PT). The team’s composition consists of representatives of all departments, such as the Anaesthesiologist, Surgeon, Planner, OR- and Ward management. With such a diverse formation the team takes all important opinions into account, these representatives are the spokesperson for their department. Together with the dedicated planning team, the PT reviews the upcoming OR schedule and evaluates the OR’s performance of last week. Through a diverse team and the critical focus, issues in planning and scheduling could be highlighted and adequate action can be taken directly towards the department. Also each sub-specialism should be confronted with the accuracy of made predictions and OT should be taken of their total declarable time.

Ideal performance results are attained when the team’s composition is stable for a longer period, it has frequent review sessions and the team is trained in Lean Six Sigma learning tools. Apart from tackling and preventing issues around the planning, the increased understanding will enhance all practices around planning.

5.2. Enhanced planning

The new process design will focus on the operational part, on optimal planning and sequencing of patients by respecting set constraints. It was clear that time blocks are mandatory for University Medical Centres, as surgeons have multiple responsibilities, but the use of semi-flexible time blocks would be beneficial (figure 5.1). Semi-flexible time blocks allow neighbouring time blocks to overlap their planning if slack OR time is present, which would increase the OR planning effectiveness. Furthermore, all planning activities will centralized and are to be managed by a dedicated planning department. This team operates
for all specialisms and the work is executed by trained planning professionals.

Figure 5.1: Example of execution of Semi-Flexible Time Blocks

Internal planning
For internal planning, the team is supported by a planning tool in which patients can register for their treatment. The tool present patients possible time windows, which represents when their treatment could start\(^1\). This results in a two-fold solution, the patient still knows when he will be treated and the hospital has enough flexibility to increase the schedule's efficiency later on. Supported by planning software, the team is able to oversee how to create the best schedule; the supporting tool should give insights on ideal patient sequences and the impact on other resources.

Surgery planning
The proposed \textit{surgery planning} process will be on par with the internal process, planning and scheduling decisions are supported by a planning tool. All decision making power is given to the planning team and they discuss the planning with the performance team, who could ask the surgeon in question for consult. This reduces the complexity of the planning procedure. The accuracy of the planning is increased by giving specialists a \textit{SCT prediction tool}, which forecasts given historical data and all important characteristics of the procedure (type, team composition and patient).

\(^1\)e.g. 3rd of July between 07:00h - 13:00h
5.3. Advanced ICT

The ICT department will manage the new supporting tools and relevant decision making tools which require digital communication. These new tasks are considered autonomous, but for simplification of the SLD all is put under the tag 'ICT support'. Hospitals need to adapt to the current technology standards by creating a electronic environment in which patients can register for their treatments, receive consult or information and receive real-time updates concerning their procedure.

5.3.1. Supporting tools

The above discussed supporting tools are a combination of mathematical models and data mining applications. The exact algorithm and execution of these models are outside of the research's scope but the following models are required:

- SCT prediction: specialist SCT historical data should be subjected to a data mining algorithm. For each type of procedure knowledge could be retrieved on how this correlates with the surgeon's team, in terms of composition and experience, and patient characteristics. The specialist's estimation will be more accurate when his past performance is visualised, by showing e.g. his past procedures and their spreading.

- Planning and scheduling: the model supporting the planning team should incorporate both a LP and an Erlang B queue model. The first constructs both ideal time blocks and patient sequences by respecting all constraints. The queue model gives insight on possible constipation of the wards, which is then translated to a constraint in the LP model. The planner is supported by receiving schedule proposals and a visualisation of the impact of these schedules on both the OR and wards.

5.4. Swimlane diagrams

Figures 5.7 to 5.8 show the improved SLD for both internal and surgery planning. The SLD's have been split up and to increase readability only the active departments are shown per phase\(^2\). The complete SLD's are listed thereafter, but due to the scaling on paper it is difficult to read. The following changes, when compared to the former SLD's, are:

- The Patient's first line of communication will be the internet, admissions are made via an app, pc or screens within the hospital. This increases transparency as patients receive real-time updates concerning their treatment and planning.

- For internal planning, all planning and scheduling is managed by the planning team and the supporting tools. Patients, however, may assign for a preferred timeslot which is managed by the planning tool.

- For surgery planning, all planning and scheduling is managed by the planning team and the PT; the PT takes the desires of the different departments into account.

- Rework in planning should be prevented, by using smart planning software and strict regulation rework should only be exceptional.

\(^2\)The clinic visit phase is only shown for Internal treatment, it is the same for surgery.
• The nurse should be trained in order to have authorization to discharge patients, in case of complications the specialist can still be consulted.

5.5. Conclusion
This research was conducted in order to have insights on how to increase the efficiency of the planning process within hospitals. This conclusion will try to answer the research's main question, which was:

How can a hospital planning and scheduling process be further enhanced, by keeping in mind the complex multi-actor organization and increasing patient service level?

The first part of the study consisted of a literature review, which showed that current understandings in the scientific community have already matured but large healthcare facilities are lacking the implementation. Literature showed that Lean Six Sigma, mathematical models on planning, scheduling and forecasting, understandings on integrating Erlang B Queues for bed management insights and proposals on increasing the effectiveness of the discharges will lead to better Hospital performance.

Empirical research was conducted in the benchmark Hospital the LUMC in Leiden, which showed that a horizontal link in the supply chain was missing; this connection was discussed in literature. Also the analysis of the complete process, which was visualised in an Information Flow Diagram and Swim-lane diagram, showed potential rework, segregation, over-complicated decision making and lack of transparency. Next to empirical research, patient data was analysed which also gave some insights and confirmed some assumptions from empirical research. The relative low turnover of beds and seats showed that increasing the planning performance would increase the turnover. Also the graphs on arrival rates and occupancy showed that enhanced scheduling would level these rates and allow the hospital to take either less resources or higher patient volumes.

With the above learnings taken into account, this section has proposed two SLD’s which should improve the current planning process while increasing customer satisfaction. Recommendations for the future will be the introduction of the Internet of Things into hospitals, allowing artificial intelligence to increase the performance of planning activities.
Figure 5.2: Swimlane internal treatment planning: Appointment making

Figure 5.3: Swimlane internal and surgery planning: Clinic Visit.
Figure 5.4: Swimlane internal treatment planning: Treatment
Figure 5.5: Swimlane surgery planning: Create appointment.
Figure 5.6: Swimlane surgery planning: Surgery.
Figure 5.7: Swimlane internal treatment
Figure 5.8: Swimlane surgery
Bibliography


