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Lauri Anttila

THE EFFECTS OF CONGESTION IN THE DAILY MANAGEMENT OF A TRAUMA HOSPITAL

Master's Thesis

Helsinki, April 22, 2015

Supervisors: Associate Professor Ville Ojanen
Professor Timo Pirttilä

Instructors: D.Sc. (Tech.) Antti Peltokorpi
M.D., Ph.D., Docent Jarkko Pajarinen

ABSTRACT

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Today's healthcare organizations are under constant pressure for change, as hospitals should be able to offer their patients the best possible medical care with limited resources and, at the same time, to retain steady efficiency level in their operation. This is challenging, especially in trauma hospitals, in which the variation in the patient cases and volumes is relatively high. Furthermore, the trauma patient's care requires plenty of resources as most the patients have to be treated as single cases.

Occasionally, the sudden increases in demand causes congestion in the operations of the hospital, which in Töölö hospital appears as an increase in the surgery waiting times within the yellow urgency class patients. An increase in the surgery waiting times may cause the diminution of the patient's condition, which also raises the surgery risks. The congestion itself causes overloading of the hospital capacity and staff.

The aim of this master's thesis is to introduce the factors contributing to the trauma process, and to examine the correlation between the different variables and the lengthened surgery waiting times. The results of this study are based on a three-year patient data and different quantitative analysis. Based on the analysis, a daily usable indicator was created in order to support the decision making in the operations management. By using the selected indicator, the effects of congestion can be acknowledged and the corrective action can also be taken more proactively.

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Nykyajan terveydenhuollon organisaatiot ovat jatkuvien muutospaineiden alla, sillä rajoitettujen resurssien avulla sairaaloiden tulisi pystyä tarjoamaan parhainta mahdollista hoitoa potilailleen sekä säilyttämään samalla tasainen tehokkuus toiminnassaan. Tämä on erityisen hankalaa varsinkin traumasairaaloissa, joissa asiakaskunta vaihtelee suuresti niin määrällisesti, kuin myös tapaturman laadun näkökulmasta. Traumapotilaiden hoito sitoo lisäksi runsaasti resursseja, sillä potilaita joudutaan pääsääntöisesti käsittelemään yksittäistapauksina.

Toisinaan äkillisesti kasvanut kysyntä aiheuttaa ruuhkautumista sairaalan toiminnassa, joka Töölön sairaalassa näkyy etenkin keltaisen kriittisyysluokan potilaiden leikkaukseen pääsyaikojen kasvuna. Leikkaukseen pääsyaikojen kasvu saattaa aiheuttaa potilaiden terveydentilan heikentymistä sekä se nostaa tutkitusti myös leikkausriskiä. Itse ruuhkautuminen puolestaan aiheuttaa sairaalakapasiteetin sekä henkilökunnan ylikuormitusta.

Tämän diplomityön tarkoituksena on esitellä traumaprosessissa vaikuttavia tekijöitä sekä eri muuttujien vaikutusta kasvaneeseen leikkaukseen pääsyaikaan. Työn tulokset pohjautuvat kolmen vuoden ajalta kerättyyn potilasaineistoon sekä erilaisiin kvantitatiivisiin analyyseihin. Analyysien pohjalta päätöksenteon tueksi luotiin päivittäin käytettävä toiminnanohjauksellinen mittari, jonka avulla ruuhkatilanteita sekä niiden vaikutuksia pystytään jatkossa paremmin havainnoimaan ja myös korjaaviin toimenpiteisiin voidaan ryhtyä ennakoidusti.

FOREWORD

Master's thesis is a learning experience in both pragmatic topics and in self-management. During this journey, I have familiarized myself with a topic, which really was not what I was studying for. However, as I was told on the first days of my studies, the Industrial Management students from LUT are multi-talents who adapt themselves to the dynamic environment. This really seems clear now. The past six years at the university have been the best time of my life and thus I would like to thank our professors, Industrial Management guild Kaplaaki, and especially my dear friends.

I wish to express my gratitude to Antti Peltokorpi who shared his knowledge and guided me through this thesis project with a professional manner. Moreover, I would like to thank HUS, and especially, Jarkko Pajarinen who made the topic of this thesis possible. As this thesis project is only a small part of the whole university path, I am also grateful to my family who have supported and encouraged me during the studies. Finally, I would like to thank my girlfriend Veera who has been there supporting me even during the weakest moments of this thesis project.

Helsinki, April 22, 2015

Lauri Anttila

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ABBREVIATIONS

ED	*Emergency department*
HUS	*Hospital District of Helsinki and Uusimaa*
HUCS	*Helsinki University Central Hospital*
ICU	*Intensive care unit*
LOS	*Length of stay*
OR	*Operating room*
O&T	*Orthopedics and Traumatology*
PACU	*Post-anesthesia care unit*
SQ	*Surgery queue*
WIP	*Work in process*

1 INTRODUCTION

1.1 Background

Healthcare is one of the most important building blocks of the modern society. It is predictable that in the future the healthcare industry is facing a lot of challenges as the average age of the population is increasing, which therefore increases the need for the health organizations (Parkkinen 2007, p. 5; OECD 2014, p. 10). The actual demand in the health services can be divided into two categories, which are the planned elective patients and the non-elective patients. The demand caused by the elective patients is easier to control as the patients are usually placed on the waiting list in order to wait for the treatment. The non-elective patients, in turn, need to be treated urgently, which therefore creates more challenges to the planning of the patient treatment processes. The management of trauma patient care involves coping with a large uncertainty in demand as the patient inflows are, due to the external factors, almost impossible to forecast accurately. (Bowers & Mould 2004, p. 599) In addition, the patient case mixes in trauma hospitals usually differ significantly from the routine patients who arrive at the health centers, as the trauma patients are usually suffering from severe and multiple injuries. Therefore, most of the patients need to be cared as single projects. (Peltokorpi et al. 2011, p. 1)

In trauma centers, a sudden rapid increase in demand may cause congestion in several parts of the patient treatment process and thus effect negatively on the quality of the treatment and even cause extra costs for the hospital. As accidents happen unpredictably, the indicators used in operation management need to follow the average values of demand, so that the capacity and the resources can be adjusted in the different operational units. In Töölö Hospital, which is the main trauma unit of Helsinki University Central Hospital (HUCS), the demand burdens first the emergency department (ED), from which the patients are either discharged or forwarded inside the hospital for follow-up actions. Even the number of the emergency visits is significantly varying on a daily basis, still from year to year the amount of patients, who need immediate surgical operation, is almost standard and independent on the workload level.

With the retrospective analyses in Töölö hospital, it has been possible to perceive certain statistical connections regarding congestion between different stages of the patient treatment process on a monthly level. For example, it has been discovered that in the ED the throughput times of the patients increase as the patient volumes grow. The overcrowding of the ED has also been acknowledged as the reason for diminution of the operating rooms' (OR) performance. Additionally, the waiting time for the surgical operations seemed to increase during the congested times due to the patient load in the ED. In turn, at the end of the treatment process, congestion has appeared as the patients return to the follow-up check. This phenomenon shows that the service chain is not able to respond sufficiently to the increased demand, especially, when the demand exceeds the buffer, which is contained in the system and its resource allocation.

As the bed capacity acts as one of the limiting factors, the wards might quickly fill up as a consequence of the crowded ED. Thereby, hospital cannot guarantee decent access to care for all of its patients. In addition, the overcrowded wards take time to empty, which therefore increases the workload within the staff and shows as a tightened work atmosphere. These preliminary findings show that problems are mostly caused by the insufficient information flows within the operations management. New information is needed to support the process management, so that the operational and resource decisions can be made more agile in order to minimize the patient queues. One of the additional research needs relates to the new trauma hospital, which will be located in the Meilahti health campus in the future. One of the aims is to improve waiting and throughput times of the emergency surgery patients and increase the productivity of the surgical operations by 10-20%.

The described problems are not only related to Töölö hospital, as congestion exists also among the emergency surgery operations and partly in elective procedures. The significance of the corresponding phenomenon is currently studied within the

HUCS cancer center (Department of Oncology) as new operations are planned and developed. In the cancer center, the varying amount of referrals causes congestion, from time to time, to the reception, medical care, radiotherapy and to isotope treatment. As the trauma patient process follows the same treatment steps in different hospitals, even globally, are the problems also usually similar. Therefore, the new knowledge can be widely utilized in different hospitals.

1.2 Research objectives and questions

The previous researches relating to the operations of Töölö hospital have focused more on enhancing patient throughput, capacity management, and how to bind and utilize the existing resources (Torkki et al. 2006; Peltokorpi et al. 2011). This master's thesis will focus more on analyzing the trauma patient treatment process and the causal relationship between the inflow of the ED and the operations of the operating unit. Based on the patient data analysis and interviews, different factors, which cause congestion on the patient treatment process, are searched.

The purpose of the thesis is to discover and create an indicator for the operation management, which enables the management to have more time to react on the increased demand and thus decrease the amount of congestion in different phases of the patient treatment process. As the right indicators are used within the operations management, facilitates it to streamline the patient flow by allocating the resources to respond to the dynamic environment. One of the additional objective of this thesis is to introduce suitable follow-up actions and reaction models, which bases on the usage of these new indicators. The new knowledge will be exploited in the current operation of Töölö hospital, and especially, in the planning phase of the new trauma hospital. According to the plans, the current operating models will be deployed into the new hospital in the future, which therefore increases the need for the new information about the trauma treatment processes.

To attain the goals of the research two research questions are formulated:

1. *Which factors explain and anticipate the congestion of the trauma process?*

2. *What kind of daily indicators and operation management support can be used to forecast and avoid the congestion?*

1.3 Limitations

The operation of Töölö hospital is observed from the industrial management perspective, without forgetting the special characteristic of the healthcare industry. Vissers & Beech (2005, p. 47) have outlined three different and well-known industrial management aspects, which are suitable being used also in the healthcare industry. These are the unit logistics approach, the chain logistics approach and the network approach. In the unit logistics approach, operations are examined from a single unit point of view, which can be, for example, an emergency department, intensive care unit or operating unit. At this point of view, resource utilization and the workload control are the focus points. For a single unit, it is essential to keep track of the total amount of patients served and maintain a constant and fluent flow of patients through the unit. Occupancy level can be seen as an indicator measuring the unit's total efficiency. (Vissers & Beech 2005, p. 48)

The chain logistic approach, in turn, focuses more on a certain patient group, such as trauma patients or oncology patients. The chain perspective looks into the entire patient treatment process of the selected patient group, which might include several visits in different units within the hospital. The aim is to optimize the treatment process according to some time-based targets, such as short throughput time, short access time to care or short in-process waiting times. The final aim, at this point of view, is to maximize the service level for the selected patient group. The chain logistic approach does not focus on resources, as those are allocated to units, and therefore not for the single patient groups. (Vissers & Beech 2005, p. 48)

The network approach aims to combine the unit and the chain perspectives, by bringing out the trade-offs between the service levels and resources. At this point of view, all the patient chains and units should be considered. This approach can be seen as far too complex in order to improve the performance of the process for a single patient group. However, this approach could be used by taking all the patient groups, with a certain specialty need, into consideration. This would make it possible to examine the impacts of the change on the use of resources with selected patient groups, who have the same specialty needs. (Vissers & Beech 2005, p. 49)

This master's thesis focuses on the chain approach as the aim is to investigate the whole process of the trauma patients, who are visiting the different units on their journey through the hospital. The research focuses only on Töölö hospital and the trauma patient processes. In order to analyze the trauma process and to discover the most suitable indicators for the operation management, patient data is gathered from the emergency department, different wards and from the operating unit. After the ED arrival the surgical patients are divided into different urgency classes, which defines how fast the patient need to be operated. During the congested times, it has been acknowledged that the surgery waiting times are increasing, especially within the yellow urgency class, where wait time target is 48 hours. These patients are waiting for the surgery always within the hospital and thus they utilize a lot of the hospital resources during the pre-operative length of stay (LOS). Therefore, the data analysis is focused mainly on yellow urgency class patients within the specialty of orthopedics and traumatology.

1.4 Structure of the thesis

This master's thesis has been divided into six main chapters. The structure of the thesis has been illustrated in Figure 1. The first chapter addresses the background and research problem for this study. The output of the first part is to formulate objectives and limitations, and to introduce the research questions. The second chapter provides a descriptive literature review about the different industrial management tools and methods used in the healthcare industry, as the trauma care context itself is quite specified and has been scantly studied. In addition, this chapter provides information about the congestion from a more theoretical perspective.

The third chapter introduces the empirical case environment by describing the different process steps, which the trauma patients are going through in Töölö hospital. The aim is to provide information about the daily operation of the trauma hospital. The different methods used in this study are introduced in the fourth chapter. As this study bases on a data analysis, this chapter focuses more to describe the different data processing steps and statistical methods. The fifth chapter introduces the results from the process mappings, data analysis and regression model, and describes the creation of the predictive operating model. Finally, the key findings and results of this study are concluded and discussed in the sixth chapter. In addition, this chapter presents the different managerial implications, contribution to the research scope, and provides topics for the further research.

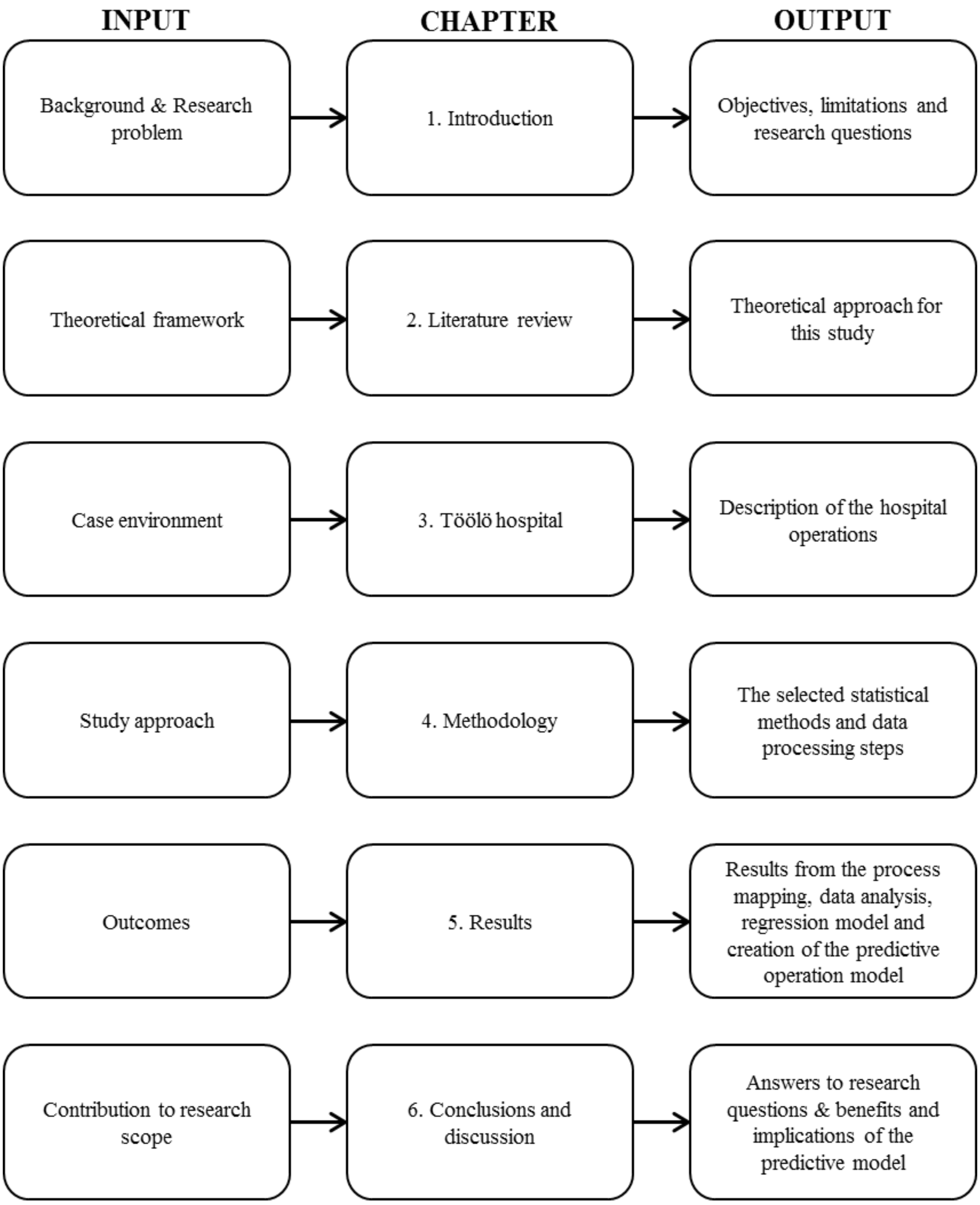

Figure 1. Structure of the thesis

2 LITERATURE REVIEW

During the long history of the healthcare services, also its operating models and processes have been modified in order to respond to the growing needs of the population. With limited resources, healthcare organizations should be able to maintain a steady process flow in the patient care and a high resource productivity at the same time. This is challenging, especially in trauma hospitals, where there is a lot of variation in demand and in the patient cases. As the trauma care context is quite specified, it was very difficult to find similar academic research. The literature view of this study bases on several industrial management principles, which have been used in the healthcare industry.

A descriptive literature review was conducted in order to find the most suitable theoretical framework for this study. Elsevier's Scopus database was used as the main search database and the results were complemented with searches in Medic-database, Ovid Medline, Web of Science and Google Scholar. Relevant articles were selected based on keywords, abstract and amount of citations made to the article. Snowballing was used as one of the methods in order to find the most relevant articles and key authors in the field. The used keywords and the searched abstract themes were mostly related to the trauma process, congestion, production planning and control, and to process and capacity management in healthcare. A descriptive list of the keywords used in the literature search has been illustrated in the Appendices (see Appendix I).

2.1 Industrial management principles in healthcare

Industrial management principles and theories have been widely benchmarked to the healthcare industry. For example, production planning and control, process management and lean thinking, are just a few theories to mention, which have been successfully implemented from manufacturing to healthcare services (Vissers et al. 2001; Laursen et al. 2003). By using different industrial management tools, it has been possible not only to improve the efficiency and productivity of the hospitals, but also to reduce the amount of bottlenecks in the treatment processes. Bertrand & Vries (2005, p. 27) have summarized the similarities and differences between manufacturing and healthcare organizations, which have been collectively presented in Table 1.

Table 1. Similarities and differences between manufacturing and healthcare organizations (adapting Bertrand & Vries 2005, p. 27)

Characteristics	**Manufacturing**	**Healthcare**
Object	Material flow	Patient flow
Specification of end-product requirements	Specified in advance	Subjective and vague
Means of production	Equipment and staff	Equipment and staff
Buffers	Stock and lead-times	Waiting times and lead-times
Financial goal	Profit	Cost control
Market environment	Market competition	Competition between the public and private healthcare

In manufacturing industry, organizations are focused on material flows, as in turn the core process of healthcare organizations focuses on patients who need treatment. In manufacturing, it is essential to create the explicit specifications of the end-products, plan the production processes and delivery requirements. Healthcare organizations, in turn, cannot follow strictly planned production processes as the product specifications are often fuzzy and unclear. (Bertrand & Vries 2005, pp. 26-27)

The manufacturing and the healthcare organizations differ from the market environment and financial goal perspectives. The financial goal for the manufacturing organizations is to create profit with created products, as for the healthcare organizations it is more important to keep the costs in the control. Market environment in manufacturing is usually highly competitive within the markets. In healthcare, the competition is limited only between the public sector and private healthcare organizations. (Bertrand & Vries 2005, pp. 26-27)

2.2 A framework for healthcare production planning and control

According to Vollmann et al. (2005, p. 8), the process of production planning and control can be divided into three phases: creating a production plan, defining the material and the capacity need, and executing these plans. As hospitals are struggling with an increasing demand and higher expectations for improved service delivery with tighter budgets and limited resources, is the importance of the production control obvious to the healthcare organizations. The main objective for the production control of hospitals is to maximize the utilization of resources by using acceptable standards of the service quality. In order to maximize the utilization of resources, hospitals should focus its production control effort on the most expensive resources. To control the service quality level, hospitals should focus their production control effort on the elimination of the waiting lists that are longer than the buffers, which are required for the efficient use of resources. (Vissers et al. 2001, pp. 591-593)

Vissers et al. (2001, p. 592) argue that hospital production processes are driven by medical specialists, who actually do not manage that process. Therefore, from the production control point of view, hospitals should be considered as a virtual organization, which consists of a number of relatively independent business units in a common framework. To support their analysis, which bases on the design requirements for the hospital production control systems, Vissers et al. (2001) developed five level framework, in which different planning decisions and time horizons are included. The levels are: 1) Patient planning and control, 2) Patient group planning and control, 3) Resource planning and control, 4) Patient volumes planning and control, and 5) Strategic planning.

Based on the framework of Vissers et al. (2001), Peltokorpi et al. (2006) created a hieratical process model in order to describe the production planning and control of surgical services. This has been illustrated in Figure 2.

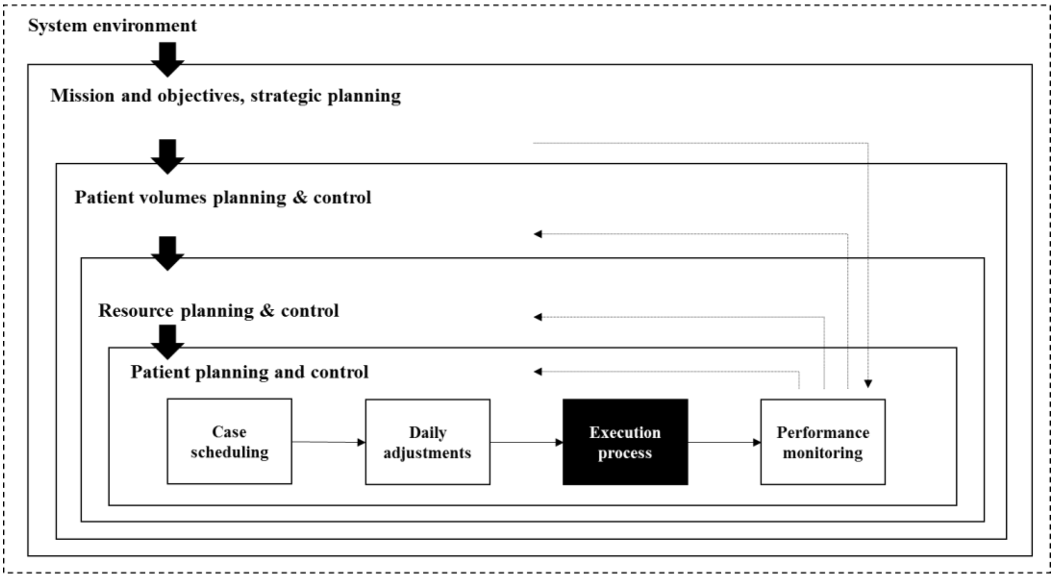

Figure 2. Production planning and control hierarchy for surgical services (adapting Peltokorpi et al. 2009, p. 202)

The *System environment* level describes the environment, where the healthcare organizations are operating. In given environment, organizations define their mission and objectives by considering the different laws, values, markets and customer needs. At this level, the organizations define their service range, customers and primary measures for success. (Peltokorpi et al. 2009a, p. 201)

The *strategic planning* is the highest level of production control. Here organizations define their missions and objectives, and strategies for producing the surgical services (Peltokorpi et al. 2009a, p. 201). At this level, when the operations of an entire hospital are concerned, hospitals should decide the operational direction, in which they are heading during the next years. This means decisions related, for example, to the patient categories, volumes and target mixes. (Vissers et al. 2005a, p. 91)

The *patient volumes planning & control* level focus on estimating the future demand and building fixed capacity, which are, for example, the existent facilities and the core personnel (Peltokorpi et al. 2009a, p. 201). According to Vissers et al. (2005a, p. 90), at this level hospitals should estimate the amounts of patients within different patient groups. Based on these estimations resources and capacity are roughly planned, so that the wanted service quality level can be guaranteed. (Vissers et al. 2005a, p. 90)

On the third level, *Resource planning & control* focus on the weekly, daily, and even the hourly plans of the hospitals functions. These plans consider, for example, the use of the shared core resources, specialist time allocation and surgery scheduling. For example, daily operating room sessions are allocated to the specialties or directly to surgeons and patient groups. (Peltokorpi et al. 2009a, p. 203)

The lowest level of the hierarchy, *Patient planning & control,* concentrates on coupling the individual patients to resources in the daily scheduling. (Vissers et al. 2005a, p. 85) From the surgical operations perspective, individual patient cases are scheduled to operating room sessions, typically couple weeks before the actual day. However, emergency surgeries may cause last minute adjustments in the planned operation room sessions. Performance monitoring of the execution process is an essential part of the control process. Monitored measures should base on organization’s objectives and the results of the performance monitoring, in turn, should be reflecting in the future strategies and plans. (Peltokorpi et al. 2009a, p. 203)

2.3 Capacity planning and management in healthcare

Vollmann et al. (2005, p. 337) argue that the organizational capacity planning decisions should be made based on five level framework, which considers the long, medium and short range capacity plans. The capacity planning framework starts from the long term planning, where an all-encompassing plan of the needed resources is made. Resource planning provides the basis for matching the manufacturing plans and the existing capacity. After resources have been defined, a rough-cut capacity plans should be made. In the medium range, the focus is on the time-based material planning and on the evaluations of the actual capacity needs. In the short range, any adjustments to the plans should not be done, as the capacity utilization has been fixed. Additionally, at this stage, the used capacity should be monitored and the executed plans should be evaluated. (Vollmann et al. 2005 p. 338-339)

As capacity planning describes one side of the coin, capacity management is the other. Basically the capacity management means that the plans need to be executed and completed effectively. (Vollmann et al. 2005, p. 352) The main objective of capacity management in hospitals, is to efficiently use the resources so that the best medical care can be provided to the current and the future patients. The capacity management in healthcare involves decisions regarding the acquisition and allocation of three types of resources, which are the staff, equipment and facilities (Smith-Daniels et al. 1988, p. 890).

Many of the resources within the hospitals are shared by several specialties, such as the operating theatres, ward beds and the nursing staff. When the division of capacity to specialties is not in balance for each specialty, it may result that one capacity is always overloaded and thus becomes as the bottleneck for this specialty. (Vissers 2005b, p. 67) This has been illustrated in Figure 3, which shows the imbalances between the allocated operating room hours, beds and nursing staff.

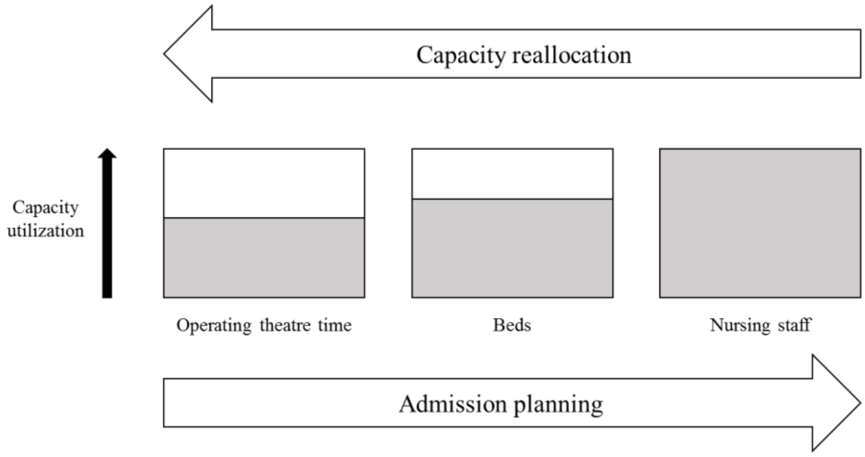

Figure 3. Capacity workload levelling per specialty in inpatient process (adapting Vissers 2005b, p. 67)

In this example, the fully utilized nursing staff works as the bottleneck capacity, affecting negatively to the efficient usage of the operating rooms and creating underutilization within the bed resources. The biggest reason causing capacity losses in hospitals is that the resource allocation is based on historical averages and thus occasionally creating overcapacity for one specialty and under capacity for another. According to Vissers (2005a, p. 119), the resource allocation within the hospitals should be flexible and based on the flow of the patients.

Hospital’s capacity structure can be divided into two categories based on the different resources. The categories are the leading and the following resources. Basically, the leading resources trigger the need for the following resources within the production line. Therefore, the capacity requirements of the following resources are generated based on the way the capacity is allocated to the leading resources. For example, in hospitals the patients, who need surgical operations, create the need for the operating theatres. The operating theatre capacity acts as the leading resource, which triggers the need for the following resources, such as beds and nursing staff. (Vissers 2005a, p. 119)

Green (2006, p. 305) argues that efficient capacity management in healthcare must deal with complexities, such as tradeoffs between the bed flexibility and the quality of care, demands from competing sources and types of patients, changing demands, and with the perspectives of administrators, physicians, nurses and patients, which often also differ. Utley et al. (2005, p. 150), in turn, argue that the decisions made at the level of *resource planning and control,* will have a high influence on the decisions made at the lower levels within the production planning framework. For example, hospitals can offer only limited amount of post-operative care at the time, as the bed capacity and the nursing staff work as the limiting factors. From the *patient volumes and control* perspective, this affects the management of the patient admissions and discharges at the organizational level. On the *patient planning and control* level, effects can be seen within the management of the individual patients during their post-operative stay in hospitals. (Utley et al. 2005, p. 150)

Vissers (2005a, p. 123) described some factors that affect to the patient inflows in hospitals. This has been illustrated in Figure 4. On the strategic planning level, new medical technology, such as surgery techniques, may influence the throughput of patients by shortening the length of stay in hospitals. The growing needs and the current structure of the population, in turn, determines the potential demand for the impatient care. Market share basically describes the competition within the healthcare industry. Nowadays, as private health organizations raise their positions as a service providers, the competition of patients is rising, and therefore, it is affecting on the patient inflow of the hospitals. On the tactical planning level, hospitals may improve the patient throughput with the efficient use of the existing capacity, such as beds, operating theatres and staff. (Vissers 2005a, p. 122)

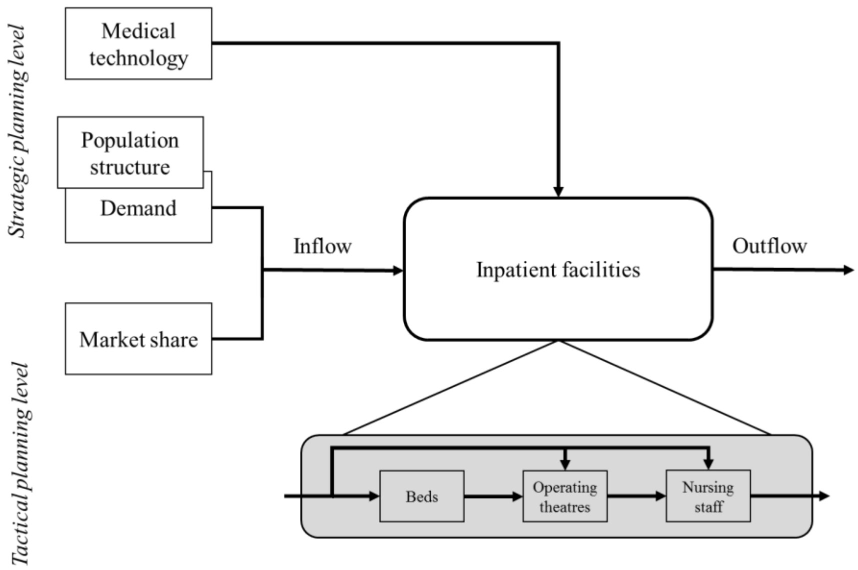

Figure 4. Variables included in the long-term projections of patient flows and resource needs in hospitals (adapting Vissers 2005a, p. 123)

Healthcare is a challenging environment from the capacity management point of view, as the healthcare facilities generally experience a high level variation in demand over the day, over the week, and even over the year (Green 2006, p. 301). In addition, the high contact environment, uncertainty in the patient length of stay, and the variability in patient cases, add complexity on the overall hospital management (Smith-Daniels et al. 1988, p. 890).

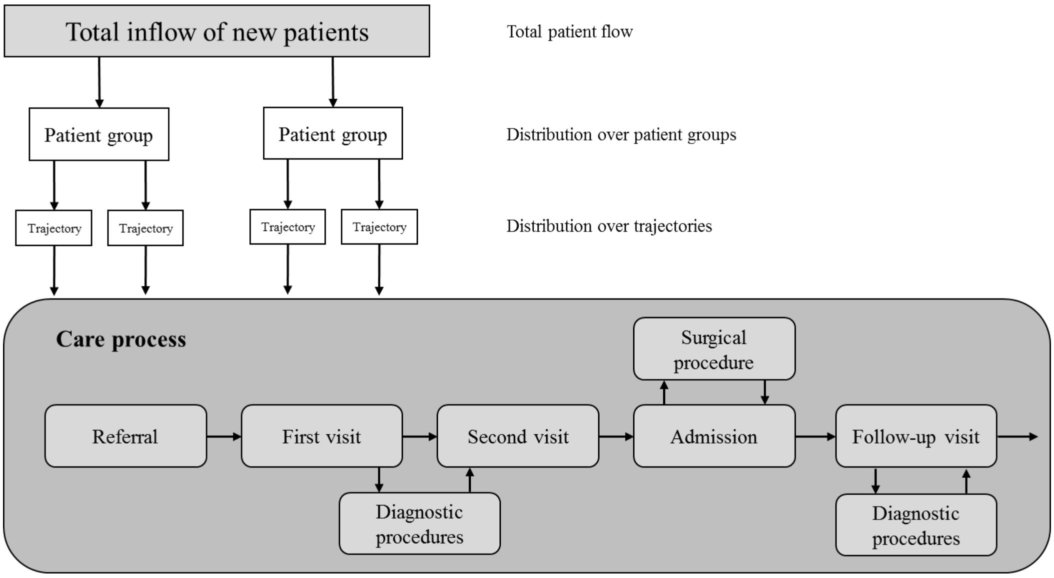

Figure 5. Outline for modelling demand in healthcare (adapting Vissers. et al. 2005b, p. 210)

Figure 5 by Vissers et al. (2005b, p. 210) illustrates the general care process and how the demand can be modelled in healthcare. The total inflow of new patients can be divided into multiple patient groups. Patients with similar diagnostics and conditions form a patient group, which usually follow a certain treatment path. Patient groups can be, for example, trauma patients, fracture patients or infection patients. Often patient groups will be divided on the basis how they use different resources. As an example, for the fracture patients it is common to use the plaster room. The different patient groups, in turn, can be broken down into a number of trajectories, which helps to expose the similarity between the resource usage and the routing of the patients. Different trajectories within a certain patient group can be, for instance, patients who need surgical operation and conservative treatment patients. (Vissers et al. 2005b, p. 209)

2.4 Process approach in healthcare

A simple process consists of things or events, which share a common progress-logic. The definition of a process includes some kind of presumption about the continuity and repetition. Processes are built in order to repeat similar things with routine methods, every time. (Lillrank et al. 2004, p. 93)

Several healthcare related studies have resulted that certain process management principles may be used to improve the efficiency of healthcare, without sacrificing the clinical quality (Vissers et al. 2001; Young et al. 2004; Torkki et al. 2006). With process management principles, hospitals are able to define and map patient processes, identify bottlenecks in service chain and designate process owners. For example, the usage of process mapping as a tool for identifying a problem in important patient flows, has often been proven successful. (Benner & Tushman 2003, p. 3; Hellström et al. 2010, p. 502)

In healthcare, patients are treated in supply chains or supply networks, which combine interventions and processes. Together those are linked into clinical pathways. However, there are a lot of situations in healthcare where a process approach is difficult to use. For example, in the ED, patient's condition may change unpredictably, and therefore planned processes and schedules cannot always be followed precisely. Sudden changes in tightly planned processes can effect on the operations of the whole supply chain. (Lillrank et al. 2011, p. 194)

By using the process mapping approach in healthcare, patients can be described as the objects of production going through the healthcare production system. (Vissers et al. 2005b, p. 205) Different points of services in the patient treatment process can be described as the episodes of care. These episodes describe different time-sequences of health related events, where the patient works either as a performer or as a subject. In turn, the process concept can be described as a set of steps, which are performed by one service organization. (Solon et al. 1967, p. 402; Lillrank et al. 2011, p. 195)

Lillrank et al. (2011, p. 196) used the term *'service events'* in order to describe the point where the episodes and processes meet. These service events are performed in interaction with a patient either by one producer, a person or a team. The aim of a single service event is to produce an output, which could be used as an input to another event. The difference between the process and the episode point of view comes from the planning and the scheduling of the production steps and events. In healthcare processes, the production steps follow an established medical or technical logic, which allows some sequences to be planned in advance. A single episode, in turn, can be unpredictable and it needs to follow its own process logic. (Lillrank et al. 2011, p. 196)

Lillrank & Liukko (2004, p. 44) divided the patient processes of the public healthcare services to three different classes: standard, routine and non-routine. Standard processes describe events, which are repeated in the same way every time. Routines are repetitions of cases, where the treatment process is similar, but input conditions may vary. Non-routine processes emerge when events are dissimilar. Division to standard, routine and non-routine cases is based on a fact that in healthcare, some of the patient cases are complicated and require more creativity and thus bigger amount of resources are aligned to those patients. The opposite are, of course, the cases, which can be repeated according to a certain routine with minimalized resources. (Lillrank & Liukko 2004, p. 42) Most of the processes in healthcare can be classified as non-routine processes, as the variation of patient cases is limitless. When the patients cannot be treated in the same way, it means that each of the treatment processes will become unique. From the process quality perspective, this means that the treatment quality objectives cannot be consistently adjusted. (Niemi et al. 2004, p. 13)

2.5 Process bottlenecks in healthcare

In order to examine the effects of congestion in the patient treatment process diligently, it is essential to discover the bottlenecks in the process. A principal assumption of Theory of Constraints, introduced by Eliyahu M. Goldratt (1984), is that there is always at least one bottleneck or constraint on each process, which temporarily limits the throughput (Goldratt 1984). In hospital processes, bottlenecks may increase the patient waiting time, the length of stay and reduce the total treatment efficiency.

Torkki et al. (2006) emphasized that the operating rooms are typically the bottlenecks of the surgical process, which supports the original argument from Vissers et al. (2001) that the time of specialists are the most essential bottleneck resource in hospitals. Peltokorpi et al. (2009a) concluded both of the previous arguments by suggesting that the staffed operation room time is an expensive bottleneck resource in the surgical process, and must therefore be used efficiently.

By Vissers (2005b, p. 59), the operating unit represents one of the most critical, important and expensive resources in the hospitals, because the work performed in operating rooms is very labor-intensive and involves expensive materials and equipment. In addition, the surgical interventions form a high percentage of the total hospital admissions. (Guerriero & Guido 2011, p. 89)

2.6 Congestion and crowding in healthcare

Congestion is commonly known as a term from manufacturing, telecommunications or transportation industries. The current literature uses the word *'crowding'* also to describe the problem. Congestion can be seen as a phenomenon in the production process, where excessive amounts of input cause a reduction of the output.

Färe & Svensson (1980, p. 1745) have defined congestion in production as follows: *"if a proper subset of production factors (inputs) is kept fixed, increases in the others may obstruct output"*. Cooper et al. (1996, p. 17), in turn, took two way approach to the phenomenon by stating that congestion appears "*when reductions in one or more inputs can be associated with increases in one or more outputs or, proceeding in reverse, when increases in one or more inputs can be associated with decreases in one or more outputs.*" Both the definitions have the same meaning, as they differ only in the way of measurement.

Congestion in the healthcare industry does not differ much from the other industries. The common characteristic of congestion in processes is that often there is a service provider who has limited economic resources to add capacity to the congested areas. This therefore causes problems in the process flow. According to Hall et al. (2006, p. 10), congestion is an unusual event within the healthcare systems, which results from the patient treatment delays within the treatment process.

Banker et al. (1988) showed that uncertainty and variability are increasing the prospect of the congestion in the production processes. This can be seen also in the healthcare industry and especially in trauma centers, where the future patient flows cannot be predicted and the variability in the patient cases is high. The crowding phenomenon has been widely studied, as the crowding of the emergency department has become a major issue, especially, in the United States (Trzeciak & Rivers 2003, p. 402; Twanmoh & Cunningham 2006, p. 54). One of the key missions of the ED is to provide immediate access to care for those patients with acute and chronic injuries and illnesses. Due the overcrowded emergency departments, hospitals are not able to provide decent care for all of its patients (Derlet et al. 2001, p. 151). When patient treatment delays are measured on the healthcare system level, the emergency departments can be seen as one the most challenging components as the patients arrive at the ED from various locations using multiple channels, including walk-in or ambulance. (Hall et al. 2006, p. 2)

According to Schoenmeyr et al. (2009, p. 1293) in the perioperative treatment process, congestion usually occurs when the amount of patients in pre- or post-operative locations exceeds a certain critical level. This means that patient treatment process slows down because the demand outstrips the available resources, such as the number of beds in wards.

Overcrowded inpatient wards, waiting rooms and treatment areas, loss in privacy and increased waiting times for medication or treatment can all be added to the patient suffering. From the employer’s perspective, long-lasting patient queues in different treatment units will burden and demotivate the employees. (Hall et al. 2006, p. 11) This has been also studied by Kc & Terwiesch (2009), who showed that congestion in hospital operations has a two-way impact on the behavior of the employee’s. They found that the increased workload usually made the employees more efficient at first, which raised the service level. However, the increased speed of performing individual tasks lasted only for a few hours, after which the amount of mistakes increased in the work performance. (Kc & Terwiesch 2009, p. 1496)

Congestion in the treatment process may also have a significant impact on the patient’s condition. When the treatment of a patient, who is listed on a surgical waiting list, is delayed, the patient’s condition might degenerate, and therefore require urgent medical attention. At this point, planned elective surgery might turn into emergency surgery. In addition, it is possible that the patient’s condition deteriorates to such an extent that the surgery is no longer possible. (Sobolev et al. 2006, p. 80)

2.7 Length of stay

Time is an essential factor in manufacturing as it measures the quality and the expenses of a product. When speaking of time in industrial management, it usually means throughput time - the time, in which a product or other object goes through a certain process. In case of healthcare, these objects are patients and the patient treatment time indicates the effectiveness of the process. (Lillrank et al. 2004, p. 138)

In addition, to the industrial management theories, several indicators have been developed to measure the service level of the healthcare services. The concept of *‘Length of stay’* has often been used in the current literature as a measurement of hospitals cost effectiveness (Siegel et al. 1994), resource management, quality of the treatment, and patient satisfaction (Gorelick et al. 2005). LOS can be defined as the length of an inpatient episode of care, starting from the moment of admission and ending at the moment when the patient is discharged. The total LOS time can be divided into smaller parts in order to measure the time spend on the different treatment process steps (Peltokorpi et al. 2011, p. 3).

The perioperative process can be used to define the pre- and post-operative LOS in more depth. The perioperative process is the time period describing the patient's surgical procedure. Perioperative process can be divided into three time periods, which are the pre-operative, intra-operative and post-operative care. Pre-operative care starts when the patient is scheduled and admitted to the hospital for the procedure. At this stage, the patient is physically and psychologically prepared for the surgical operation, according to their needs. The pre-operative period ends at the time the patient arrives at the operating unit. The intra-operative period starts from the time the patient is admitted into the operating unit. At this point the selected anesthesia and the surgical operation are conducted. Intra-operative period ends as the patient is transported to the recovery room or post-anesthesia care unit (PACU). (Lukkari et al. 2007, pp. 20-21) Post-operative period is the last stage of the process and it extends from the time the patient arrives at the recovery room, until the time the patient is discharged from the hospital (Lukkari et al. 2007, pp. 23-24).

From the theoretical point of view, the congestion in hospitals contributes to the length of stay of the patients. The queuing theory by Little (1961) assumes that as the work in process (WIP) inventory increases with a certain service rate, the throughput time increases at a constant and predictable rate. As this thought is applied to the healthcare processes, it would basically mean that if the number of patients in the input flow is increasing and the output rate is not increasing, the total LOS will increase. Therefore, as patient throughput time is an essential factor in trauma management, it is important to clarify how the congestion contributes to the length of stay in Töölö hospital.

3 TÖÖLÖ HOSPITAL

This chapter introduces the case environment, which in this study was the trauma center located in Töölö hospital. The history of Töölö hospital reaches far to the beginning of the 1930's when a new hospital project was launched as a joint venture of the Finnish Red Cross and city of Helsinki. The new hospital opened its doors on 24th of September in 1932 and it was titled by C. G. E. Mannerheim, who was leading the Finnish Red Cross at the time. (Väisänen et al. 2014, p. 17)

Nowadays, Töölö hospital is a part of the Helsinki University Central Hospital. From the administrative side, Töölö hospital belongs to the Hospital District of Helsinki and Uusimaa (HUS), which is a joint authority formed by 24 municipalities. The trauma center located in Töölö hospital is the largest unit in HUS area specializing in the treatment of trauma patients. In addition to patients arriving from the district of Uusimaa, patients with severe injuries from the hospital districts of Kymenlaakso and Etelä-Karjala are also sent to Töölö hospital to receive medical care. As a single trauma center, Töölö hospital is also one of the largest in Scandinavia. (HUS 2014)

Töölö hospital operates 24 hours per day, seven days a week. The hospital serves patients within the specialties of Orthopedics and Traumatology, Neurosurgery, Hand surgery, Oral and Maxillofacial surgery and Plastic surgery. However, the biggest part of the total activity of the hospital is composed of daily surgical operations (HUS 2014). Trauma patient care consists of chain of care phases, which are provided by several units inside the hospital. These are the Emergency Department, the Intensive Care Unit (ICU), Operating unit and pre- and post-operative ward units.

3.1 Emergency department

The emergency care area in Töölö hospital consists of three different units, which are the emergency department, the intensive care unit and the emergency ward.

Patients arrive at the emergency department mainly with a referral, either by walking or with an ambulance. The emergency department operates daily 24 hours and it is staffed with three trauma physicians on duty, who work together with a number of nurses. The first physician on duty is specialized in general medical care. The second physician on duty is usually a specializing physician or a specialist within the specialty of orthopedics or traumatology. The third physician is an oral and maxillofacial surgeon. Physicians on duty are in charge of patient’s first aid and immediate examinations.

Triage is the first stage, which the patient passes through in the emergency department. It is a fundamental process for the safe and efficient use of the emergency department. In Triage, patients are divided into different urgency classes depending on the condition and treatment needs of the patient. In Töölö hospital, Triage is coordinated by the department secretary and the Triage nurse.

In the ED, the patient receives the first aid and they are thoroughly examined. Examinations, such as X-ray and laboratory tests can be conducted directly after the arrival. Also several treatments can be done directly within the ED. For example, in case of fractures, plaster care can be done at the ED, after which the patient can be discharged.

The trauma physician on duty decides whether the patient has a need for surgical operation. Patients who need surgical operations are divided into different urgency classes depending on the significance of the injury and the condition of the patient. Töölö hospital is using the color codes to separate the surgical patients on the surgery list. These colors are violet, red, orange, yellow and green. Different urgency classes have been illustrated in Table 2.

Table 2. Patient classification

Urgency class	Target time	Specification
Violet	< 2 h	The patient needs immediate operative care. A state, which threatens the patient's life.
Red	< 8 h	Urgent operative care needed (e.g. compound fracture of lower limb).
Orange	8-24 h	Patient needs operative care, but patient doesn't need immediate care. Over 24h delay in the care may weaken patient's prognosis or the injury recovery.
Yellow	24-48 h	Patient needs operative care, but patient doesn't need immediate care. Surgical operation can be delivered after 24h without immediate influences to patient's prognosis or injury recovery. Patient cannot be discharged at this point.
Green	1-7 days	Patient needs operative care, but can be sent home to wait for the surgery.

In 2013, the total amount of emergency visits in the ED was 13 926. This count includes only the pure emergency visits, as some of the patients arrive at the ED for an additional visit. From the ED patients are sent either to the emergency ward, inpatient wards, other hospitals, or home. Based on the statistics of the year 2013, approximately, 15 patients were transferred to inpatient wards per day.

3.2 Wards

Töölö hospital has 9 inpatient wards, an intensive care unit and a neurosurgery intensive care and observation unit. All the wards have a certain medical orientation. The data analysis of this thesis focuses only on patients located in the inpatient wards two, four and five. These inpatient wards are specialized in patients within the specialty of Orthopedics, Traumatology and Hand surgery. All the inpatient wards have bed capacity for 25 patients.

The emergency ward works as a holding and treatment place for patients who need surgical operations. The surgical patients arrive at the emergency ward to wait for the surgery mainly with a referral. The patients arrive at the emergency ward either from the ED, outpatient clinics or from home. In addition, the non-surgical patients, such as patients who have been in a traffic accident and need to be monitored, are also treated at the emergency ward. The emergency ward has bed capacity for 15 inpatients in total. After the surgical operations, patients are transferred to ICU, inpatient wards, to other hospitals for the follow-up treatment or directly home.

3.3 Operating units

In Töölö hospital, the patients arrive at the operating units either from ED, intensive care unit, different inpatient wards, multipurpose outpatient department, or occasionally also from other hospitals. Töölö hospital has two separated operating units, where orthopedic and trauma surgeries are performed. These two separated operating units have seven operating rooms in total, which all operate during the weekdays.

The vast majority of the patient care in the clinical unit of orthopedics and traumatology consist of the surgical operations of the trauma patients. The orthopedic operating unit has four operating rooms, from which two are focused on elective surgeries, such as back and lower limb surgeries, during office hours. The other two operating rooms are reserved for the emergency surgeries. All the operation rooms are coordinated by the third trauma physician on call and orthopedic senior, which is called the L-senior. During the afternoon and evening hours, 3pm-10pm, the orthopedic operating unit operates with two or three operating rooms, depending on the queuing situation. As during the night time the risk level in surgeries is higher, between 10pm-8am the orthopedic operating unit operates mainly with one operating room. During the night time, the surgical operations are focused on critical patients. In 2013, the orthopedic operating unit had 6 131 surgical operations in total, from which around 80% were emergency surgeries. The amount of elective surgeries in 2013 was 1 550 in total.

The so called B-operating unit is located on the other side of the hospital. Two of the operating rooms, located in the B-operating unit, are used by the clinical unit of orthopedics and traumatology and the hand surgery unit. These ORs focus on elective and emergency surgeries, only during the office hours. The last operating room located in the B-operating unit is used by the plastic surgery department.

3.4 Access to surgery

After a patient is thoroughly examined in the ED, the surgeon on duty makes the decision, whether the patient needs surgical care. Patients are placed on the surgery waiting list if are not in need of an immediate operation. Patients listed as green line patients are sent home to wait for the surgery, which date has determined. The orange and the yellow line patients are transferred either to emergency ward or to some of the inpatient wards to wait for the surgery. The placement of these patients depends on the occupancy level of the wards. Violet and red line patients are handled as emergency cases and therefore those are sent to the operating room upon arrival or within a few hours of arrival. In some of the critical cases, the patient's condition does not enable immediate surgical operation and therefore patients might be sent to the intensive care unit for state stabilization. Before the surgery, all patients are assessed by the anesthesiologist who decides whether the patient is suitable for surgery. If patient's condition does not fulfill the surgery criteria, the scheduled operation will be postponed.

Patients with non-life-threatening conditions, which means green and yellow line patients, the enrollment for the surgery is done on a first-come, first-serve basis. In turn, the patients with life-threatening conditions are registered on a priority wait list. Basically, this categorization means that patients with a higher priority will be selected for the service ahead of those patients with a lower priority, regardless of when they are placed on the list. Emergency cases usually mix up the surgery lists and cause delays and possible cancellations of scheduled elective operations.

The surgical planning in Töölö is done by using a basic Excel timetable and Opera - operating room management software. Surgical operations are described as different colored blocks on the timetable. The surgery list is planned by the L-senior and the third trauma physician during the daytime. In the afternoon and during the evening hours, the list is coordinated by the third trauma physician on call. All the emergency surgeries planned for the day are discussed in the morning meeting of the emergency area. The first surgeries of the day are mostly booked for the green line patients as the surgical operations are more straightforward and the condition of the patient is more foreseeable.

As described above, there are several steps in the treatment process of the trauma patients. From the managerial perspective, the variability in the patient cases and the unpredictability of the patient flows create challenges to the daily operations of the hospital. In Töölö hospital, the increased demand seems to create congestion in the surgical processes, which also increases the surgery waiting times within the non-acute patients. Therefore, new information is needed to support the decision making, so that the process flows could be stabilized. The problem setting has been discussed more in Chapter 4.2.

4 METHODOLOGY

Case study was used as the primary research method in this master's thesis. This research method was chosen, as the main objective of a case study is to collect as diverse data as possible and do a rigorous analysis of the research subject. (Yin 2002, p. 13) As a part of this study, qualitative and quantitative material was collected in order to understand the effects of congestion within the case environment.

Yin (2002, p. 13) defines a case study as an empirical research, which investigates a concurrent phenomenon within its real-life environment, especially, when the boundaries between the handled phenomenon and the theoretical framework are not obvious. As a research strategy case study is a comprehensive method, as it covers the logic of design, data collection and specific approaches to the data analysis. (Yin 2002, pp. 13-14) According to Eisenhard (1989, p. 534), case study as a research strategy focuses on the comprehension of certain dynamics and effects, which are present in the selected business environments or activities.

A case study is a preferred approach when 'how' or 'why' questions need to be answered. In business world, case studies are often used when a single organization or some aspect of the organization is studied. In addition, a case study is an effective method in order to identify factors causing a certain phenomenon within the organization. (Ghauri & Gronhaug 2010, pp. 109-110) Case studies usually combine data collection methods, such as archives, observations, interviews and observations. The evidence may be, for example, words (qualitative) or numbers (quantitative). (Eisenhard 1989, pp. 534-535) The research methods used in this thesis were the descriptive literature review, the quantitative analysis of the patient data and qualitative interviews.

4.1 Regression analysis and other quantitative methods

The central tendency and the spread are most commonly used measures describing the statistical data. The central tendency can be measured by using several measures, from which the arithmetic mean and the median are maybe the most used ones. The arithmetic mean, or simply the average, is the sum of the sample divided by the number of subjects. The median, in turn, describes the value falling in the middle, as the data sample is ordered from the lowest to the highest and split into two parts, which have an equal number of subjects. By comparing the average and the median, an idea of the form of the distribution is obtained. In normal distribution, the average and the median are the same, but when they differ, the distribution is oblique. (Agresti & Finlay 1997, pp. 45-48) The selection of the measure for the central tendency depends mostly on the purpose of the study. The median is more suitable, if the most common occurrence within the sample is searched. In turn, if the more rarely occurring cases needs to be counted, the average is more truthful.

The variance and the standard deviation are the most commonly used measures of the spread. The measurement of variance is calculated in square units, which makes it difficult to interpret. The standard deviation, in turn, is the square root of the variance. In data analysis, the standard deviation is more practical to use as the unit is the same with the original variables. Basically, the standard deviation tells how much on average the findings differ from the mean value. (Agresti & Finlay 1997, pp. 57-58)

The regression analysis can be used to study the effect of the independent variables (one or more) on the dependent variables. The advantage of the regression analysis is that it can be used to investigate the effects of several variables and each variable’s separate effect when the effects of other variables have been removed. (Balnaves & Caputi 2001 pp. 156-160) Variables used in the regression analysis should be at least at the interval scale. Variables from the ordinal and nominal scale can also be used, once the so called dummy variables are created based on the original variables. The dummy variables can only have values zero or one, which describe whether the situation occurs (1) or not (0). (Fox 1997, p. 124) Usually, the regression model describes the dependent variable only partially. The R^2-value, also known as the coefficient of determination, is the ration describing the amount of variance of the response variable explained by the regression model. The R^2-value varies from zero to one and the bigger the percentage of the R^2 is, the better the regression model is describing the dependent variable. (Balnaves & Caputi 2001, p. 161)

4.2 Problem setting

Töölö hospital has a long history on the trauma patient management. In scale of the Finnish public healthcare, the importance of the hospital of Töölö is reflected by the fact that, in Finland, there is no other hospital, to which the trauma patients could be send forward. As in any other hospital, one of the biggest problems in Töölö hospital, from the operations management perspective, is that it is almost impossible to forecast the future demand. Especially, in trauma management as accidents happen unpredictably, the variability of patients is high and independent on the timing.

A trauma patient is defined as a patient with a trauma injury, who needs surgical care, either operative or non-operative, within three weeks. The trauma patient care process consists of four phases, which are the emergency department care, pre-operative care, operating unit care and post-operative care. In order to understand the complexity of the problem, we need to understand the patient flow in Töölö hospital. The main phases of the trauma patient treatment process are illustrated in Figure 6.

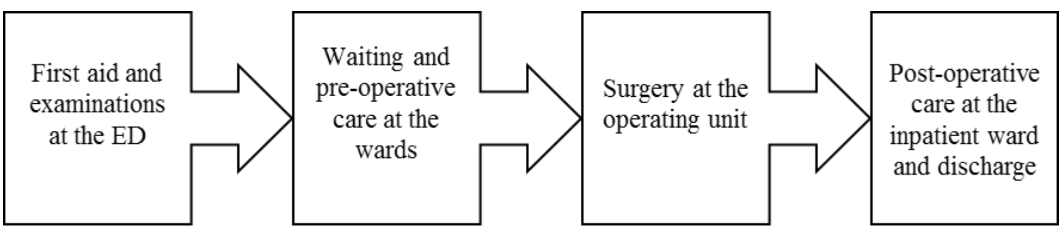

Figure 6. The main phases of the trauma patient treatment process (adapting Alho et al. 2004, p. 4)

As it was mentioned in the literature review, the effects of congestion and overcrowding have been studied more from the ED point of view. However, in Töölö hospital the emergency department is not seen as the main bottleneck in the treatment process. The patient throughput times in Töölö emergency department are the fastest within the HUS region, which shows that patients are quickly transferred to the follow-up treatment.

From the process management point of view, the operating unit can be seen as the main bottleneck of the treatment process, as its utilization rate controls the input and the output flows of the surgical patients. In Töölö hospital, the congestion has been described as an increase of the surgery waiting times within the yellow line patients. For the yellow line patients, it is essential to maintain the steady process flow, as they form the majority from the total patient flow. In addition, these patients are always transferred to wards to wait for the surgery, which therefore increases the usage of the hospital resources. The lengthened pre-operative LOS may cause changes in the patient's condition, which increases the surgery risk and possibly also the recovery time. Therefore, new information is needed to support the decision making in the operations management, so that the operational and the resource decisions can be made more agile in order to minimize the amount of congestion and the patient queues in the trauma patient treatment processes. The different factors, which may have an influence and cause congestion in the patient treatment process, are discussed in the next chapter.

4.3 Preliminary interviews to create hypotheses for data analysis

The qualitative part of this thesis was done by interviews. At the beginning of the study, the patient treatment processes were mapped by interviewing one of the emergency physicians and four different managerial nurses working in the emergency department, wards and operating units. The secondary objective for the interviews was to find out the reasons and different factors causing congestion from more practical perspective.

After the data analysis and the creation of the predictive operating model, the results were presented to one of the chief physicians in order to collect feedback from the usability of the new indicators. The questions were created by the author and the interviews were conducted with each interviewee personally. The actual conversation and answers were recorded by note taking. The list of personnel interviewed for this study has been presented in Appendix III.

The different factors which may explain or anticipate congestion in the trauma treatment process were selected mostly based on the interviews. The factors can be divided into three main categories according to chronological order:

1. Emergency department related factors
2. The operative care related factors
3. Inpatient care related factors

Factors within these categories have been collectively presented in Figure 7. These factors can be measured by using the data from the hospital information systems.

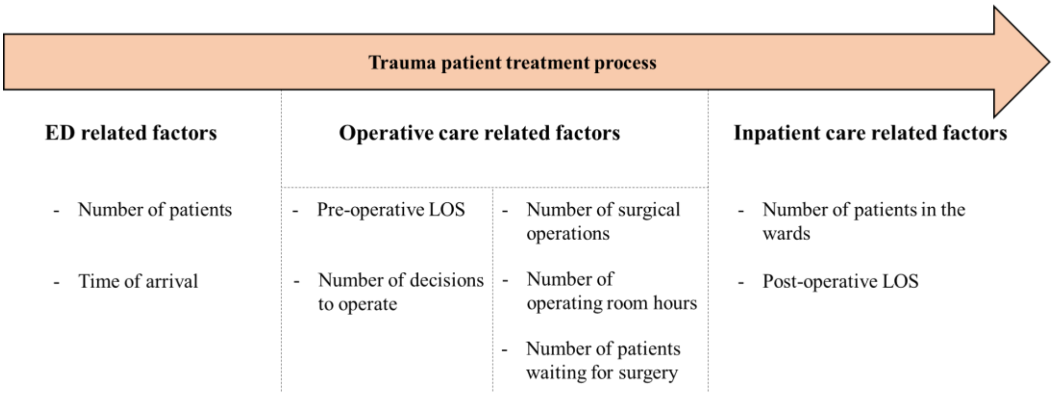

Figure 7. Factors that may explain or anticipate congestion in the trauma patient treatment process

In hospitals, congestion can be difficult to be explained by using single factors as most of the factors are extremely independent and cannot be coordinated by the operations management. For example, the patient and patient group volumes in the ED are unforeseeable in trauma hospitals as the accidents happen unpredictably. However, some of the factors can be influenced. For example, the number of the surgical operations per day is dependent on the utilization of the operating rooms and personnel capacity.

Hypothesis is that the congestion is caused by several different factors contributing to the trauma patient treatment process. As mentioned in the theoretical framework, the pre-operative LOS is a critical factor, which may correlate significantly with the patient's condition. In the trauma patient treatment process, the surgery waiting time is in a central position, which is affected by both the input and the output factors. Therefore, the pre-operative LOS is used as the dependent variable in this study. The other factors, such as emergency visits or number of surgical operations, are used as independent variables, which may explain the changes in the surgery waiting time.

4.4 Data collection

The purpose of the data collection in this study was to replicate the congestion phenomenon by using the patient data and to examine different levels of research variables. The historical data for this study was collected from different hospital information systems and it contained patient information from the emergency department, operating units and five different wards. The data was collected from 36 months within the time period of 1.10.2011–30.9.2014 for each of the patients who visited Töölö hospital during that time period. The collected data contained information, for example, about the admission date and time, type of visit, diagnosis, urgency, surgical timestamps and operations, and ward episodes. A collective list about the data items collected for this study has been presented in Appendix II.

The received raw data included 41 908 ED visits, 18 415 surgical operations and 23 827 inpatient ward treatment episodes (see Figure 8). The ED data was limited to include only the emergency visits as many of the patients arrive at the follow-up check through the ED. In addition, some patient consultations were made by using the telephone, which were counted as a patient visit within the data. The ED data was additionally filtered to include only patients from the specialty of orthopedics and traumatology. After these limitations, the total number of emergency visits was 28 206.

The data collected from the operating unit was also limited to include only surgical operations from the specialty of orthopedics and traumatology, which lowered the total amount of surgical operations to 12 813. This amount includes all the patients from different urgency classes, from which the yellow urgency class is the biggest by 6 542 surgical operations.

The data from the wards included patient information from the emergency ward, intensive care unit, and from the inpatient wards two, four and five. The selected inpatient wards are focused on the patients from the specialty of orthopedics and traumatology (O&T). The high number of inpatient ward episodes can be explained by the fact that the patients may change wards several times within the same treatment period.

The patient treatment chains were created, as some of the measurements could be done only by combining the data from different units. In order to avoid the duplicates and the data distortion, the treatment chains were created only for the yellow urgency class patients. The patient number was used as the connecting factor between the data from different units. As some of the patients had several ED visits within the selected time period, the treatment chains were created by connecting the patients, who had their first surgical operation within seven days after the first visit. This also means that if the patient had several surgical operations, only the first operation was selected. From the inpatient ward episodes, only the patients who had both, arrival and departure time, were selected. Patient treatment chains were successfully created for 4 536 yellow urgency class patients.

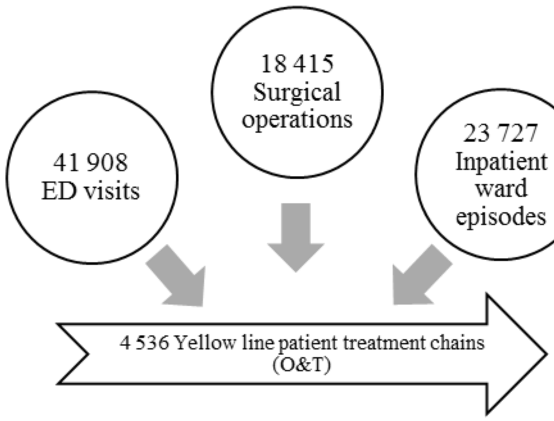

Figure 8. Data defined

4.5 Data analysis and definition of variables

In this thesis, the statistical analysis was used in order to illustrate the variation in the patient treatment processes and volumes, and to demonstrate the performance of the hospital during the congested times. In addition, data analysis was used to examine the correlations between the congestion and the different process variables, and to identify the most suitable predictive indicators for the operations management in order to avoid the congestion in the future.

The statistical analysis was based on the calculations of the central tendency, spread, distribution, and the minimum and maximum values. The average was mainly used as the measurement of the central tendency. In this study, the averages were more informative than the medians, as many of the used variables, such as the pre-operative LOS and amount of emergency visits, are Poisson-distributed. This can be explained by the fact that there are days when patients are waiting longer for the surgery, and days when the ED is more crowded. In this case, the median would outline the tale, which consists of the highest or lowest values. Microsoft Excel and IBM SPSS software were used as the statistical tools in this thesis.

The different variables measured in this study have been divided into two categories, which are the input and output variables. The input variables describe the independent variables and the output variables, in turn, the dependent variables. As it was mentioned before, the congestion has been seen as an increase in the surgery waiting times within the yellow urgency class. Therefore, the pre-operative LOS was selected as the dependent variable in this study to operationalize the existence of congestion in the trauma process. The pre-operative LOS was calculated from two different points for the yellow urgency class patients. The more statistically accurate pre-operative LOS was measured by using the data from the operating unit as it included the timestamp when the decision to operate was made. The second pre-operative LOS was calculated by using the created patient treatment chains. In this case, the starting point for the pre-operative LOS was set to the time when the patient arrived at the ED. The ending point for the pre-operative LOS was set to the time when the patient entered to the operating unit.

Some additional limitations needed to be done when the output variables were calculated. The Opera-decision describes the time when the patient is put on the surgery list by using the Operating room management system (Opera). One of the problems when calculating the pre-operative LOS from the Opera-decision, was that in some cases the Opera-decision was registered not until the patient had arrived at the operating unit. This meant that the pre-operative LOS was negative and thus needed to be outlined. In both cases, the maximum time for the pre-operative LOS was set on 240 hours, which is equivalent to ten days. The number of outlined cases in the surgery data was 31, which is less than 0.5% from the entire sample. In the patient chain data, the number of outlined cases was 29, which is roughly 0.6% from the sample. By removing the highest values, the more accurate averages could be measured. Table 3 illustrates the different output variables measured in this study.

Table 3. Output variables

Variable	Definition
1. Pre-operative LOS (Opera)	The pre-operative length of stay measured from the decision to operate
2. Pre-operative LOS (ED visit)	The pre-operative length of stay measured from the emergency department visit

The role of the input variables was to evaluate how the independent process measures could explain the emergence of congestion measured by pre-operative LOS in trauma care. Table 4 presents collectively the input variables measured in this study. The measurement of the selected variables was limited to include only patients within the specialty of orthopedics and traumatology. The measurements were done for each of the days within the time period of 1.10.2011–30.9.2014. As the operating unit can be seen as the bottleneck resource in hospitals (Vissers et al. 2001; Torkki et al. 2006; Peltokorpi et al. 2009a), most of the measured input variables were selected based on the information collected from the operating unit.

Table 4. Input variables

Variable	Definition
1. Emergency visits	Total amount of emergency visits per day
2. Opera-decisions	Total amount of O&T surgery decisions per day
3. Yellow urgency class Opera-decisions	Total amount of yellow urgency class surgery decisions per day
4. Surgical operations	Total amount of O&T surgeries per day
5. Yellow urgency class surgical operations	Total amount of yellow urgency class surgeries per day
6. Operating room hours	Amount of operating room hours used for the yellow urgency class patients per day
7. Length of the surgery queue	How many yellow urgency class patients were waiting for the surgery at the end of each day
8. Ward occupancy	Amount of patients in wards at the end of each day
9. NFB20 patients	Amount of patients with the operation code NFB20
10. NHJ10 patients	Amount of patients with the operation code NHJ10

The total amount of emergency visits describes the daily volume of the O&T patients arriving at the ED. The number of decisions to operate, in turn, were measured by using the Opera-timestamp. The amount of surgical operations measures the daily volume of the operating unit. In cases of Opera-decisions and surgical operations, it was additionally measured that how many of the Opera-decisions or surgical operations were made within the yellow urgency class.

The Operating room hours describe the amount operating room hours used for the yellow urgency class patients per day. The total hours were calculated based on the time the patient arrived at the operating room until the time the surgical operation was ended and the patient was transferred to the recovery room. The length of the surgery queue (SQ) was calculated for each of the days based on the amount of Opera-decision and the surgical operations made on that day. The surgery queue indicates the amount of yellow urgency class patients waiting for the surgery at the end of each day.

The ward occupancy describes the amount of patients in the wards. As the raw data collected from the wards included the arrival and departure times of the patients, the cumulative amount of patients could be calculated for each of the days. The cumulative amount of patients was calculated based on 23 568 inpatient ward episodes. The sample in this case is somewhat smaller than in the original raw data, as some of the patients did not have the time of departure, and therefore those were outlined from the calculations.

As the yellow urgency class includes several different surgical operations, it was also examined, whether the congestion contributes with or is influenced by certain patient groups within the yellow urgency class. The selected surgical operations are the most common surgical operations made for the yellow line patients within the specialty of orthopedics and traumatology in Töölö hospital. These selected surgical operations are explained below:

- NFB20 – Cemented hemiarthroplasty
- NHJ10 – Internal fixation of fracture of ankle using plate, wire, rod, cerclage or pin

4.6 Data processing steps

After the raw data was cleaned, patient chains were generated and the different variables were selected, several different volume based measurements were calculated in order to have an impression about the daily volumes and different throughput times. After the volume measurements were done, throughput times of different process steps were calculated and compared within the yellow urgency class. The calculations of the pre-operative LOS were additionally made for the selected surgical operations in order to have more specific results from the yellow urgency class.

After the previously mentioned data measures, the effects of congestion were examined by using different data processing methods. From a three-year data sample, it was relatively difficult to discover how the single factors were indicating congestion on a daily level within the yellow urgency class. Therefore, the historical data was first examined on the weekly level as the effects of congestion have been seen more long-lasting. The pre-operative LOS, measured from the Opera-decision, was selected as the main dependent variable, as the data sample was more comprehensive and the source of the information was more reliable.

The average weekly process flow within the trauma patient treatment process was examined by calculating the average values for the input and output variables. The years 2012 and 2014 were selected as the years of the example, as based on the data the average pre-operative LOS was higher on those years. The weekly values were compared with the average value, which were calculated based on the whole year. A top five sample was taken from both of the years, which have been illustrated in the results chapter in Table 9 and Table 10. These weeks were chosen by selecting the weeks with the highest average pre-operative LOS.

In the data analysis phase, the correlations between the independent and the dependent variables were examined by using the correlation coefficient. Measurements were done on a daily and weekly level in order to find the best correlations between the variables. The results have been presented in Chapter 5.3. Based on the analysis made from the single variables on a daily and weekly level, a multiple variable regression analysis was done as the congestion in the treatment process is caused by multiple factors. In addition, in order to create more a predictive and agile model for the operation management, the effects of the different factors needed to be examined and combined.

As one of the aims of this study was to find a predictive indicator for the operations management, a predictive pre-operative LOS was also calculated as a weighted average based on the following day's Opera-decisions and the average pre-operative LOS. In addition, it was considered whether the previous day's emergency visits, Opera-decisions or surgical operations were influencing today's pre-operative LOS. Therefore, the cumulative amounts were calculated by adding the previous day's emergency visits, Opera-decisions and surgical operations to the today's amount. This has been illustrated in Figure 9. The emergency visits were summed up from four previous days and the Opera-decisions and surgical operations from three previous days.

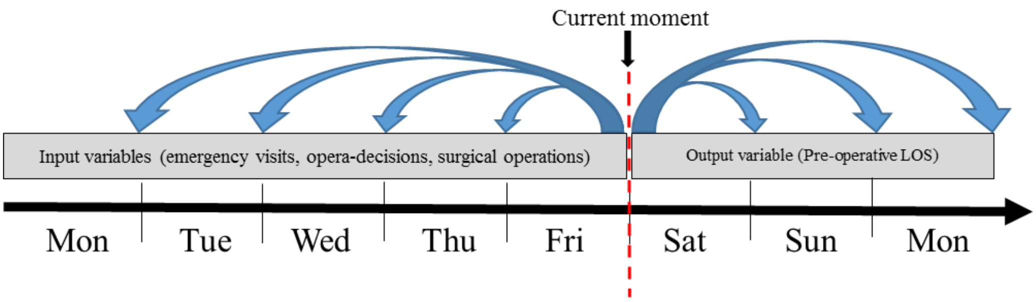

Figure 9. Cumulative calculations for the input and output variables

Before the regression analysis correlations between all the calculated variables were examined on a daily level by using the correlation coefficient. If some of the independent variables had strong correlation between each other (e.g. r>0.90), the other of the variables was removed from the analysis. For example, the length of the surgery queue was calculated based on the Opera-decisions and surgical operations made within the yellow urgency class and thus the correlation between these variables was relatively high. Therefore, the amount of Opera-decisions and surgical operations were outlined from the regression model.

5 RESULTS

The result chapter has been divided into five different subsections. The first subchapter describes the results from the process mappings, which were made based on the interviews. The different urgency class processes were mapped in order to have more detailed impression from the current operating model of Töölö hospital. The second subchapter focuses on showing the results from the volume based data measures, which describe more the daily operation of the hospital and the patient flows in the different units. The third subchapter collects the results from the data analysis where different factors were compared with the pre-operative LOS in order to find the actual factors, which may explain or anticipate congestion in the treatment process.

The fourth subchapter sums up the results from the regression analysis, which was conducted to show the actual causality between the selected variables. The actual results from the regression analysis are presented in Appendix VII. The fifth result chapter illustrates the creation of the predictive operating model and demonstrates the functionality of the model with a data example from June 2014.

5.1 Trauma patient treatment process

Trauma patient process consists of several care phases, which are seamlessly connected together in order to provide the best medical care as possible. The operational units are the ED, the intensive care unit, the operating unit and the pre- and post-operative ward units. A description of the trauma patient treatment process was created based on the interviews and the main phases are described below in Figure 10.

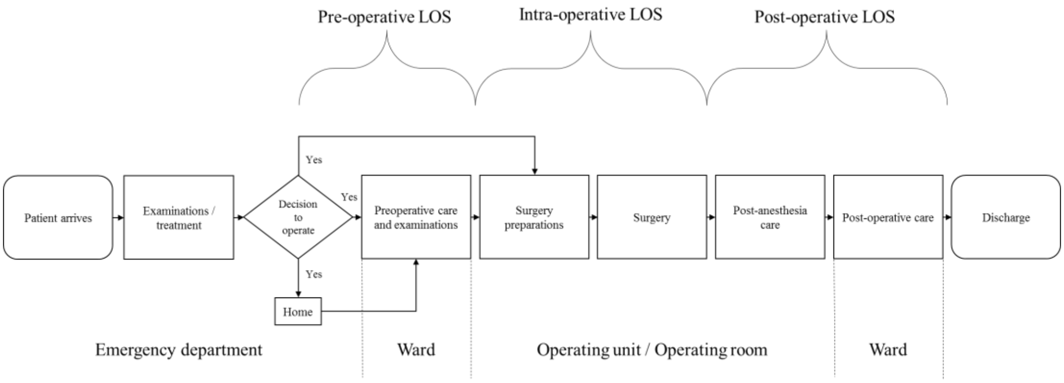

Figure 10. The main phases of the trauma patient treatment process

Figure 10 compiles the basic components of the trauma patient process in Töölö hospital. The basic treatment process is the same for all of the patients, but as mentioned before in Chapter 3.4, the access to surgery varies between different urgency classes. After the decision to operate has been made, the non-urgent cases are usually sent home or to some of the wards directly from the ED. In turn, in the urgent patient cases, a so called fast track is used, which means that the patient is transferred directly to the operating room. Therefore, the pre-operative time is also considerably dependent on the patient group. From the process flow point of view, it is clear that if there are a lot of patients who have to use the fast track, the pre-operative time will be longer for the lower urgency class patients. The comprehensive process mappings for the red, yellow and green patient groups have been illustrated in more detail in the Appendices (see Appendix IV, V and VI).

5.2 Data measurements

Table 5 illustrates the basic volume measures calculated on a daily level. The measurements were done for each of the days within the three-year time period. In order to show the scale and the daily variance of the patient data, the standard deviation, minimum and maximum values were calculated additionally for each of the variables.

Table 5. Basic volume measures during 1.10.2011–30.9.2014

	Total [n]	**Average** [per day]	**Median** [per day]	**Standard deviation** [per day]	**Min** [per day]	**Max** [per day]
Number of days	1 096					
Emergency visits [n]	28 206	25,7	25,0	7,3	6	57
Opera-decisions [n]*	6 532	6,0	6,0	2,6	0	15
Surgical operations [n]*	6 542	6,0	6,0	2,0	0	13
Operating Room hours [h:mm]*	6 542	17:45	17:39	6:07	0:00	41:07
Length of the surgery queue [n]*		9,0	8,5	4,0	0	22
Amount of patients in the emergency ward [n]		8,7	9,0	2,7	1	16

* Measured only for the yellow urgency class patients

It can be seen that on average the same amount of Opera-decisions and surgical operations are made daily within the yellow urgency class, which, from the process management point of view, describes an ideal situation. However, as the length of the surgery queue reveals, there are approximately nine yellow line patients waiting for the surgery on a daily average. Even though the yellow line patient volumes are high, it is predictable that there are days when not a single yellow patient is added to the surgery list or operated. However, from the three-year time period, the number of these kind of days was really small, as there was only five days when Opera-decisions were not made and two days when yellow patients were not operated. This, of course, describes well how the yellow line patients are keeping Töölö hospital busy. If the inflow of patients arriving at the ED stayed the same every day, it would basically mean that almost every fourth patient arriving at the ED would belong to the yellow urgency class.

The operating room hours describes how much on average the yellow line patients are daily using the operating room resources. Within the specialty of orthopedics and traumatology, roughly 55% from the daily OR hours in the orthopedic operating unit were used for the yellow line patients. Table 5 also reveals that during the three-year period, there was not a single day when the emergency ward was totally empty from the patients. For most of the patients, the emergency ward works as a waiting area before the surgery, as after the surgery patients are usually transferred to the inpatient wards. Therefore, it is obvious that the daily average correlates with the length of the surgery queue.

Table 6 illustrates the basic throughput measures for the yellow line patients from different parts of the trauma patient treatment process. The post-operative LOS was not measured as any coherent timing or a rule for the patient discharge existed in Töölö hospital. After surgical operations, some of the patients are often transferred to other hospitals for the post-operative care, which therefore would distort the measure outcomes.

Table 6. Basic throughput measures

Yellow line patients	**Number of cases** [n]	**Average** [h:mm]	**Median** [h:mm]	**Standard deviation** [h:mm]	**Min** [h:mm]	**Max** [h:mm]
Time spend at the ED	4 536	3:11	2:48	1:44	0:32	12:33
Time from ED visit to Opera-decision	4 507	13:24	2:22	28:45	0:07	176:46
Time from ED visit to surgery	4 536	43:14	28:01	38:35	0:59	185:33
Time from Opera-decision to surgery	6 501	33:57	23:02	33:25	0:02	238:12
Length of the surgery	6 542	2:00	1:33	1:39	00:01	16:14

It can be seen from Table 6 that the average time from the ED visit to the Opera-decision is quite high when it is compared with the median value. Some of the cases can be explained by fact that the patient monitoring may continue in the inpatient wards and the Opera-decision is done after the final diagnoses are ready. Based on the data from 4 536 patient chains, for 789 patients (17%), the Opera-decision was made after the patient had already been transferred to the inpatient ward. This, of course, increases the average time measured from the ED visit to the Opera-decision. From the operations management perspective, it basically means that there is no such specific point in the treatment chain where all of the Opera-decisions are made. This can be seen also from the minimum value of the Time from Opera-decision to surgery, which shows that the patient was added to the operating room management system two minutes before the patient arrived at the operating unit. The Opera-decision is one of the most important variables, which indicates the workload in the operating unit on the following days. If the patients are not listed to the Opera-systems on time, it may impact the daily planning and usage of the operating rooms on the patient planning & control level.

From the process management perspective, there are several factors, which may increase the pre-operative LOS. The impacts of the measured independent variables are presented later in Chapter 5.3. However, there are also other purely medical factors that cannot be controlled, but which may definitely increase the pre-operative LOS. The changes in the trauma patient’s condition may be a reason why the planned surgical operation needs to be postponed. For example, if the patient suffers from a fever or has some kind of inflammation, the surgical operation cannot be performed. From the current data, it was not possible to measure these kind of factors, but those might be the reason why the patient was transferred to the intensive care unit. From the measured 4 536 yellow line patient treatment chains, there were in total 1 334 patients (29%) whose pre-operative LOS was over 48 hours. From those patients, roughly 10% had visited the ICU before the surgical operation, which partly explains the lengthened pre-operative LOS.

The length of the surgery describes the time from incision to wound closure. It can be seen that the average surgery time has been quite low within the yellow line patients, which therefore describes that the individual patients do not use much from the daily capacity of operating rooms. However, as there are approximately six yellow line surgical operations per day, increases it considerably the daily usage of the ORs. The operations lasting only a couple of minutes, usually describe cases where the patient has, for example, a dislocated shoulder or a leg. Even these are relatively quick operations, the operating unit capacity is still needed. Occasionally, there are also surgical operations, which last a lot longer and need therefore much more operating room and personnel capacity than the so called standard volume operations.

Table 7 and Table 8, in turn, show a comparison of the previously mentioned surgical operations, which are the most common ones within the yellow urgency class in Töölö hospital. The pre-operative LOS was calculated from two different points as it was done with the entire yellow urgency class. It seems that the average values are much lower in the selected patient groups when compared with the entire yellow urgency class. The standard deviation is also relatively high, which shows that there is a lot of variation between the patients in these patient groups.

Table 7. Pre-operative LOS measured for the NFB20 patient group

NFB20	**Number of cases** [n]	**Average** [h:mm]	**Median** [h:mm]	**Standard deviation** [h:mm]	**Min** [h:mm]	**Max** [h:mm]
Time from ED visit to surgery*	761	27:07	22:35	19:28	1:13	174:50
Time from Opera-decision to surgery**	921	24:28	20:36	18:12	0:26	183:34

* Measured from the 4 536 patient cases, ** Measured from 6 501 patient cases

Table 8. Pre-operative LOS measured for the NHJ10 patient group

NHJ10	**Number of cases** [n]	**Average** [h:mm]	**Median** [h:mm]	**Standard deviation** [h:mm]	**Min** [h:mm]	**Max** [h:mm]
Time from ED visit to surgery*	674	33:04	24:44	28:54	1:17	166:48
Time from Opera-decision to surgery**	824	30:22	22:04	29:45	0:16	219:35

*Measured from the 4 536 patient cases, **Measured from 6 501 patient cases

Based on the comparison of these two patient groups, it can be said that the NFB20 patients have faster access to care than the NHJ10 patients. As the amounts of these kind of patients are relatively low measured on a daily level, it is hard to analyze how these patient groups correlate daily with the total pre-operative LOS.

After the volume based measures, a weekly comparison was made in order to show collectively how the different variables correlate with each other. The results are presented in Table 9 and Table 10 in chronological order from the years 2012 and 2014. The top five weeks were selected based on weekly average of the pre-operative LOS, which was relatively high on these selected weeks.

Table 9. Comparison of the selected variables on different weeks in 2012

2012	Emergency visits [n]*	Accessed to surgery within the 48h [%]	Pre-op LOS [h:mm]	Decisions to operate [n]*	Yellow line decisions to operate [n]	Surgical operations [n]	Length of the surgery queue [n]	Patients in the emergency ward [n]	NFB20 patients [n]	NHJ10 patients [n]
Average	191	77 %	35:34	86	43	43	10	9	6	6
Week 2	202	69 %	53:29	92	42	37	10	10	1	10
Week 4	213	50 %	53:01	89	38	39	13	12	4	8
Week 6	222	60 %	52:01	98	60	50	17	13	4	9
Week 7	202	55 %	56:12	76	49	57	17	11	6	9
Week 9	202	66 %	49:15	100	50	42	12	10	5	11

* Measured for all the patients within the specialty of orthopedics and traumatology

Table 10. Comparison of the selected variables on different weeks in 2014

2014	Emergency visits [n]*	Accessed to surgery within the 48h [%]	Pre-op LOS [h:mm]	Decisions to operate [n]*	Yellow line decisions to operate [n]	Surgical operations [n]	Length of the surgery queue [n]	Patients in the emergency ward [n]	NFB20 patients [n]	NHJ10 patients [n]
Average	171	79 %	33:10	75	42	41	9	8	6	4
Week 23	207	65 %	51:31	82	55	46	15	9	5	2
Week 26	188	73 %	46:24	82	48	44	14	10	6	8
Week 29	191	48 %	50:35	74	33	35	12	9	0	2
Week 34	165	63 %	54:57	88	38	36	12	10	5	3
Week 35	210	53 %	58:46	76	49	44	16	11	6	3

* Measured for all the patients within the specialty of orthopedics and traumatology

Both of the tables show that most of the selected variables have been above the weekly average values during the selected weeks. It is notable that during the congested times, the percentage of the yellow line patients who accessed to the surgery within the 48 hour timeline is relatively low. In addition, the number of emergency visits and the length of the surgery queue are both significantly above the average, especially in 2014.

As the weekly results also show, the number of patients in the selected NFB20 and NHJ10 patient groups, does not differ significantly from the weekly average values. Therefore, those were outlined from the data analysis. An interesting difference is that in 2012, the congested weeks occurred during the spring time, whereas in 2014 the summertime has been active in Töölö hospital. The correlations between these selected variables and the pre-operative LOS have been analyzed in more depth in the next chapter.

5.3 Outcomes from the data analysis

The outcomes from the data analysis have been divided into three categories based on the different factors explaining or anticipating congestion in the patient treatment process. These categories are the emergency department related variables, the operative care related variables and the inpatient care related variables. In the analysis phase, the variables in these categories were compared with the pre-operative LOS in different periods of time in order to find the most suitable variables for the regression analysis. On the weekly level comparison, the year 2014 was mainly used as an example as it represents the most recent data, and therefore demonstrates the best the current operating model.

5.3.1 The emergency department related variables

From the time based measurements, the day of the emergency visit was measured for the total patient volume within the specialty of orthopedics and traumatology. This has been illustrated in Figure 11. The statistics show that Monday is the busiest day of the week in the ED. During the weekends, in turn, the patient load is 30-40% smaller than on Mondays, which is from the capacity management point of view a considerable difference. As patients arrive usually with a referral to the ED, it mostly explains the spike in the emergency visits on Mondays. For many of the Monday's patients, the accident has happened during the previous weekend and the reason why people have not gone to the ED bases on a fact that usually there is a limited access to the respective health center or to the occupational health during the weekend. It is also possible that some of the patients have underestimated the significance of the accident, and have therefore postponed the emergency visit.

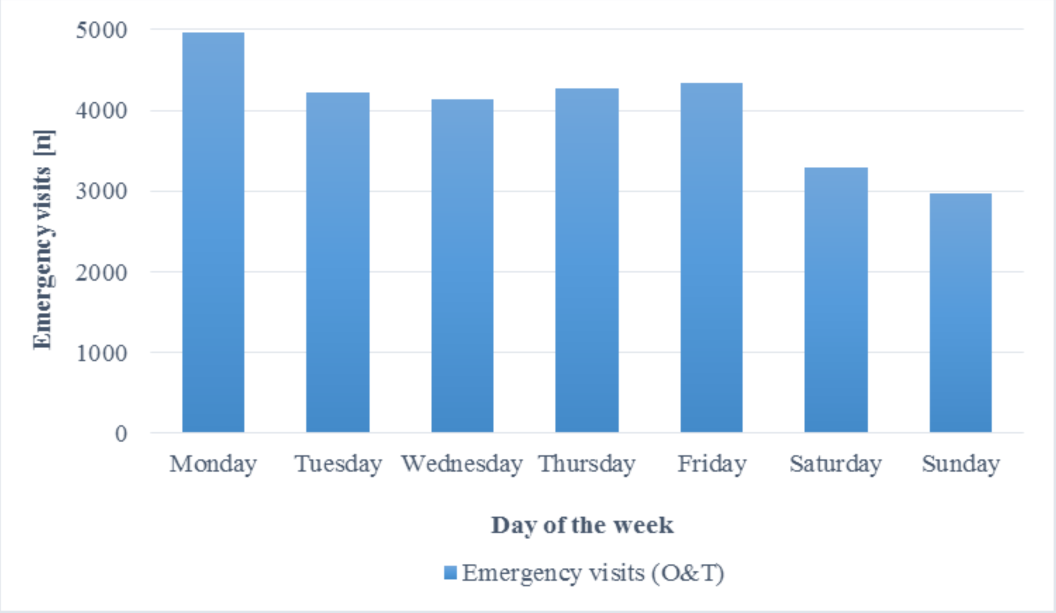

Figure 11. Amount of emergency visits on different days of the week

Figure 12, in turn, shows the daily variance in the emergency visits as it has been compared with the pre-operative LOS on the same day. It can be seen that the correlation between these two variables is not statistically significant. However, the emergency visits measure the input in the process and should be measured somehow. As mentioned in the data processing chapter, cumulative amounts of emergency visits were calculated for the regression analysis. From these calculations, the best correlation was found with the five-day sum, which counts the visits on the selected day together with the visits from the previous four days.

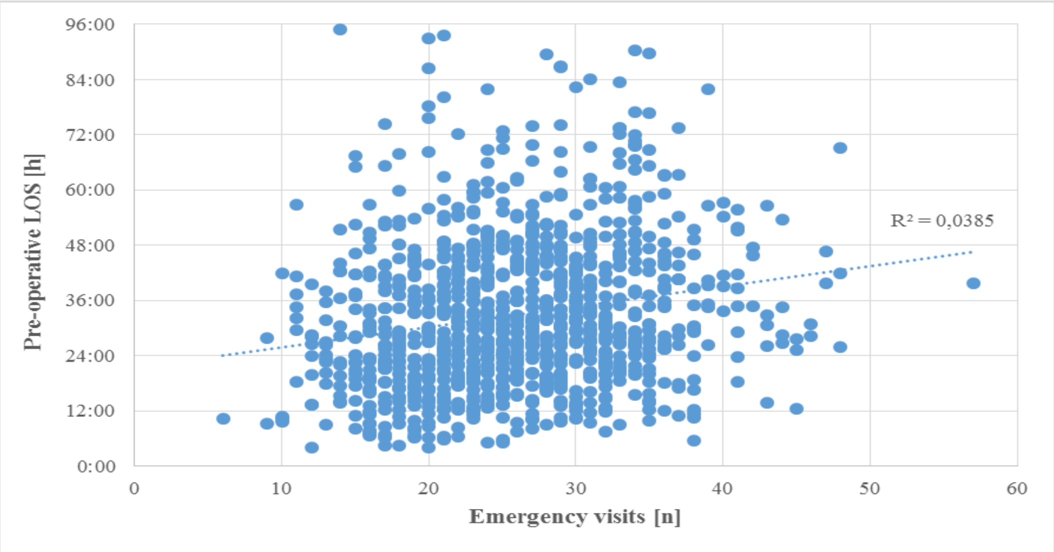

Figure 12. Correlation between the daily emergency visits and the pre-operative LOS

5.3.2 Operative care related variables

As the results from the emergency visits showed above, the input of patients might vary between the different days of the week. Therefore, the comparison was also made to the operative care related variables. Figure 13 illustrates the differences between the Opera-decision and surgical operations on different days of the week. It seems that the biggest number of Opera-decisions are made on Mondays and Fridays, which are the busiest days also in the ED. The amount of surgical operations, in turn, shows an interesting phenomenon. As the target-oriented pre-operative LOS for the yellow line patients is 48 hours and the average pre-op LOS is around 33 hours measured from the Opera-decision, it is predictable that most of the patients operated on Monday have arrived during the weekend, and even on the previous Friday. From the data it can be calculated that from the Friday's patients roughly 12% were operated on Monday, which shows as an increase in the pre-operative LOS. This can be seen from Figure 14, too. From the patients who were decided to operate on Monday, around 28% of the patients were operated at the same day and 45% on Tuesday. As roughly 78% of the Monday's patients are operated during the first days of the week, it explains also the low pre-operative LOS in Figure 14. In Finland, for most of the people Saturdays and Sundays are holidays, which therefore influences the operations of the hospitals during the weekends. In addition, the operating unit in Töölö hospital operates with a lowered personnel capacity during the weekends, which explains the lower amount of surgical operations. Except for Mondays and the weekends, the amount of surgical operations seems to be almost evenly distributed to the different days of the week.

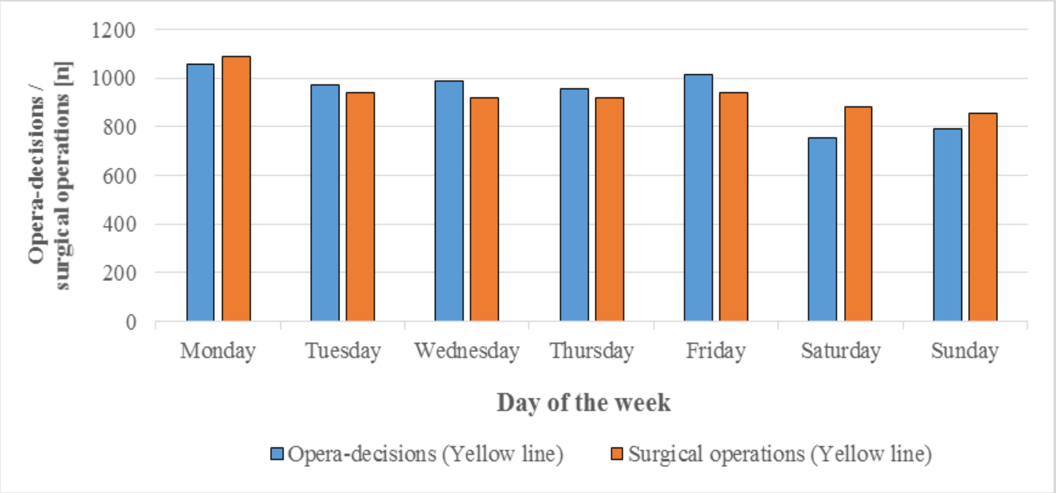

Figure 13. Amount of Opera-decision and surgical operations on different days of the week

As mentioned above, Figure 14 supports the contend from Figure 13, by showing that patients who get their Opera-decision on Mondays, have usually relatively low pre-operative LOS in comparison with patients arriving on the last workdays of the week. By increasing the amount of surgical operations during the first days of the week, it helps to reduce the workload from the previous weekend and to stabilize the process for the following days. However, as it can be seen from Figure 14, the increase in the pre-operative time takes its place on Thursdays and Fridays, which based on the data sample and from the production control point of view, would possibly be a better time to add surgical capacity.

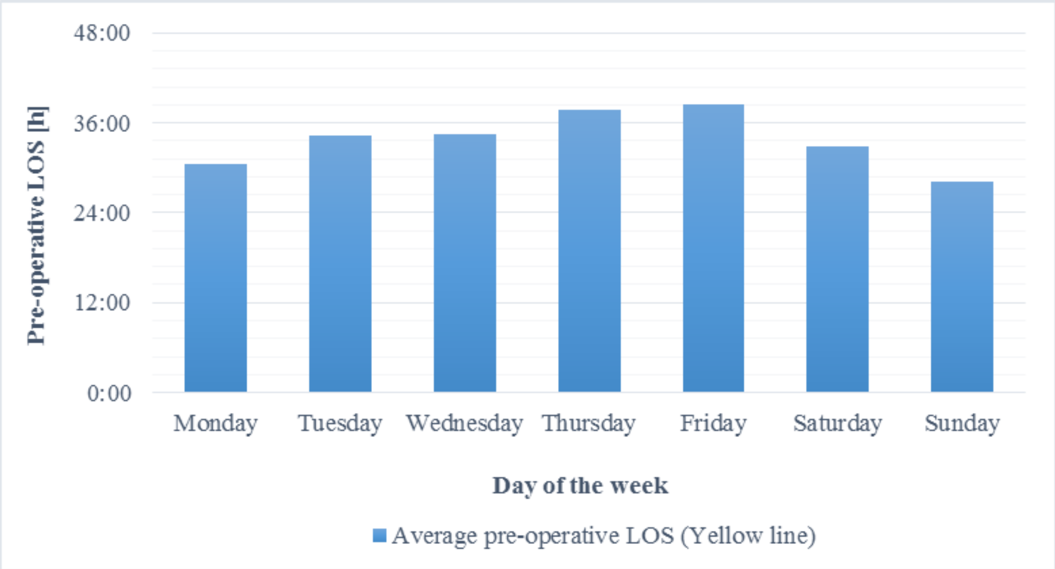

Figure 14. Yellow line average pre-operative LOS on different days of the week

Figure 15 exhibits the weekly amount of Opera-decisions and surgical operations, and the average pre-operative LOS on a weekly level. As it was shown in Table 10, in 2014, the weekly average amount of Opera-decisions was around 42 and the amount of surgical operations around 41. Therefore, it is clear that there is a strong correlation (r=0.82) between these two variables. However, Figure 15 shows that those two variables are not perfectly equal on a weekly level. This consolidates the effect presented in Figure 13. The more Opera-decisions are made at the end of the week, the more it is reflecting the workload in the operating unit in the following week. For example, on week 23 the amount of Opera-decision was high and the operating unit could not respond quickly enough to the increased demand, which therefore increased the pre-operative LOS in that week and the length of the surgery queue (see Figure 19) in the following week.

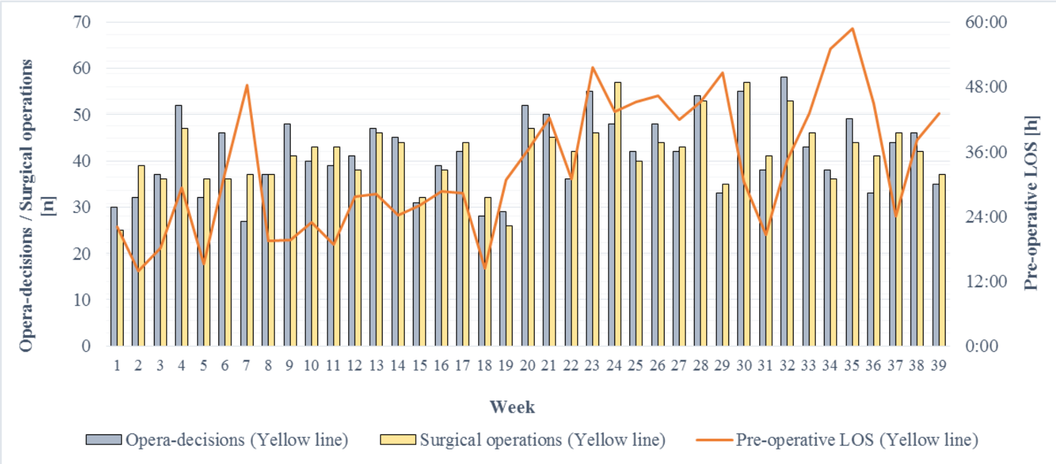

Figure 15. Weekly comparison between the Opera-decisions, surgical operations and the average pre-operative LOS within the yellow line in 2014

Neither one of the variables had significant correlation with the lengthened pre-operative LOS, in the weekly or the daily level. This can be seen from Figure 16, which shows the correlation between the pre-operative LOS and the Opera-decisions measured from 156 weeks within the three-year time period. On a daily level, the dispersion increased as the total amounts of Opera-decisions and surgical operations were not significantly changing from day to day. As the measurements for the predictive model needs to be done on a daily level, these two variables were outlined from the final regression analysis.

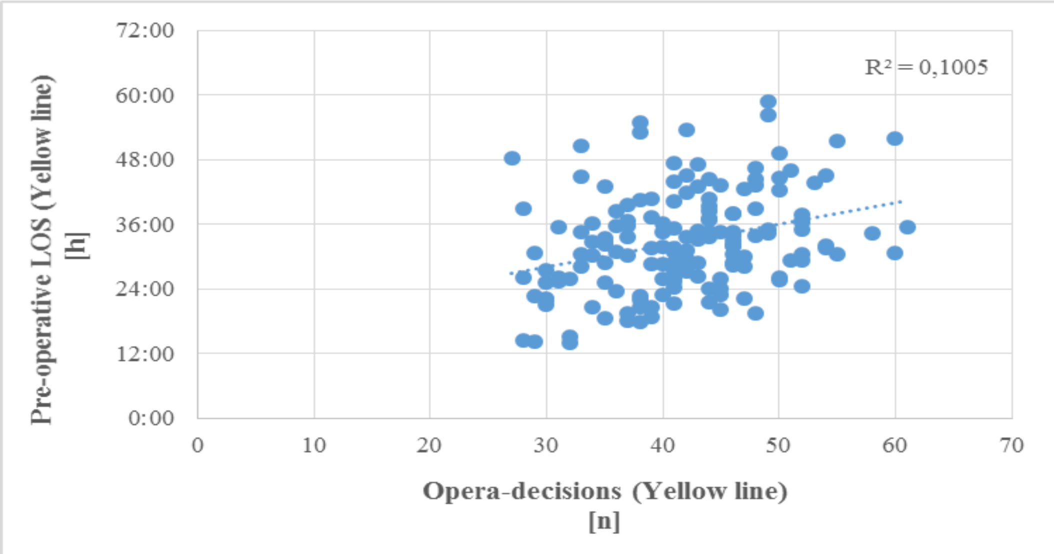

Figure 16. Correlation between the pre-operative LOS and Opera-decisions within the yellow line on the weekly level

It was previously described that the length of the yellow line surgery queue was calculated for each of the days based on the Opera-decisions and surgical operations made on that day. Figure 17 shows how the length of the surgery queue is varying on the different days of the week. Based on the entire data sample, it seems that the yellow line surgery queue is the longest on Fridays. If these results are compared with the results from Figure 14, some kind of causality with the days of the week can be seen as both figures are growing towards Friday. From the production control perspective, the surgical resources are not evenly distributed on different days of the week as both the length of the surgery queue and the waiting times are increasing towards Fridays.

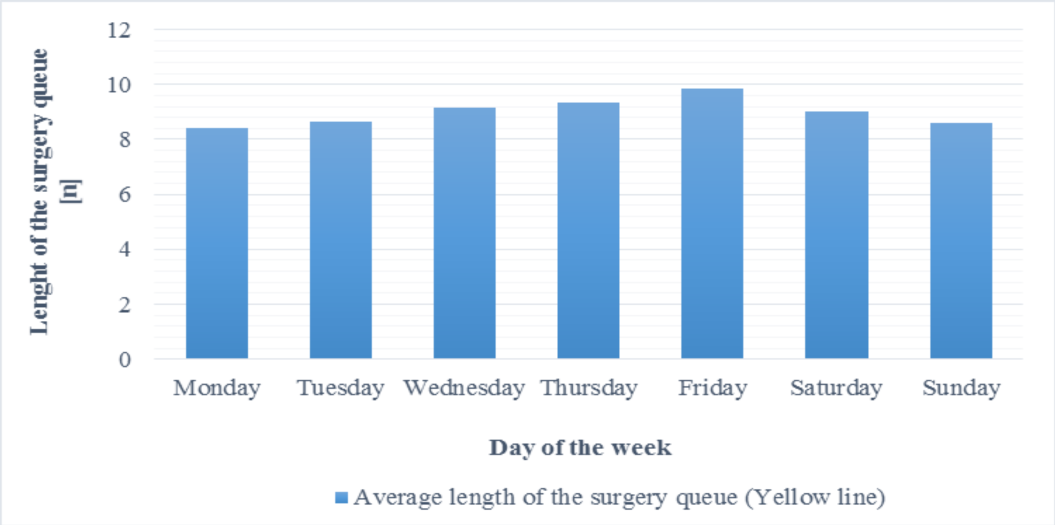

Figure 17. Average length of the surgery queue on different days of the week

From all of the measured variables, the length of the surgery queue had the best correlations with the pre-operative LOS. The correlation on the weekly level can be seen from the following Figures 18 and 19. On a weekly level, the correlation was relatively high (*r*=0.79), which can be seen from Figure 18. On a daily level, the dispersion increased and the correlation decreased, but still, it stayed relatively high (*r*=0.47) compared with the other variables measured on a daily level.

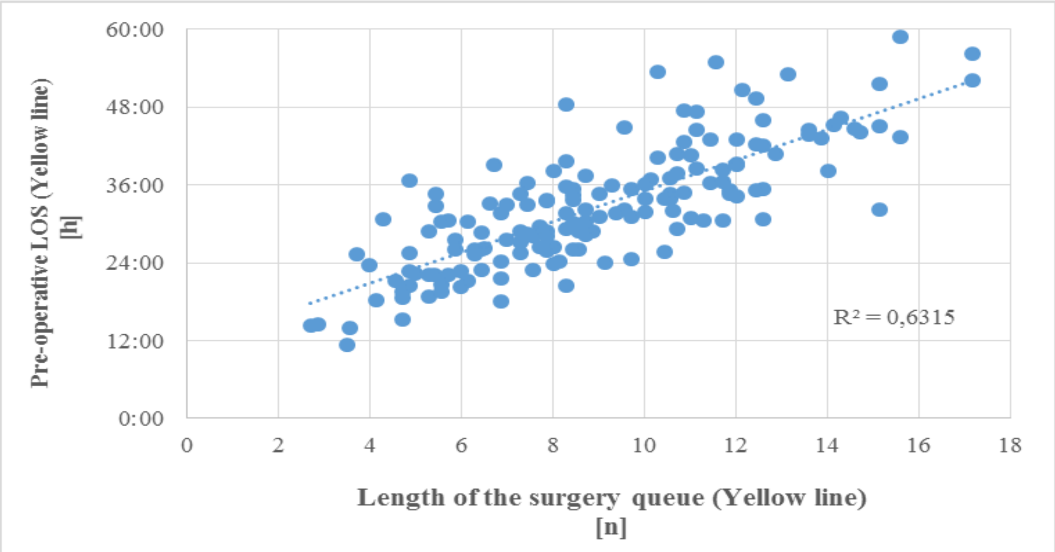

Figure 18. Correlation between the pre-operative LOS and the length of the surgery queue within the yellow line on the weekly level

Figure 19 illustrates the causal relationship between the average length of the surgery queue and the average pre-operative LOS, in different weeks of 2014. Based on the statistics and the historical data, it can be said that as the amount of patients in the surgery queue increases, it will also influence the waiting time for the surgery. The operating room hours can be used to show how the additional capacity or the increased utilization of the ORs has impacted the length of the surgery queue and pre-operative times. This can be seen from Figure 19, too. For example, in week 23 the average pre-operative time was over 51 hours, which is relatively high value for a weekly average. As the OR hours were increased during the next weeks, the pre-operative LOS and the surgery queue were both decreased.

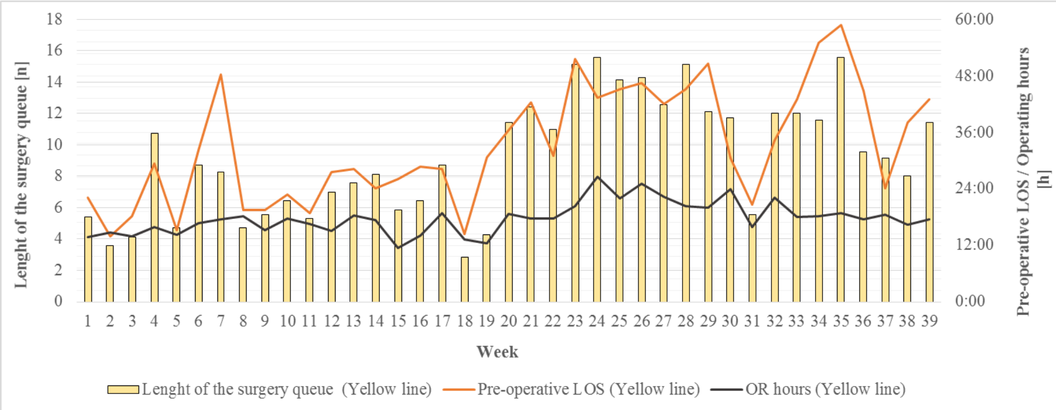

Figure 19. Weekly comparison of the average length of the surgery queue, the pre-operative LOS and the OR hours within the yellow line in 2014

The OR hours work as a good indicator to find the rushed times in the operating rooms. However, it is almost impossible to forecast the increase in the surgery waiting times by using the OR hours. For instance, it is not predictable whether some complications occur during a routine surgical operation, which may increase the length of the surgery. Therefore, the OR hours were left out from the regression analysis. The length of the surgery queue, in turn, can be daily monitored and thus it was selected as the main independent variable in the regression analysis.

5.3.3 Inpatient care related variables

The volume based measures previously showed that the daily average of patients in the emergency ward was roughly 9 patients at the end of each day. Figure 20 illustrates that there is definitely a strong correlation (r=0.58) between the average number of patients in the emergency ward and the average pre-operative LOS on a weekly level. As described before, a logical explanation for this is that most of the yellow line patients are waiting for the surgery in the emergency ward. However, from the data it was not possible to clarify how many of the patients in the emergency ward belonged to the yellow urgency class, which therefore decreases the correlation rate.

In addition, Figure 20 illustrates how the occupancy of the emergency ward and the pre-operative LOS has been higher during the summertime compared with the first half of the year. This can be seen also from the length of the surgery queue in Figure 19. An explanation relates mostly to the Finnish summer vacation period, as before the midsummer most of the hospitals in Finland reduce their operations, which therefore increases the workload in Töölö hospital. In addition, it has been acknowledged that the number of severe injuries increases during the summertime. As the correlation rate was so high between these two variables, the patient load in the emergency ward was also selected as one of the independent variables in the regression analysis.

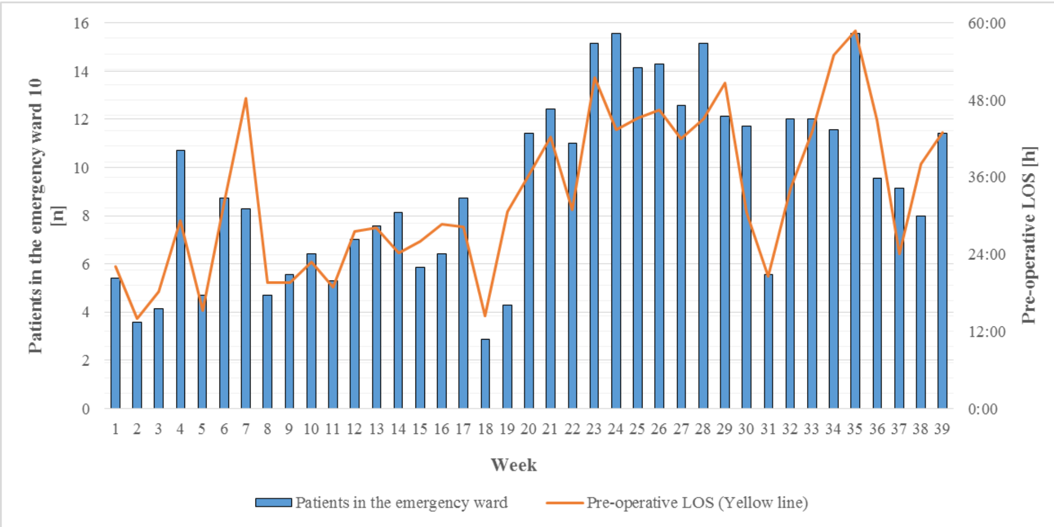

Figure 20. Comparison of the average patient load in the emergency ward and the pre-operative LOS weekly in 2014

5.4 Outcomes from the regression analysis

Based on the outcomes of the data analysis, a regression model was created. All of the variables selected for the regression analysis are listed below in Table 11. The strongest positive correlation was found between the two-day predictive average of the pre-operative LOS and the length of the surgery queue (*r*=0.53). The two-day predictive average of the pre-operative LOS was calculated based on the following formula:

$$Two\ day\ predictive\ pre\text{-}operative\ LOS\ (h) = \frac{(a * c) + (b * d)}{(\mathrm{c} + \mathrm{d})},$$

where the variables are:

a = Pre-operative LOS on the selected day
b = Pre-operative LOS on the following day
c = Number of Opera-decisions on the selected day
d = Number of Opera-decision on the following day

Table 11. Variables used in regression analysis

Variable	Definition
Pre-operative LOS*	The two-day predictive average of the pre-operative LOS
Emergency visits	The amount of emergency visits on the selected day plus on four previous days
Weekday	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday
Surgery queue*	Amount of patients in the surgery queue at the end of each day
Emergency ward	Amount of patients in the emergency ward at the end of each day

* Measured only for the yellow line patients

The two-day predictive pre-operative LOS had the best correlation (r=0.38) with the amount emergency visits counted on the selected day together with the four previous days. The weekdays, in turn, were notified in the regression analysis as dummy variables, as based on the data it was shown that, for example, the biggest amount of opera decision and surgeries were made on Mondays (see Figure 13).

The cumulative amount of patients in the emergency ward was selected as the main variable to describe the congestion in the wards. The emergency ward was chosen as based on the treatment process patients who need surgical operation are mainly transferred to emergency ward after the ED. The correlation between the emergency ward and the two-day pre-operative LOS was around 31% (r=0.31). The multicollinearity problem did not occur in the regression analysis. Table 12 illustrates the coefficients for the independent variables from the regression model. The all-encompassing outcomes from the regression model have been illustrated in the Appendices (see Appendix VII).

Table 12. Coefficients for the independent variables

Independent variable	Standardized beta	p-value
Tuesday	0.054	0.098
Wednesday	0.093	0.004**
Thursday	0.107	0.001**
Friday	0.020	0.543
Saturday	-0.072	0.028*
Sunday	-0.070	0.031*
Emergency visits	0.141	0.000**
Surgery queue	0.442	0.000**
Emergency ward	0.021	0.493

** $p \leq 0.01$, * $p \leq 0.05$

As Figure 14 and the results from the regression model show (Table 12), there is definitely a lot of variation between the different days of the week. Monday was excluded in the regression model, which therefore worked as a baseline for the other days of the week. In this model, Wednesday and Thursday were the only days, which were statistically significant (p<0.01). With this data sample, it means that on Wednesdays and Thursdays, it is more predictable that the two-day predictive average of the pre-operative LOS will be higher when compared with the other days of the week.

It can be seen from the regression model that the patient load in the emergency ward was not significantly influencing the predictive average of the pre-operative LOS (p=0.493). Based on the measurements made on a weekly level, it can be said that the patient load of the emergency ward can be used more as a retrospective variable in order to find the congested time periods within the hospital, for example, on a weekly or monthly level. On a daily level, the variance between the input and output flows is relatively high and thus can be difficult to monitor.

Based on the regression model, the emergency visits and the length of the surgery queue were statistically proven as the most significant variables (p<0.01). The results show that the surgery queue explains 44% and the emergency visits 14% from the variation of the dependent variable. By increasing the surgery queue with one patient, the two-day predictive average pre-operative LOS will increase almost with 1.5 hours. A single emergency visit, in turn, is not significantly contributing to the surgery waiting times as one emergency visit is increasing the predictive average of the pre-operative LOS only by six minutes. However, the emergency visits describe the inflow of the surgery process, which should be also monitored. Based on these results two predictive models were created for the operations management.

5.5 Predictive operating model

By using the selected variables, two predictive models, which base on the historical data, were created. The first model uses both of the selected variables, the length of the surgery queue and the emergency visits, as indicators for the predictive pre-operative LOS. The different cells in Figure 21 show the number of days from the three-year time period when the selected criteria have been fulfilled. Figure 22, in turn, shows the average two-day pre-operative LOS in those days.

By including today's surgery waiting time to the predictive pre-operative LOS calculations, the model should describes more accurately the current situation in the hospital. In situations when the two-day predictive average of the pre-operative LOS has been high, it means that some of the patients have been longer in the surgery queue. Thus, it is predictable that if there is a substantial number of patients in the surgery queue at the end of the day, the pre-operative LOS will also increase for the upcoming patients.

		Length of the surgery queue (Yellow line)							
		0-2	3-5	6-8	9-11	12-14	15-17	18-20	21-23
Emergency visits today + four previous days (O&T)	<70			2	2				
	70-89	2	11	3	1				
	90-109	9	55	53	16	5			
	110-129	8	92	145	103	55	18	3	
	130-149	3	35	107	101	79	28	13	3
	150-169		7	15	29	36	31	8	1
	170-190				6	7	2		1

Figure 21. Number of days in three years with the selected variables

Figure 21 shows that on most of the days the length of the surgery queue has been between six and eleven patients. The amount of emergency visits, in turn, has mostly been between 110 and 149 visits. For the emergency visits, this result corresponds also to the daily average of 26 patients. In those days, the two-day average pre-operative LOS has been approximately 32 hours, which is also near the daily average time.

Relating to the regression model, Figure 22 shows that the two-day pre-operative LOS is increasing together with both of the variables. The reddish area in the right bottom corner describes the days when the average pre-operative LOS has been relatively high. This has been also marked with a red rectangle in Figure 21. It can be seen that within three years, there has been 87 days when a bigger amount of emergency visits occurred and the surgery queue was relatively long for the yellow line patients. This means that every second week there was a day when the two-day average pre-operative LOS has been high. However, as mentioned before congestion is usually more long-lasting and thus the increase in the pre-operative LOS contributes also to the following days.

		Length of the surgery queue (Yellow line)							
		0-2	3-5	6-8	9-11	12-14	15-17	18-20	21-23
Emergency visits today + four previous days (O&T)	<70			37:35	32:14				
	70-89	13:50	24:45	22:01	29:21				
	90-109	15:34	20:07	25:26	32:45	30:01			
	110-129	27:43	25:24	29:22	34:04	40:20	41:13	38:50	
	130-149	17:01	30:13	30:33	34:57	40:49	45:38	48:06	48:43
	150-169		29:47	30:03	36:45	41:51	46:09	45:33	51:11
	170-190				43:18	43:36	45:40		51:09

Figure 22. Predictive pre-operative LOS with the selected variables

Based on this predictive model, it seems that 15 patients could be an ideal limit for the yellow line surgery queue in order to keep the average pre-operative LOS within the 48 hours. As it is more difficult to forecast and control the number of the emergency visits, the boundary value should be more fluctuating. Based on the data, the limit for the emergency visits could be set between the 130 and 149 patients, which in daily amounts would mean from 26 to 30 visits within the specialty of orthopedics and traumatology.

The second predictive model is more straightforward as it follows only the correlation between the length of the surgery queue and the two-day predictive average of the pre-operative LOS. Figure 23 shows how the length of the surgery queue indicates the increase in the surgery waiting times. The y-value in this model shows that by increasing the surgery queue with one patient the predicted average surgery waiting time will increase by one hour and forty-four minutes.

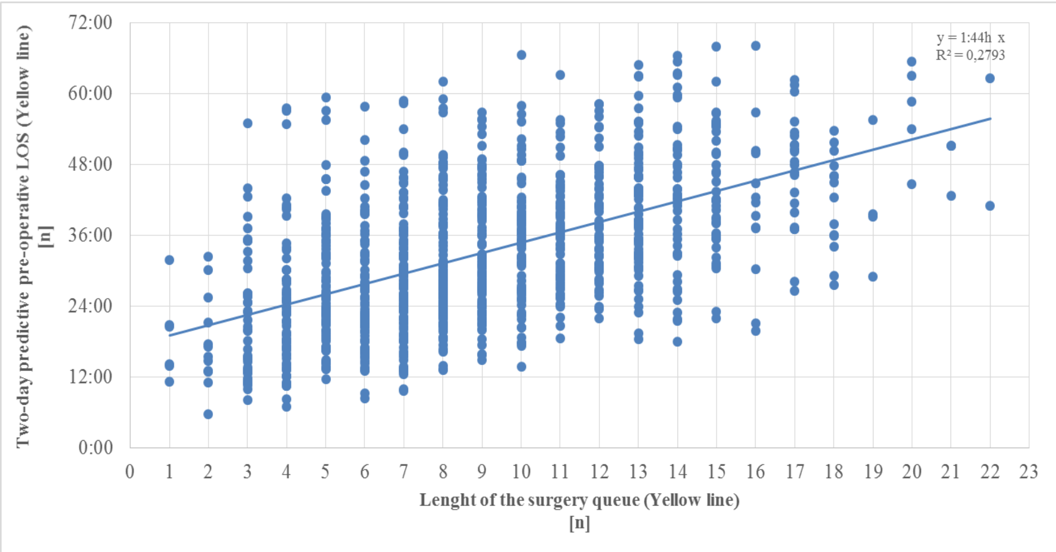

Figure 23. Correlation between the predictive pre-operative LOS and length of the surgery queue

As both of presented models are created based on the same data, similarity in the results is clear. This model also shows that 15 patients in the surgery queue could be the most ideal boundary value in order to have the time to react before the 48 hour timeline exceeds. It can be seen that by cutting the yellow line surgery queue daily even with a few extra surgical operations, the average pre-operative LOS is decreasing significantly.

A sample was taken based on the previously mentioned 87 days (see Figure 21) in order to demonstrate how the emergency visits and the selected 15 patient boundary value in the surgery queue are correlating to the following day's pre-operative LOS and operating room hours. The sample was taken on a daily level from June 2014 as most of the variables measured in this study were high above the average values on that particular time period. This has been illustrated in Appendix VIII.

Figure (Appendix VIII) shows that the pre-operative LOS varies significantly between different days during the selected time period. By following the length of the surgery queue it can be seen that the soon after the surgery queue has exceeded the 15 patient boundary value, the pre-operative LOS was increasing significantly on the following days. As it was shown previously, the emergency visits seem to correlate with the increase in the pre-operative LOS and the length of the surgery queue with a delay of a few days. The three year daily average for the emergency visits was around 26 visits within the specialty of orthopedics and traumatology, which has been almost daily exceeded during the first half of the month.

A causality can also be found between the length of the surgery queue and the used operating room hours. In the current operating model, the decisions for the additional OR capacity are mostly made based on intuition, as no such a concrete boundary value or such an indicator for the lengthened pre-operative LOS has been found. This effect can be seen also from the example presented in Appendix VIII. After the surgery queue exceeded the boundary value of 15 patients, it has been taking a few days, after which the OR hours have been increased. Based on the statistics, it can be said that if the increase in operating room hours would have been done a couple of days earlier, the flow of the surgical operations could have been more stable during the first haft of the month. The late reaction in many of the cases can be explained by the fact that the additional capacity increase bases on overwork, which is optional for the employees.

The weekly comparison showed (see Table 9 and Table 10) that the amounts of surgical operations NFB20 and NHJ10, were not correlating significantly with the lengthened pre-operative LOS. In addition, the number of patients in these patient groups remained really low on a daily level. As the predictive operating model should be on a daily level, it would be difficult to take these patient groups into consideration.

Nevertheless, Table 13 illustrates how the 15 patient boundary value in the surgery queue is contributing to the pre-operative LOS in these selected patient groups. The pre-operative times have been measured as averages from two different points of time. In this analysis, the length of surgery queue has been grouped into two groups, under fifteen patients and fifteen patients or more. According to the results, there has been a significant increase in average waiting times after the length of the surgery queue exceeded the 15 patient boundary value.

Table 13. Comparison of the pre-operative LOS with selected surgical operations and the length of the surgery queue

Surgical operation	Pre-op LOS (ED) SQ < 15 [h:mm]*	Pre-op LOS (ED) SQ >= 15 [h:mm]**	Pre-op LOS (Opera) SQ < 15 [h:mm]*	Pre-op LOS (Opera) SQ >= 15 [h:mm]**
NFB20	24:57	43:06	12:45	24:59
NHJ10	31:19	43:56	14:27	24:23

* n = 988 days, ** n = 108 days

6 CONCLUSIONS AND DISCUSSION

In Töölö hospital, the daily changing demand, which consists of highly varying patient cases, is occasionally creating pressure to the patient treatment process. There are several phases in the trauma patient treatment process where congestion might occur. The overall process can be concluded to three care phases, which are the emergency department care, the ward related pre- and post-operative care, and the operating unit care. The actual treatment process starts when the patient arrives at the ED. The overcrowding of the EDs has been globally recognized as one of the most significant problems in healthcare and it has been also studied widely, especially in the United States (Derlet et al. 2001; Trzeciak & Rivers 2003; Twanmoh & Cunningham 2006). However, the ED throughput times of Töölö hospital are the fastest within the HUS district, which shows that the beginning of the process is not the main problem in the treatment chain.

Most of the trauma patients arriving at the ED require surgical care, which therefore burdens more the middle part of the process. However, the current literature barely provides information about the relationship between the congestion in the treatment processes and the surgery waiting times. In Töölö hospital, the causality is explicit as based on the experiences, the congestion shows in the form of lengthened surgery waiting times within the yellow urgency class patients. The operating unit controls the input and output flows, which consolidates the previous arguments that the operating unit can be seen as the bottleneck of the surgical process.

The primary outcome investigated was that there should be some kind of boundary value in the patient inflow, which could indicate the increase in the surgery waiting times within the yellow urgency class patients. Surgery waiting time was calculated for each of the patients based on the number of hours from the Opera-decision until the patient arrives at the operating unit. Different factors were defined and correlations were calculated between the measurable variables and the pre-operative LOS. The answers to the research questions have been presented in the following Chapter 6.1.

The data analysis and the interviews revealed that Töölö hospital is more crowded during summertime than during the spring and wintertime. As mentioned before, the logical explanation is relating to the Finnish summer holidays and the reduced operations of the other hospitals during the summertime. In addition, it has been acknowledged that the number of complicated and long lasting surgical operations are typically increasing during the summertime, as there are a lot of traffic, machinery and falling accidents. Usually, these accidents require a lot of OR hours, which also exacerbates the bottleneck. Therefore, it is interesting that these seasonal increases in demand have been recognized within the staff, but no such corrective actions have been taken, as based on data this effect has repeated on each of the examined years.

In addition to the seasonal changes, there is a lot of difference regarding how Töölö hospital works on different days of the week. The biggest spike in the inflow focuses on the first days of the week as, in turn, the actual congestion usually starts to build up towards the end of the week. In addition, the daily comparison showed that the operating room capacity is unevenly used during the different days of the week, which describes how the hospital is not able to retain the steady surgical process flow for the whole week. It is understandable that during the weekend the operating unit cannot operate at the same effectiveness level as on the weekdays. However, as it was mentioned in the result chapter, from the production control point of view, in order to stabilize the surgical process flow of the yellow line patients, more OR capacity should be reserved for the last days of the week.

Many of the results of this thesis are showing that Töölö hospital should centralize its production control effort to the operations of the operating unit. In order to maximize the operational efficiency of the operating unit, one opportunity would be an increase in the daily OR hours. This could help the hospital to eliminate the surgery queues that exceed the system buffer and to maintain the wanted service level for its patients. However, one of the biggest problems in the public healthcare is that most of the resources are fixed and the operation is remarkably regulated.

For example, the different laws complicate the increase in the working hours of the staff. The benefits of this option have been discussed more in Chapter 6.2.

There are also some other relevant factors in the daily operation of Töölö hospital, which complicate the daily surgical planning and the production control of the hospital. It has been acknowledged that not all of the departments, even within the hospital, are actively using the same information systems, such as Opera - operating room management system. This, of course, slows down the treatment process as sometimes the information need to be fed to the management systems as the patient arrives from another department to the orthopedic operating unit. In addition, the throughput measures revealed that there is no such a precisely defined point of time in the current treatment process when all of the Opera-decisions are made. As it was previously mentioned, if the patients are not listed to the Opera-systems on time, it may impact the daily surgical planning, the trauma patient process flow and the efficient usage of the operating rooms.

6.1 Answers for the research questions

This chapter answers the research questions, which were defined at the beginning of this thesis. The answers provide a recapitulation from the previously discussed results and conclusions.

1. *Which factors explain and anticipate the congestion of the trauma process?*

As it was expected, the congestion in the trauma treatment processes is influenced by a combination different internal and external factors. The most of the factors are uncontrollable as the inflow of trauma patients cannot be precisely forecast. For example, one of the external factors, which increases the amount of patients in Töölö hospital, are the slippery roads during the wintertime. Some of the other seasonal differences in demand may relate to the operations of the other Finnish hospitals as some of them are reducing their operations, for example, during the summertime. Even if Töölö hospital could increase its capacity during these seasonal times, the patient inflow is still extremely difficult to predict, which therefore could only cause additional staff expenses to the hospital. As the data analysis showed, the number of the emergency visits was anticipating congestion with a delay of a few days. Therefore, from the production planning perspective, the daily amounts should be monitored, even if it is difficult to predict the amount of trauma patients arriving at the ED.

As the results from the data analysis showed, the different days of the week have an impact on the surgical process flow. The amount Opera-decisions and surgical operations, and the length of the surgery queue showed that the surgery process is not constant between the different days of the week, which describes well the current operating model. The biggest pressure in the current operating model falls upon the last weekdays, which is also indicated by the lengthened pre-operative LOS and length of the surgery queue in those days. In addition, the regression analysis showed that Wednesdays and Thursdays were statistically the most significant days, which supports the fact that there is an increase in the surgery waiting times on the last weekdays. Therefore, the different days of the week may partly explain congestion in the treatment process.

There are several factors in the operating unit, which may cause congestion within the entire hospital. The number of emergency surgeries is one of the factors which contributes to the daily surgery planning and to the waiting times of the lower urgency class patients. As the accidents cannot be predicted, a certain amount of OR capacity is always needed in order to provide immediate surgical care for the fast track patients. It is therefore clear that when a substantial number of acute patients arrive to the hospital at the same time, the waiting time of the non-urgent patients is increasing. However, the predictability of these kind of situations is challenging, which also complicates the usability of these factors in the predictive operating model.

The amount of Opera-decision and the amount surgical operations made within the yellow urgency class are essential variables to be followed as the length of the surgery queue can be daily calculated based on those variables. As single variables, the daily amounts are considerably varying, and therefore a direct relationship with the lengthened pre-operative LOS is challenging to perceive. The length of the surgery queue, in turn, correlates significantly with the surgery waiting time, which is relatively logical. Based on the different analysis and the regression model, it can be said that the length of the surgery queue can be used to indicate the congestion within Töölö hospital.

The operating room hours can be used as a measure for the utilization of the operating unit. This variable shows retrospectively how the increase in the operating room hours is contributing to congestion within the hospital. However, occasionally there are surgical operations which last longer and thus reserve the operating rooms for several hours. Another unexpected incident is the lengthened surgical operations. Even though these kind of cases are rare, they do influence the surgery waiting times of other patients.

The number of patients in the wards is a good indicator to describe the current situation in the hospital, as the bed capacity is one of the limiting factors in Töölö hospital from the capacity management point of view. The results showed that the occupancy of the emergency ward correlates significantly with the lengthened pre-operative LOS on a weekly level, but on a daily level patient flows are hard to monitor proactively. Therefore, it can be concluded that the ward occupancy can be seen as an important factor, which partly explains and anticipates congestion in the treatment process. However, the ward occupancy should not contribute to the daily operation of the operating unit as patients could be transferred to other hospitals after the surgery.

2. *What kind of daily indicators and operation management support can be used to forecast and avoid the congestion?*

One of the key objectives for this study was to find a simple and a daily usable indicator, which could predict the increase in the pre-operative LOS. Based on the data analysis and the regression analysis made, the length of the surgery queue was selected as the most suitable indicator for the operations management.

The created predictive models provide an estimation for the operation management of how many patients within a certain patient group can be treated simultaneously with a fixed capacity within the hospital, so that the wanted service quality level can be guaranteed. In addition, the created predictive operating models are easy to exploit in the daily operations of the hospital, as the length of the surgery queue and its impact on the pre-operative LOS can be monitored within the operating unit. Based on the results of this thesis, the patient volumes should be easier to plan and control.

As two different predictive models were presented, it is intuitive that the length of the surgery queue describes the situation better than the emergency visits from the previous days. However, the emergency visits describe the inflow of surgical patients, and therefore those should be also monitored. Based on the predictive models, the boundary value of the length of the surgery queue was set at 15 yellow line patients, after which the average pre-operative LOS started to close up the 48-hour limit. By following the trend line in the second model, new temporal limits for the yellow line patients can be set also in the future.

As the length of the surgery queue has not been previously followed, it creates direct value for the operations management, thus to the entire hospital. By using the predictive models, the management is more aware about the consequences of the congestion and corrective measures can be taken proactively.

6.2 Managerial implications

In order to reduce the pre-operative LOS, this thesis presents a few follow-up actions, which could be conducted after the boundary value in the yellow line surgery queue has been exceeded. All of the presented options have advantages and disadvantages. Therefore, a combination of different actions would create a solution where both the patient and the hospital would benefit the most. The different options have been listed and explained below:

- Additional surgery team for the evening hours
- Flexible working hours within the staff
- Surgical operations during the night time
- Cooperation with other hospitals / inpatient transfers

From the options mentioned above, probably the most realistic and stable option, which could also be quickly tested and executed, would be an additional surgery team for the evening hours. Based on the interviews it was revealed that there is often unused operating room capacity within the hospital and the biggest problem is the lack of personnel capacity. An additional evening surgery team would possibly be the best solution in order to maintain the steady process flow in the operating unit. However, in the long run as the demand is highly fluctuating, there would be also times when the daily patient input would not feed the evening shift and thus permanent evening shift could only be an unused resource expense for the hospital. As it was mentioned in the theoretical framework, the resource allocation within the hospitals should be flexible and based on the flow of the patients (Vissers 2005a, p. 119). Therefore, the flexible working hours within the staff would be an idealistic solution also to Töölö hospital.

The flexible working hours are more commonly used in the private sector than in the public sector. The lack in the usage of the flexible working hours within the public sector bases on the legislation for the working hours, which are more restricted and regulated for the organizations under the public administration. If the staff capacity could be added flexibly, for example, by naming surgeons and nurses on extra working shifts, it would make the operations management more agile and capable to respond to the changing demand and thus reduce the congestion in the patient treatment process.

As mentioned before, even during the daily hours, some unused OR capacity exists. If the process would have to be enhanced to its limits, the operation room capacity should also be used during the night time hours. This is seen as one of the undesirable measures. During the night time, the risks for the surgical operations are much higher and would therefore risk the patient's medical condition. Based on the experiences from the night time surgeries, the efficiency of the surgeries slows down. In addition, transfer times between the different surgical operations seems to increase. Therefore, one additional surgical operation during the timeframe of six to seven hours, would not bring any tangible benefit for the hospital. In addition, during the night time the personnel costs are higher and thus would create more additional expenses.

In the current operation, there is some kind of collaboration with other hospitals within the HUS region, especially, during the congested times. However, there is no common procedure for the surgical patient transfers and a lot of variation occurs in the decision making process. In the future, in an ideal situation would be that after the 15 patient limit in the surgery queue has been exceeded or seems to be exceeding during the following hours, the new yellow line patients could be proactively transferred to other hospitals within the HUS region, such as the hospitals of Jorvi, Peijas or Herttoniemi, in order to receive faster surgical care. However, the medical condition of the patient and the requirements for the treatment should always be taken into consideration.

This option would need active communication, knowledge transfer and collaboration between different hospitals. In order to maintain the surgical effectiveness also in the receiving hospitals, the similar boundary values, as in Töölö hospital, should be defined and the surgery queues and the surgery waiting times should be regularly monitored. One of the key factors relates also to the proficient usage of the operating room management system. As all of the hospitals in the HUS region are using the same Opera-information system, the needed information should be obtainable. In addition, all of the L-seniors and other surgery list planners should have the capability and courage to make the transfer decisions for the incoming patients as the boundary value in the length of the surgery queue has been exceeded or is about to exceed.

6.3 Reliability assessment

Although the results of this study were based on historical data and statistical analysis, yet the reliability and validity of the study need to be reviewed. In order to measure the usability of the created predictive operating model, these should be reviewed and tested in the daily operations of the hospital.

The data collected for this study can be seen as a reliable source of information as it bases on the actual patient data collected from the hospital information systems. During the data gathering process, it was noted that some of the current information systems are occasionally duplicating patient cases, which may cause distortion in the daily volume measurements made in the hospital. However, in this study all of the duplicate cases were diligently removed during the data processing phase. In addition, as there is always a possibility for data distortion, all damaged and defective data was removed in order to have more accurate results.

6.4 Contribution to previous research

As it was mentioned at the beginning of this study, the previous academic research in Töölö hospital have focused more on enhancing patient throughput, capacity management, and how to bind and utilize the existing resources (Torkki et al. 2006; Peltokorpi et al. 2011). The literature review revealed a gap in the trauma care literature, as no previous research was found about the causal relationship between the length of the surgery queues and the lengthened surgery waiting times in the acute patient care.

Some studies with similar results were found relating to the waiting times of the elective surgeries, which seem to be a general problem around Europe (OECD 2014, p. 116). A previous research by Peltokorpi et al. (2009b) discussed the effects of queue length and care guarantee of maximum waiting time on OR productivity. The study showed that the increase in the surgery queues is also increasing the surgery waiting times, which therefore supports the results from this study.

As this study showed, the surgery queues should be actively monitored, especially, in the trauma hospitals where time is an essential factor as the increase in the surgery waiting times may risk the patient's medical condition. The analysis and the findings of this study gave additional support to the existing body of knowledge about the congestion on the treatment process, which was previously based only on intuition. Based on the interviews it was revealed that the congestion in the surgical processes is a nationwide problem as it occurs in many Finnish hospitals. As the correlation between the surgery queues and the surgery waiting times can be easily defined based on the historical data, the predictive indicators can be implemented to other hospitals without difficult calculation models.

6.5 Future research

Based on this study, several interesting future research topics have come forth. As this study is more focused on the creation of the daily indicator for the operations management in Töölö hospital, it would be interesting to study how these selected methods and variables work in other hospitals in Finland. In addition, it is essential to study what would be the most cost effective compensation mechanism, after the surgery queue reaches its boundary values and what are the actual financial implications of this particular indicator.

Another example for a future thesis could be creation of a simulation model, which could demonstrate how the increase in the OR hours has been contributing to the surgical process flow after the length of the surgery queue has exceeded its boundary value. The needed capacity could be calculated based on the historical data and thus the simulation model could provide information about the ideal amount of additional capacity needed as the trauma process starts to stall.

Based on the interviews it was also revealed that there is no common protocol for the patient discharge process in Töölö hospital. Currently, after the physician has made the final examinations after the surgery and the approval for the discharge or for the transfer has been given, many patients still spend hours waiting in the inpatient wards without a sensible reason. After the physician has visited the dischargeable patients, some obligatory procedures and steps need to be followed as, for example, there might be a need for a discussion with the physiotherapist. However, within the hospital staff it has been discovered that still a lot of unnecessary wait time exists in the discharge and transfer processes. The existing patients in the inpatient wards are blocking the inflow of the new patients, which therefore creates congestion to the process from the outflow side. By creating a more consistent and predictable discharge schedule for patients it could help to improve the output flow and reduce the workload in the inpatient wards. Therefore, one of the future research topics could relate to the improvements of the patient discharge processes. This topic has already been widely studied (Atwal 2002; Ou et al. 2009; Lämsä 2013), but no common process model exists in Finland. In order to have more statistical arguments and results, research could be conducted by using similar patient data and qualitative interviews from different hospitals.

The analysis of the post-operative LOS was outlined from this study as the turnover of the patients is relatively high in trauma hospitals. Many yellow line patients arriving at Töölö hospital are usually transferred to other hospitals during the post-operative care, which therefore complicates the calculations of the accurate post-operative LOS. From the perspective of production planning and control, it would be interesting to study whether the increase in the pre-operative times increases also the post-operative time within the yellow line patients. This occurrence has already been notified in clinical care, for example, within the NFB20 patients. However, no statistical research has been done. Measurements could be done for the patients who spend the whole perioperative process in the same hospital. By creating complete patient chains from the hospital information systems, the causality between these two variables could be measured.

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APPENDICES

Appendix I – Keyword used in the literature search

(“emergency department” OR “emergency unit” OR “intensive care unit”) [1] AND (“congestion” OR “crowding”)
[1] AND (“bottleneck” OR “theory of constraints”)
[1] AND (“health process” OR “medical process” OR “patient process”)
[1] AND (“healthcare management” OR “health care management”)
(“emergency surgery” OR “urgent surgery” OR “surgery unit” OR “operation theatre” OR “operating theatre”) [2] AND (“process” OR “process management” OR “process development”)
[2] AND (“waiting time” OR “scheduling” OR “estimating”)
[2] AND (“congestion” OR “crowding”)
[2] AND (“capacity planning” OR “efficiency”)
(“trauma center” OR “traumatology” OR “trauma”) [1] AND (“process management”)
(“trauma process” OR “trauma patient process” OR “trauma care process” OR “trauma management”)
(“production planning” OR “production planning and control” OR “production process”) AND ("health care" OR "healthcare" OR care OR "patient centered care")
(“estimating” OR “forecasting”) AND (“congestion” OR “crowding”) AND (“emergency department” OR “emergency unit”)
("process management") AND (“healthcare management” OR “health care management”)
("leadership model" OR “management model”) AND ("health care" OR "healthcare") AND ("trauma" OR "traumatology" OR "trauma center" OR “trauma management”)
("pre-operative LOS" OR "pre-operative length of stay" OR "preoperative length of stay" OR "preoperative LOS")
("operations management") AND ("trauma" OR "traumatology" OR "trauma center")

Appendix II – List of the data collected

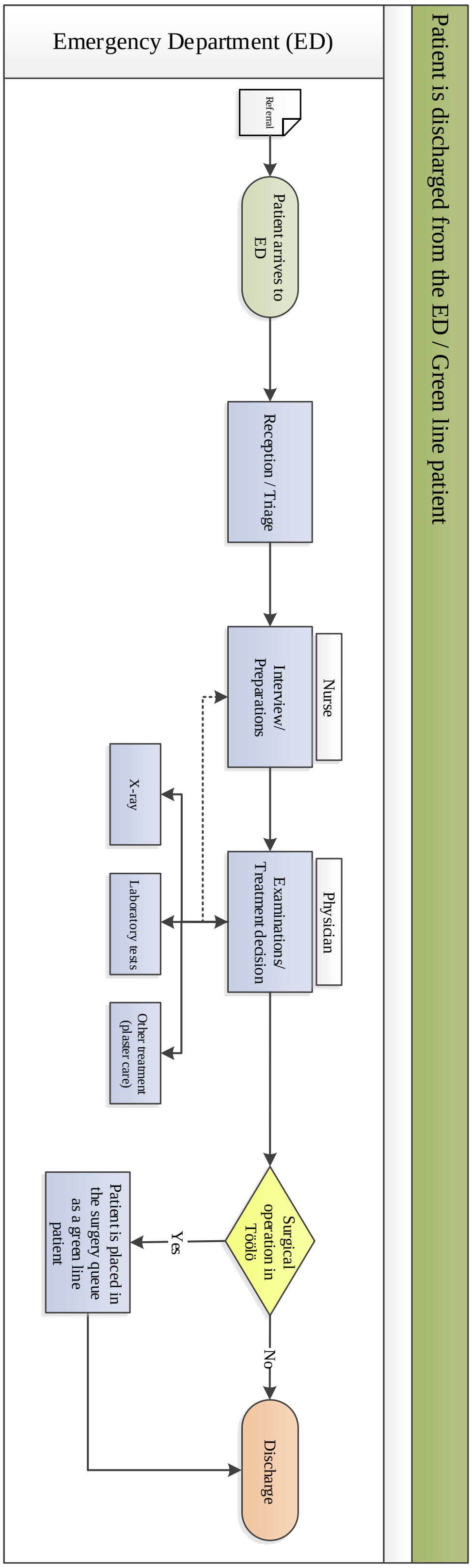
Emergency Department	Orthopedic operating unit	Wards*
- Patient number - Patient product number - Time of arrival (date & time) - Time of departure (date & time) - Day of the week - Workday / midweek holiday - Age of the patient - Sending institution - Specialty - Name of the specialty - Urgency of the reference - Main diagnosis - Definition of the main diagnosis - Operation code - Definition of the operation - Type of visit - Follow-up treatment	- Patient number - Patient product number - Name of the operating unit - Name of the operating room - Date of the operation - Opera-decision - Patient arrives to the operating unit - Patient arrives to the operating room - Starting time of the operation - End time of the operation - Patient leaves the operating room - Patient leaves the recovery room - Urgency class - Main diagnosis of the operation - Definition of the main diagnosis - Operation code - Definition of the operation - Side operation - Definition of the side operation - Specialty - Name of the specialty - Surgeon - Anesthesiologist - ASA-class of the patient	- Patient number - Patient product number - Ward number - Name of the ward - Main diagnosis - Definition of the main diagnosis - Patient arrives to the ward (date & time) - Patient departures from the ward (date & time)

*Only for the following wards: 8502, 8504, 8505, 8509 and 8510

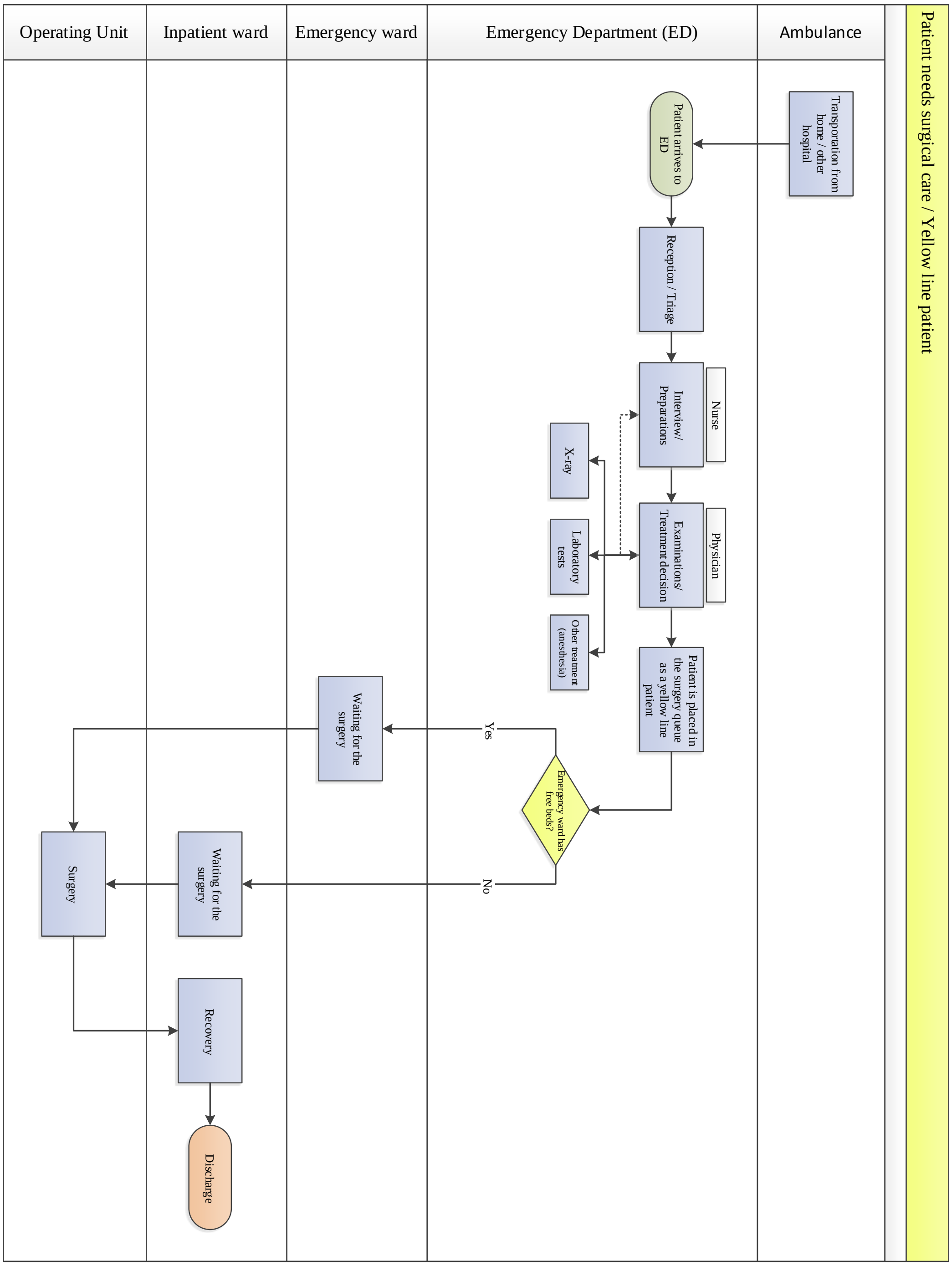
Appendix III – List of the personnel interviewed for this study

Date of the interview	Title	Department
18.11.2014	Head of nursing	Emergency department
18.11.2014	Head of nursing	Orthopedic operation room
20.11.2014	Head of nursing	Emergency department
21.11.2014	Emergency physician	Emergency department
24.11.2014	Head of nursing	Inpatient wards
6.2.2015	Chief of Division	Department of Orthopedics and Traumatology

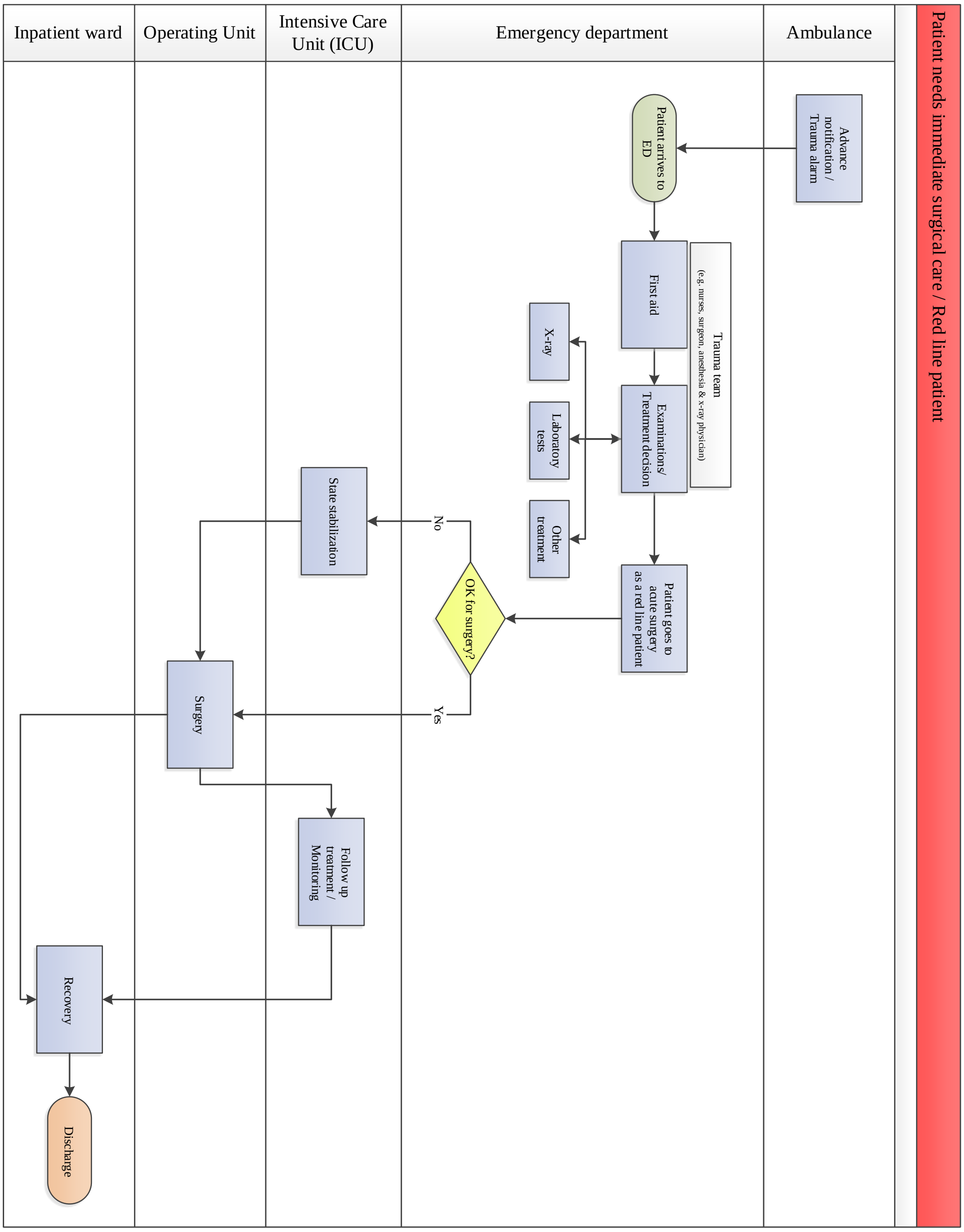
Appendix IV – Process mapping for the green line patients



Appendix V – Process mapping for the yellow line patients



Appendix VI – Process mapping for the red line patients



Appendix VII – Results from the regression analysis

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,579[a]	,335	,329	10:44:42

a. Predictors: (Constant), Ward10, Thursday, Sunday, Friday, Wednesday, Tuesday, Emergency_visits_td_plus4_pre, Surgery_queue, Saturday

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	814572890572,963	9	90508098952,551	60,486	,000[b]
	Residual	1617546012807,230	1081	1496342287,518		
	Total	2432118903380,190	1090			

a. Dependent Variable: Pre_op_LOS_td_plusnextday

b. Predictors: (Constant), Ward10, Thursday, Sunday, Friday, Wednesday, Tuesday, Emergency_visits_td_plus4_pre, Surgery_queue, Saturday

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	5:29:21	2:34:18		2,134	,033	0:26:35	10:32:08
	Emergency_visits_td_plus4_pre	0:05:59	0:01:17	,141	4,617	,000	0:03:26	0:08:32
	Tuesday	2:01:01	1:13:08	,054	1,655	,098	-0:22:27	4:24:31
	Wednesday	3:29:58	1:13:16	,093	2,865	,004	1:06:10	5:53:45
	Thursday	4:00:23	1:13:23	,107	3,275	,001	1:36:22	6:24:24
	Friday	0:45:40	1:15:08	,020	,608	,543	-1:41:44	3:13:06
	Saturday	-2:41:29	1:13:19	-,072	-2,203	,028	-5:05:22	-0:17:36
	Sunday	-2:37:59	1:13:20	-,070	-2,155	,031	-5:01:53	-0:14:05
	Surgery_queue	1:27:20	0:06:14	,442	14,004	,000	1:15:06	1:39:34
	Ward10	0:05:55	0:08:37	,021	,686	,493	-0:10:59	0:22:50

a. Dependent Variable: Pre_op_LOS_td_plusnextday

Excluded Variables[a]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Monday	,000[b]	0,000	1,000	0,000	8,271E-14

a. Dependent Variable: Pre_op_LOS_td_plusnextday

b. Predictors in the Model: (Constant), Ward10, Thursday, Sunday, Friday, Wednesday, Tuesday,

Appendix VIII – Data example from June 2014