Prediction of Surgery Time

Masters's Thesis at Aalborg University Hospital

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Pontoppidanstræde 103
9000 Aalborg
http://www.aau.dk

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Mikkel Lyngholm Olsen

Supervisor:

John Johansen

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Synopsis:

The graduating project is developed in collaboration with Aalborg University Hospital in Aalborg, Denmark. The project addresses the challenge of predicting future surgical duration at the elective surgeries conducted at O6. The missing accuracy of estimated surgery duration results in under- and over coating of the operating theatres. Undercoating at O6 results in 21 % none-utilised capacity in 45.9 % of annual available days while over coating increases labor cost through overtime or compensatory time off. The project seeks to increase the accuracy of predicted surgery time from a statistical process control perspective, with the purpose to increase capacity utilization without using overtime. Patterns of procedure codes, operating surgeons, and patient characteristics based on historical data are used to identify tendencies and patterns relative to process variability. The distribution of required operating time associated with the three factors makes it possible to estimate future surgical duration time based on a statistical approach. Three solutions are developed to illustrate how productivity is affected by the extent of the detected probability used when patients are scheduled.

Contents

Preface

The graduation project is elaborated by Mikkel Lyngholm Olsen on the 4th semester at Operations & Innovation Management master program at Aalborg University. The graduation project is based on the foundation of knowledge and skills in the domain of operations and innovation management. The graduation project is developed in collaboration with Aalborg University Hospital in Aalborg, Denmark, where engineering skills have been applied to analyse and solve an academically challenge and industrial relevant problem at Aalborg University Hospital. The project focus on how future surgical duration can be estimated with the purpose to eliminate under- and over coating and find an acceptable capacity utilisation of the operating theatres.

It has been a privilege to corporate with Aalborg University Hospital and a special thanks to all employees who have contributed to the progress of the project. The support from John Johansen sincerely acknowledges. Through competent guidance, patience, and enthusiasm he has been helpful to the execution of the project. He had contributed with knowledge and constructive criticism to increase the learning experience and validity of the project.

Readers guidance

Throughout this project, the Harvard citing method is used. The references are compiled and arranged at the end of the report as a complete reference list. The references in the report will lead the reader to the entire reference list at the end of the report, where books are submitted by author, title, edition, and publisher. The web pages will be submitted with author, title, and URL. Figures, equations, and tables will be numbered according to the chapter, i.e. the first figure in chapter 3 is numbered 3.1 and the second 3.2 etc. Supplementary text to each figure and tables will be displayed below where information of etc. the figure is provided.

Mikkel Lyngholm

Mikkel Lyngholm Olsen

<mlol15@student.aau.dk>

1 Abstract

Projektet er udarbejdet som et kandidatspeciale på Operations & Innovation Management ved Aalborg Universitet. Kandidatspecialet er udarbejdet på baggrund af den tilegnede viden indenfor domænet med det formål at analysere, og løse et akademisk og industrielt relevant problem i tæt samarbejde med Aalborg Universitets Hospital (UH).

Projektet tager udgangspunkt i afdeling O6 på Aalborg UH, som er en afdeling der kun håndtere elektive operationer ud fra de to operationsstuer, der på nuværende tidspunkt er til rådighed. Som en del af den fremtidige om okering til New Aalborg University Hospital (NAU) vil O6 ikke have deres egen operationsstue.

Operationsstuerne på O6 er tilgængelige fra kl.8:00-15:00 fra mandag til fredag, hvor fem speciale har fået tildelt et fast råderum til at kunne møde efterspørgslen indenfor den faste åbningstid. På baggrund af historisk data belyses produktivitet for O6 i for-analysen, hvor det kan konkluderes at produktiviteten er faldende, samt at der i 2019 i gennemsnit behandles 6,90 patienter om dagen, svarede til 3,45 patient pr. stue pr. dag. Derudover, var det tydeligt at den nuværende præcision ift. antallet af planlagte patienter og dets varighed ikke stemmede overens med ovenstående åbningstid, da operationsstuerne er præget af under- og overbelægning. Den manglende præcision gør, at O6 ikke opnår den maksimale produktivitet, som et resultat af underbelægning og dermed også ikke-udnyttet kapacitet, mens overbelægning resulterer i overarbejde. Den manglende præcision belyser et nuværende to-sidet problem hos O6, hvor den ikke udnyttet kapacitet i 2019 har resulteret i en tabt produktivitet svarende til 6.65 % ift. volumen. I fremtiden vil den manglede præcision også påvirke andre afdelinger, eftersom operationsstuerne skal deles og bookes på tværs af diverse afdelinger når Aalborg UH flyttes til NAU.

Den tosidet er problemstilling forårsaget af manglende præcision af estimeret operations tid er blevet brugt som ledestjerne for det efterfølgende arbejde, hvor den nuværende planlægningsprocedure er undersøgt, samt mulighederne for mønstergenkendelse ift. den nødvendige operationstid er analyseret fra et statistiks proces kontrol perspektiv. Formålet er at kunne skelne mellem "random variation" og "assignable variation" for at kortlægge, hvad der har forårsaget en udvidet eller kortere operationstid ud fra procedure koder, kirurger og patient karakteristika. På baggrund af statistike algoritmer er det muligt at estimere den nødvendige operationstid ud fra de tre faktorer. Med den øget præcision for den estimeret operationstid er der udarbejdet tre løsningsforslag, for at illustrer effekten af hvor stor en sandsynlighed der ønskes afdækket når fremtidige patienter planlægges.

Introduction 2

The graduation project is elaborated in collaboration with Aalborg University Hospital in Region North. The scope of the project is limited to the department of Orthopedic surgeries called O6 where only elective surgeries are conducted. The two operating theatres at O6 have fixed opening hours from 8:00 am to 3:00 pm but, missing accuracy of predicted surgical duration causes under- and over coating of the operating theatres. The cause-effect of missing accuracy is non-utilised capacity which affects productivity negatively since the full potential is not utilised. The issue of non-utilised capacity leads to lost production time, covering lost productivity of at least 6.65 % by volume. Furthermore, when Aalborg UH changes their location to NAU, the operating theatres are shared among departments which makes it even more important that estimated surgical duration is estimated as accurately as possible.

The current scheduling approach is challenged by investigating the opportunities for using historical data and the theoretical perspective of statistical process control as a supporting scheduling tool. By using already collected historical data of completed surgeries at O6, characteristics of procedure codes, operating surgeons, and patients were investigated. By looking into the characteristics of the three factors, it was possible to divide the population into minor sample sizes and decrease process variability related to time. But, the complex nature of real-world variables makes it almost impossible to correctly predict future surgical duration on a regular basis. Therefore, it is necessary to consider the scope of probabilities that should be included when future surgical time is estimated to achieve an acceptable capacity utilization of both operating theatres.

Introducing the Ambulatory Surgery 3

The following chapter briefly covers information of Aalborg University Hospital and the characteristics of the O6 department as the department used as origin.

3.1 Aalborg University Hospital

Aalborg University Hospital (UH) is a service organization and the largest hospital in terms of capacity, resources, and volume in Region North located in North Jutland. Aalborg UH consists of two hospitals in Aalborg, called South and North, however, departments in Farsø, Hobro, and Thisted are also a part of Aalborg UH. Aalborg UH has a vision of being a hospital with the human at the center focusing both on employees and patients at the hospital. The hospital is established and focusing on three guiding principles who also are set to be the mission of Aalborg UH: Aalborg University Hospital [2019]

- We create secure and effective treatments with the patients as a partner.
- We develop the treatment of tomorrow.
- We educate the employee of tomorrow.

The top management at Aalborg UH consists of a hospital director, nursing director, medical director, and director of economics & operation. Together they have the responsibility to drive Aalborg UH and the 6,646 employees as a sustainable organization. The four directors are as follow:

- Hospital director: Jens Ole Skov
- Nursing director: Lisbeth Kjær Lagoni
- Medical director: Michael Barüner Schmidt
- Economics and Operation director: Kim Mikkelsen.

3.2 Orthopedic Surgery - O6

The orthopedic surgery department O6 is a part of Aalborg (UH) as a service organization that only conducts elective surgeries. Elective surgeries are also referred to as one-day surgeries where the patient enters and leaves the department the same day. The department is available from Monday to Friday within the opening hours of 7:30 am - 5:00 pm and the operating theatres are available from 8:00 am - 3:00 pm available in 220 days annually. The productivity of O6 from 2017 - 2019 is illustrated in table 3.1. In 2017 the department of

O6 had extended opening hours every Wednesday but, these are removed from the data to have a comparison annual output. The annual output of the completed number of patients has decreased with 14.85% within the three years.

Year	**2017**	**2018**	**2019**
	1,784	1,542	1,519

Table 3.1: *Total number of annual completed surgeries from 2017 - 2019.*

The number of completed patients is illustrated per quarter in figure 3.1. As illustrated in figure 3.1, variations of the output occur even though it could be assumed to be static when all surgical operations are scheduled.

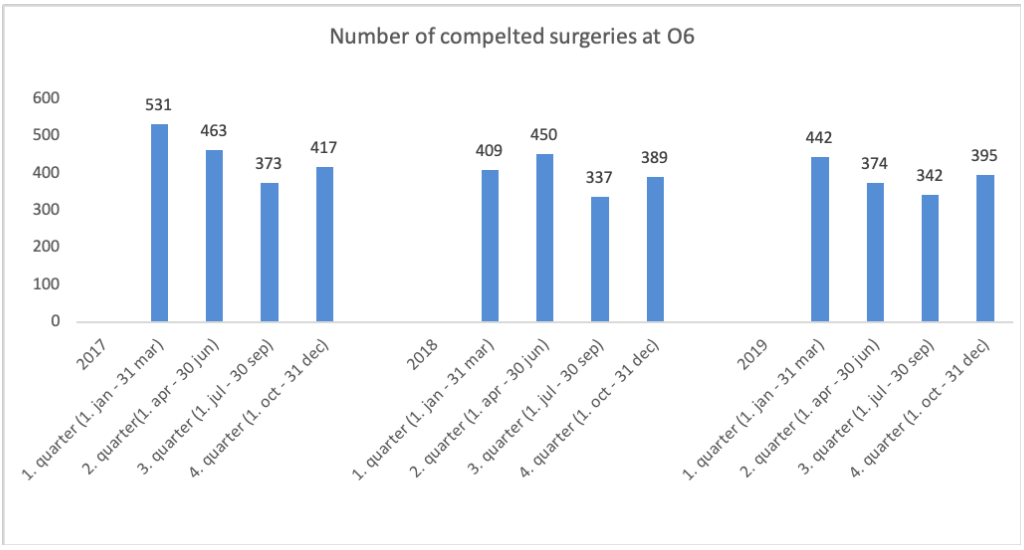

Figure 3.1: *Number of completed surgeries at O6 from 2017 - 2019*

In the period from 2017 to 2019, it can be concluded that the lowest number of completed surgeries are conducted in the third quarter every year. Since the output is consistently lower in the third quarter it could be assumed that holidays could be used as an explanation of the decreased output. The surgeries managed at O6 are divided into five sectors of surgery, Athletics, Children, Feet, Trauma, and Tumor.

3.2.1 Staff members at O6

Department O6 is divided into two areas, Arrival & Recovery and Operating Theatre as illustrated in figure 3.2 with numerated arrows showing the sequence of patients based on the principle First in, First out (FIFO). The staff required at O6 is distributed by each professionalism based on an annual activity plan. The activity plan shows where and the number of resources who are required at each department. The annual activity plan is used to create the dusty roster every fourth week required by law. All resources are located at the operating theatre for a whole day regardless of the number and type of surgery. Each professionalism affiliated to their area of professionalism where static guard and coordination across professionalism is largely absent. The professionalism is located at O6 but, their affiliation lies at their professionalism. The patients are received in the arrival area by two Post Anesthesia Care Unite (PACU) nurses who prepare the patient before operation and take of the recovery after the surgery is completed. In the operating theatres, 11 staff members from four different professionalism, Orthopedic nurses, Anesthetic nurses, Anesthetic doctor, and Operating surgeon is located as illustrated in Appendix A, figure A.1. The operating principles during a patient flow is illustrated in appendix A, figure A.2 for each professionalism. The processes handled at O6 is categorised as low technical complexity meaning the staff has a central role to play during the treatment of patients. The workers need to have a high skill level and processes are primarily driven by both explicit and tacit knowledge but, formalized procedures are difficult to elaborate within the sector of healthcare, Daft [2009]. Staff members as Cleaning staff and Hospital porter are supporting resources and are not directly linked to the department.

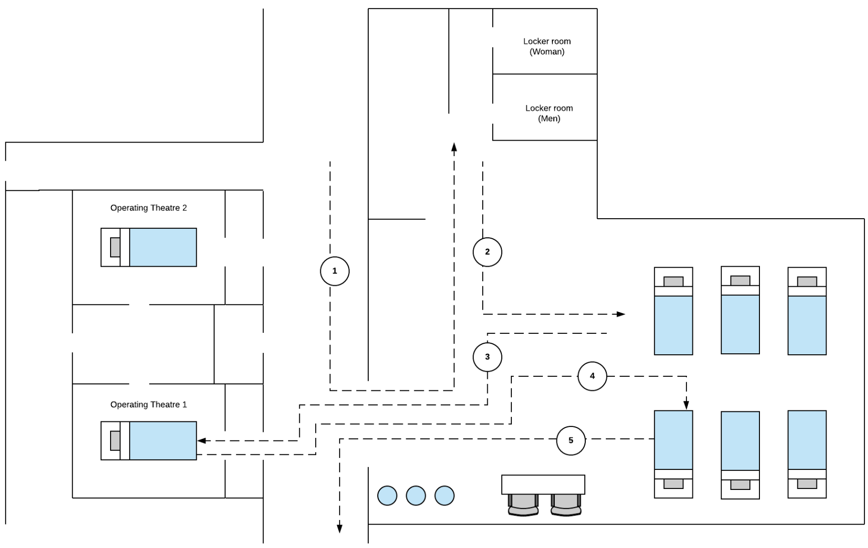

Figure 3.2: *Facility Layout of O6 including a standard flow of a patient.*

The explanation of characteristics at O6 involved employees has established a common understanding of the environment that affects O6. The obtained information will be used as a foundation for the initial analysis in chapter 5. Before the initial analysis is covered in chapter 5, the following chapter 4 will elaborate on the execution and used methodologies of the project through a project design in chapter 4.

Project Design 4

The chapter elaborates on the considerations taken into account for the chosen framework applied to conduct this project. The chapter is used to secure the validity of the analysis and findings of the project. Firstly, the framework used throughout the project is presented before further considerations are elaborated.

4.1 Framework for Project Assessment

The projects is driven by framework of Gertsen [2017] illustrated in figure 4.1. The approach consists of two interactive phases starting with the Problem framing. Real-world problems are identified in collaboration with O6 before they are analysed and supported with theory to defined the core problem used to narrow the scope of the project before the second phase Problem solving is started based on research questions. The second phase consists of analysing and developing suitable solutions to the core problem defined in the first phase, Problem framing, where limitations and boundaries have been set.

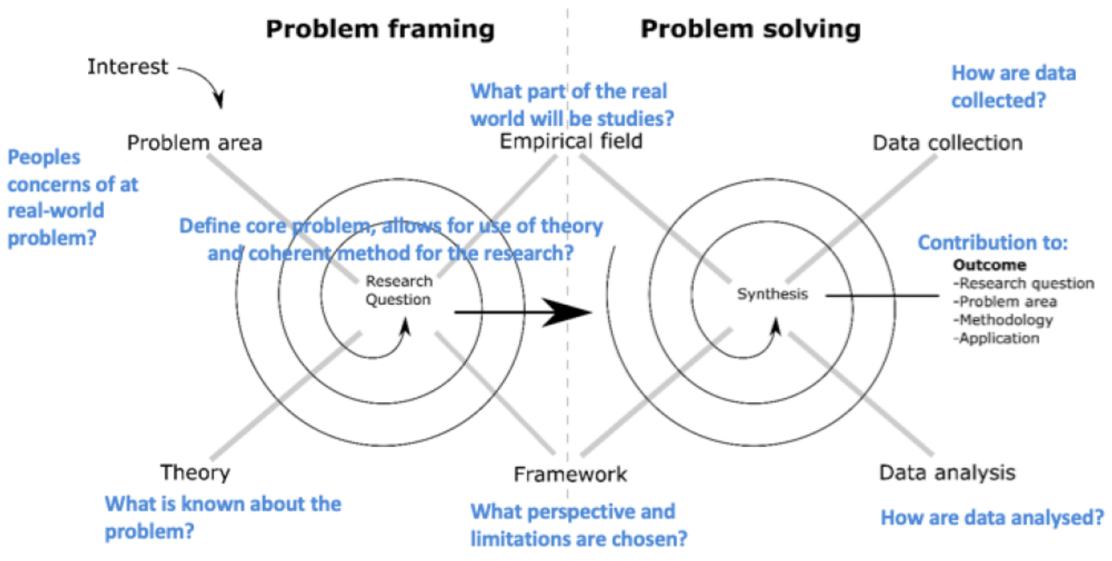

Figure 4.1: *Inspirational framework by Gertsen [2017]*

As illustrated in figure 4.1, the framework consists of a circular approach where the project loop back and forth between the phases when ideas are redefined and new directions are taken. The structure of the project is based on the Design Thinking process as guidance where the project passes through three spaces during project execution. The three spaces are categorised as Inspiration, Ideation, and Implementation, Brown [2008].

- **Inspiration:** The first space is a part of the problem framing used to detect to reveal and specify the underlying problems or opportunities to motivate the search for suitable solutions. The purpose of the initial analysis is to verify the real-world problem based on data, facts, and theory. Henceforth, a problem statement is established to concertise the goal of the project and set up boundaries, limitations, and assumptions who create the basis of the main analysis and solution.
- **Ideation:** The second space consists of the main analysis used as further investigations of the core problem that underpins solutions development. During the main analysis, investigations will be driven by generating, developing, and testing ideas leading to a solution. The ideation phase is conducted in collaboration with the employee at O6 to secure the relevance and setup acceptable limitations used when patterns based on historical data are investigated.
- **Implementation:** Cover the suitable solutions fitting to the requirements matching the problem statement reflecting a real-world problem. The solution is developed and presented, however, the implementation phase is out of the scope of the project. Recommendations are briefly elaborated in chapter 10.

To illustrate the structure of the project including the Design Thinking process and the Inspirational framework figure 4.2 are created. The report will be driven by examples using Athletics as the sector of surgery and the procedure KNGD11 as the most frequent perform surgery based on volume. The findings of the remaining sector of surgeries and procedure codes are illustrated in the Appendix.

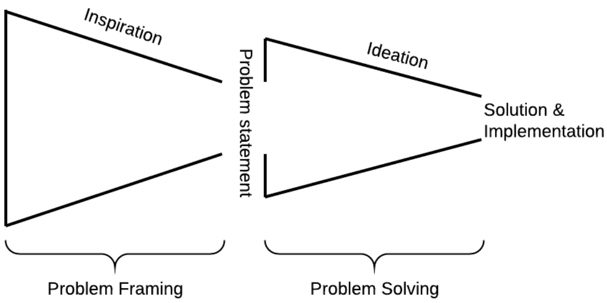

Figure 4.2: *Structure of the project*

4.2 Data Collection

The project is based on primary and secondary data provided by Aalborg UH or collected through field studies. Throughout the project has process of collecting data become more specified in proportion to the scope of the project is narrowed, as illustrated with the loops in the project framework in figure 4.1.

4.2.1 Qualitative data

Qualitative data is defined as data that can not be measured or stored and is conducted through observations or records. The data used throughout the projects is collected through interviews and communications with employees who are related to O6, such as Orthopedic- and Anesthetic nurses & doctors, Operating surgeons, Planning department, and Management at O6. Furthermore, field observations were conducted used to understand, investigate, and explain different parameters of the current situation at O6. Further, inputs and knowledge from employees have been taken into account during the progress to embrace and involve the knowledge and opinions of the employees at O6. The field studies are based on information gathered on last semester (9.semester - OIM) since O6 has been closed due to COVID-19. The issue of COVID-19 did also influence the ability to interact, communicate, and involve the employees negatively because other duties were prioritised.

4.2.2 Quantitative data

Quantitative data is defined as data that can be counted and measured. The data is extract their ERP-system (BookPlan). The quantitative data primarily consists of excel sheets. The trustworthiness of the data was detected in collaboration with fixed employees who are a part of the daily operations at O6 to secure the validity of data. While data was cleaned it was noticed that the available data was affected by missing registrations and unrealistic values in proportion to time caused by a poor registration practice at the operating theatres. The unrealistic and non-valid data was removed in collaboration with the employee at O6.

4.3 Data at Aalborg University hospital

The historical data covers the period from primo 2017 to ultimo 2019 used to analysis performance at O6. The data from 2017 and forward is used to clarify the output of patients and the utilisation rate of the operating theatres. Data registrations from primo 2018 to ultimo 2019 is used to analysis the flow of patient relative to time. The data registrations expose the scope of time when the patient enters the operating theatre until they leave the operating theatre as illustrated with arrow three and four in figure 3.2. The data registrations before 2018 are not usable because missing validity which narrows the scope of data used to establish the project. Even though the time horison was decreased to secure valid data registrations in proportion to time and detailed characteristics of procedure code, surgeon and patients characteristics lack of quality was still present in the data. Table 4.1 illustrates the availability of data relative to completed surgeries at O6. In total 3,370 rows were available in the excel sheet, illustrated with the first line "Data" and the scope of missing and unrealistic data is illustrated below in proportion to specific characteristics.

Patient info:	Gender	Age	ASA cat.	BMI
Data	3,370	3,370	3,370	3,370
Missing data	0	0	1,604	1,634
Available data	3,370	3,370	1,766	1,736
Available data (%)	100	100	52.40	51.51

Table 4.1: *An overview of the data available related to characteristics of the patients from 2018 - 2019.*

Secondly, information of the completed surgeries where used to investigate patterns between surgical information. The availability measured surgical duration is illustrated in table 4.2.

Surgery info:	Procedure code	Operating surgeon	Surgery time	Type of anesthesia
Data	3,370	3,370	3,370	3,370
Missing data	0	160	250	1,598
Available data	3,370	3,210	3,120	1,772
Available data (%)	100	95.25	92.58	52.58

Table 4.2: *An overview of the data available related to information of the surgery from 2017 - 2019.*

As illustrated in table 4.1 and 4.2, the availability of information vary among the different categories. The variation of available data affects the scope data to support the findings of the report. Furthermore, the quality of data registrations among procedure codes and operating surgeon vary which affect the detail level of investigations in proportion to the above-mentioned factors. In addition, it should be noted that table 4.1 and 4.2 only focus on the availability and not the quality of the data. The disadvantages of missing and none-valid data used to draw conclusions and futuristic decisions is illustrated in figure 4.3.

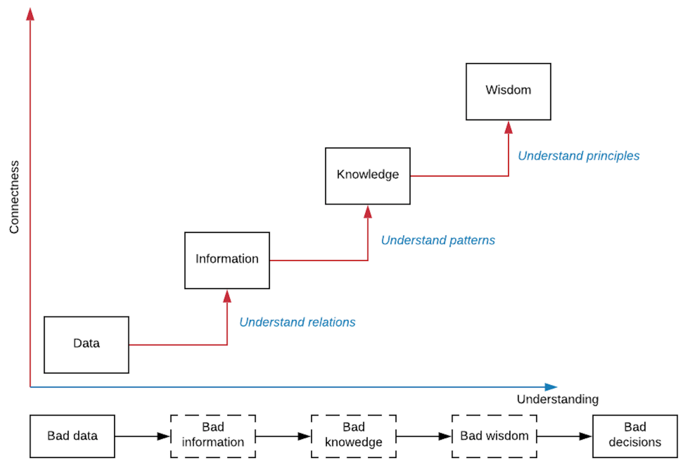

Figure 4.3: *Data used as a foundation to make decision Shamieh [2011].*

Simply, the content of figure 4.3, can be put as, garbage in, garbage out. Data errors can be caused by multiple factors however human errors are assumed as the primary explanation to data errors as a result of the current manual registration procedure. Human errors are primarily caused by Typing errors, Spelling errors, Right data in the wrong field, Stopped in-typing data half ways, or Lack of commitment to capturing data, Manning [2015].

Furthermore, the current organisation structure makes it difficult to use the captured data in daily work. Data is managed by the Digitalisation & IT (BI) department and is not directly available to other departments, Region Nordjylland [2019]. If a department would like to analysis performance or obtain information and knowledge through data they need to request the BI department who managed the request within 14 working days, but extended waiting time is not unfamiliar. The current organisation structure makes it difficult to included data in daily work and has been an obstacle throughout the project.

Initial Analysis 5

The following chapter investigates the current scheduling principles at O6 and how it affects the productivity of the O6 department. Further, future requirements as a part of the relocation to NAU will be taken into account to clarify how the new location will affect the internal processes related to planning if the current approach continues at NAU.

5.1 Planning Procedure

As mentioned in chapter 3, only elective surgeries are handled at O6 which decreases the uncertainty compared to emergency surgeries and urgent surgeries, but complexity could still not be despite. Elective patients make it possible to reserve the operating theatre, and the staff will have been provided with the required information in advance. When future surgeries times are predicted it is a formalisation of what is intended to happen in the future however, uncertainties and changes could still occur since the patient has been scheduled. These changes are not possible to predict in advance and are solved through daily adjustments if necessary. Guido and Conforti [2016]. The planning procedure is illustrated in figure 5.1 where the sequence is shown starting with a preliminary examination conducted by an operating surgeon. The collected information is required before the second phase could be started.

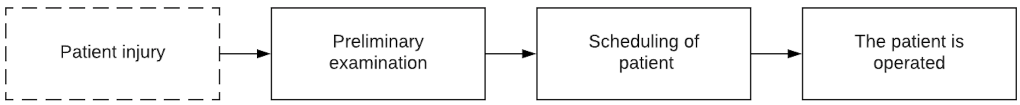

Figure 5.1: *Planning procedure when patients are scheduled at O6*

When patients are scheduled information collected during the preliminary examination as illustrated in figure 5.1 is required. The preliminary examination is conducted by an operating surgeon and anaesthesia doctor covering the following points:

- **Operating Surgeon**
  - Is it necessary to operate the patient?
  - Procedure code.
  - Estimated surgery time.
  - required equipment.
  - Priority of patient.
  - Positioning of patient during the surgery.
  - Any request related to surgeon?

- **Anaesthesia Doctor**
  - Type of Anaesthesia (GA or LA)
  - ASA category
  - BMI

When the preliminary examination is completed it is possible to schedule the patient. The patients are sequenced by the principles of Customer Priority and Due date. The due date is determined through patent rights and every patient has the right to be operated within 30 days after preliminary examination, RN. [2018].

Otherwise, patients have their right to be sent to another hospital in another Region or the Private sector unless they accept the extended waiting time. If patients are managed by another Region or the Private sector extra costs are added compared with the cost of in-house surgeries. The cost increases with 40-50% if the patients are sent to another Region and 10-20% in the Private sector compared with the internal offer-price. It not possible to detect the exact amount of patients from O6 who is handled by external organisations because it is computed on the clinic level and not at each department. In total, 295 patients related to the feet and ankle sector and 563 patients related to arthroscopy and athletics are handled by external organisations in 2019 and it is assumed that some of the patients are linked to O6. Furthermore, patients are scheduled by using customer priority sequencing, which allows emergency or highly prioritised due to the extent of injury to be processed before others, irrespective of their arrival. The priority of customers can also be managed across the sector of surgery if necessary. Slack [2013].

5.1.1 Capacity Planning

Previously, the long term planning was based on last year's productivity, where it was expected that productivity increases with 2% in the following year. The long term horison planning is changed to non-measurable performance criteria because financial resources are allocated to the department and they have the responsibility of producing as much as possible.

The capacity at O6 is distributed among the five sectors of surgery as illustrated in figure 5.2. The distribution of days is fixed based and is not equally distributed as a result of variance in demand within the sectors. Flexibility among the different sectors can be used, if prioritised patients need to be moved forward or if waiting list attends to exceed. Furthermore, capacity can be released one week ahead if the case-mix not can complete the entire day. When capacity is released it could be used by other sectors of surgeries at O6.

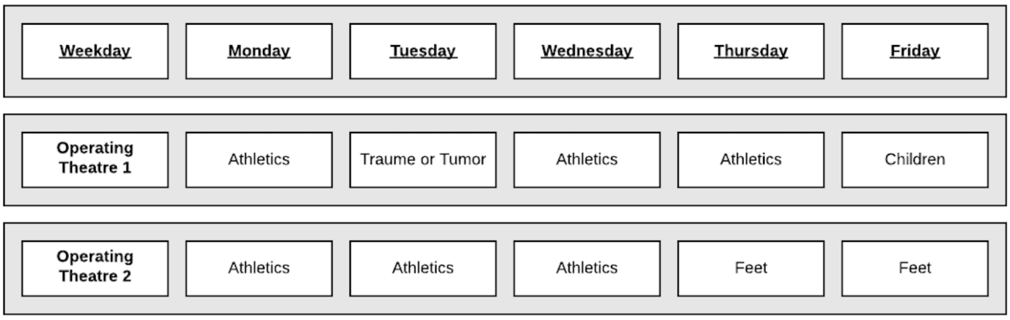

Figure 5.2: *The fixed distribution of weekdays among the five sector of surgeries.*

The scheduling process of future patients is decentralised to each sector of surgery managed by a Secretary and an Operating surgeon. The scheduling process is not managed by a Master Planner team but, always by these two types of professionalism. The process of scheduling is limited by the capacity limitation due to the fixed opening hours from 8:00 am to 3:00 pm at the two operating theatres using a level capacity strategy and finite loading approach. Slack [2013]. Each sector of surgery uses explicit knowledge to schedule future patients based on a standard summons template illustrated in Appendix B. The summons template has 4-6 available time-slots. The variation of time-slots is required because of the variation of required surgery time among the elective surgeries.

5.1.2 Planning principles at O6

The scheduling process is started by checking if the required operating surgeon and equipment are available before the optimal case-mix is established. The case-mix is defined based on the summons template illustrated in appendix B where the surgical procedure codes are scheduled.

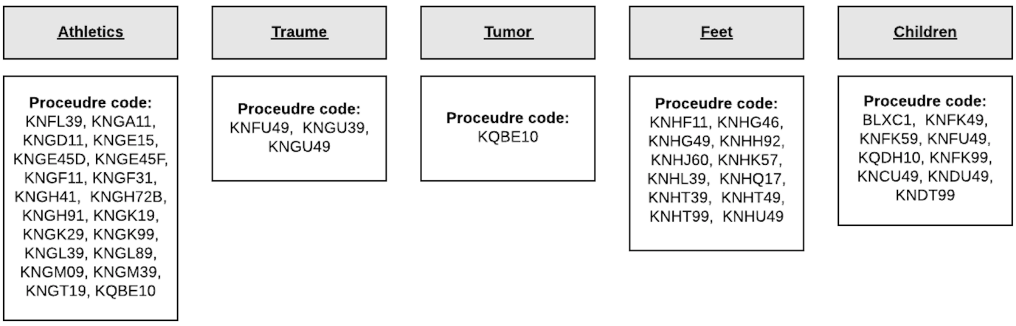

Figure 5.3: *The different surgical procedure codes distrusted on respective their sector of surgery.*

The approach of how to establish the optimal case-mix varies across the sector of surgery. Some sectors use the assumption of the average time of surgical procedure codes as an indicator of the required time. The assumption is based on gut feeling and tacit knowledge. Other sectors use the estimated surgery time collected through the preliminary examination. Both approaches rely on estimations therefore embedded knowledge is required which also makes the process of planning dependent on tacit knowledge by the secretary or operating surgeon despite the available explicit knowledge. Both approaches are useful and acknowledge within the sector of healthcare, Pandit [2019]. Additional, intern performance measurements based on soft values are taken into account to secure the best possible treatment with the best patient in the center. The included factors are summarised in figure 5.4

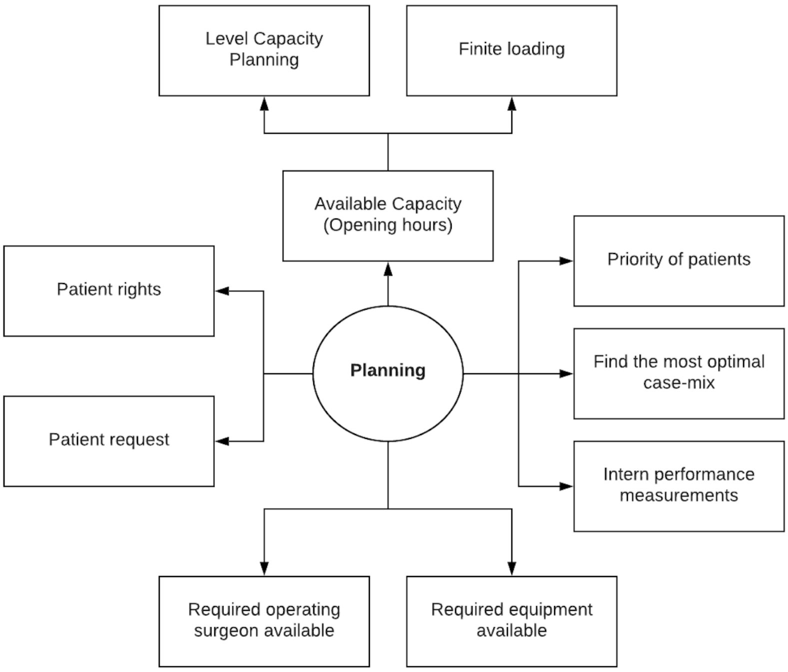

Figure 5.4: *Factors that is considered by the secretary and operating surgeon when patients are scheduled.*

5.2 Operating Theatre at O6

Every patient at O6 is managed throughout a standard process divided into four steps: 1) Arrival, 2) Surgical preparation, 3) Surgery and 4) Recovery. The squares marked with light-grey are activities conducted outside the operating theatre and the white squares are managed inside the operating theatre as illustrated in figure 5.5. The flow of patients is based on a pull system in the first three squares until the surgery is completed, and the patient will move further to recovery before home transportation. The third square "Surgical operation" is the drum that controls the overall output as the control point of the patient flow, Slack [2013]. The surgery conducted at the operating theatres has to be completed before cleaning and surgical preparation for the next patient can get started. To minimise idle time and secure a constant input, step 1 handled by the PACU nurses is handled in advance and patients at the arrival area operate as a buffer in front of the operating theatres.

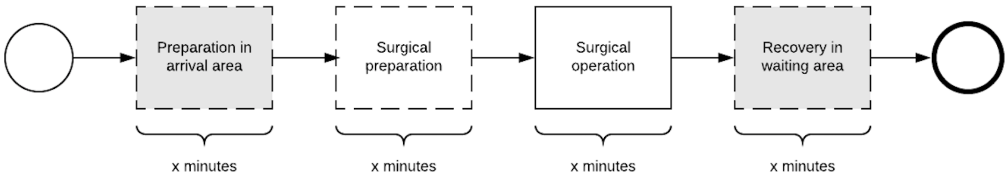

Figure 5.5: *A model illustrating a patient flow at O6 divided into four steps.*

The variation of completed surgical procedure codes is analysed to clarify if the elective surgeries conducted at O6 could be categorised as high variance. As illustrated in table 5.1 it can be concluded that a high number of surgical procedures are recognisable and variation of handled surgeries are categorised as a low variance.

Year	**Output**	**Top 10**	**Top 3**
2017	1,784	78.31%	45.85%
2018	1,542	81,58%	50.60%
2019	1,519	81.33%	45.98%

Table 5.1: *A illustration of how much 10 and 3 surgery code constitutes of the total distribution*

The variation of completed surgeries at O6 is low since 78-81.5% of the annual output is covered by 10 different surgical procedure codes and repetitive work could be present. Since, all patients are scheduled and the product type could be categorised as low variance it is assumed that uncertainty is rather low compared to other departments at Aalborg UH, Daft [2009]. The assumption of low uncertainty will be investigated by evaluating the process variability measured in time at operating theatres in the following section.

5.3 Process Variability

The following analyses are based on a sampling distribution consisting of 20 randomly picked observations distributed on a sample size corresponding to the annual working weeks. The sample size is monitored weekly, meaning the process variability is analysed across the sector of surgery, as illustrated in figure 5.2. The process variability is illustrated with control charts as a time-ordered plot of the sample statistics used to distinguish between random variability or non-random variability. A Mean and Range chart of surgery time in 2018 and 2019 is used to monitor variables. Furthermore, Upper Control Limits (UCL) and Lower Control Limits (LCL) are set to indicate the expected extent of common cause variation and to clarify whether the process is stable or unstable as a result of random or non-random variation. Stevenson [2012]

5.3.1 Surgery time - 2018

A sampling distribution of completed surgeries is illustrated in figure 5.7 and 5.9. Figure 5.7 illustrates a Mean control chart used to monitor the central tendency of a process to illustrate if changes in the average output occur. Changes of the mean indicate that the process is moving away from the supposed process average weekly. The control limits have a UCL of 56.18 minutes and LCL an of 16.32 minutes. The control limits are calculated with the following formula as illustrated in figure 5.6.

$$\text{UCL} = \bar{\bar{x}} + A_2\bar{R} \qquad \text{LCL} = \bar{\bar{x}} - A_2\bar{R}$$

Figure 5.6: *Calculation of UCL and LCL used in a mean control charts. The value of A2 is a factor from table 10.3 in Stevenson [2012]*

The control limits are used to detect if the process is deemed as stable or unstable. Furthermore, a central line or grand mean calculated by putting together all means and divided it with the number of observations are illustrated with "Grand mean". As illustrated in figure 5.7 surgery time across all completed surgical procedures has a grand mean of 35.25 minutes in 2018.

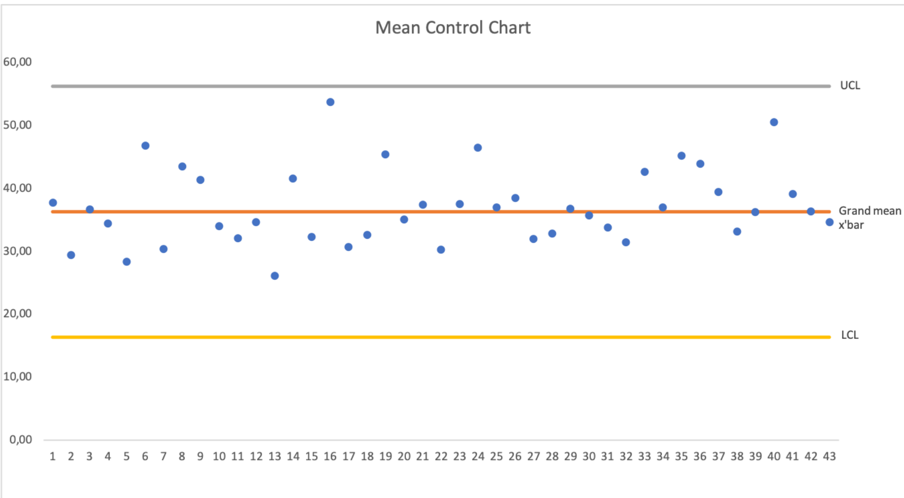

Figure 5.7: *Mean control chart of surgery time of 20 observations distributed on the annual working weeks in 2018.*

The mean of each week (x'bar) is all inside the control limits and is deemed as random variation caused by combined influences of countless minor factors, each one is so unimportant that even if it could be eliminated the impact of the process variation would be negligible. Since all x'bars are inside the control limits the process should be deemed as stable, but the dispersion of plots could be categorised as "Too much Dispersion" from the central line. Therefore, the average spent time across all types of surgeries are not in statistical control. Stevenson [2012].

Range Control Chart

The dispersion of x'bar makes it relevant to analysis the range between surgery time used across all types of surgeries in 2018. To monitor whether the variability of the process is changing a Range control chart is created and illustrated in figure 5.9. The advantages of r-chart are that it shows the differences between the largest and smallest measurements useful to monitor process dispersion by using the following formula:

$$R = x_{max} - x_{min}$$

UCL and LCL are calculated to detect if the process is in control or if the assignable variation has occurred. The UCL and LCL are calculated with the following formula as illustrated in figure5.8:

$$\text{UCL} = D_4\overline{R} \qquad \text{LCL} = D_3\overline{R}$$

Figure 5.8: *Calculation of UCL and LCL used in a range control charts. The value of D3 and D4 is a factor from table 10.3 in Stevenson [2012]*

A central line illustrated with R'bar is calculated by taking the total amount of all R-values divided with the total number of weeks (43). The central line illustrates the average of the range within the period.

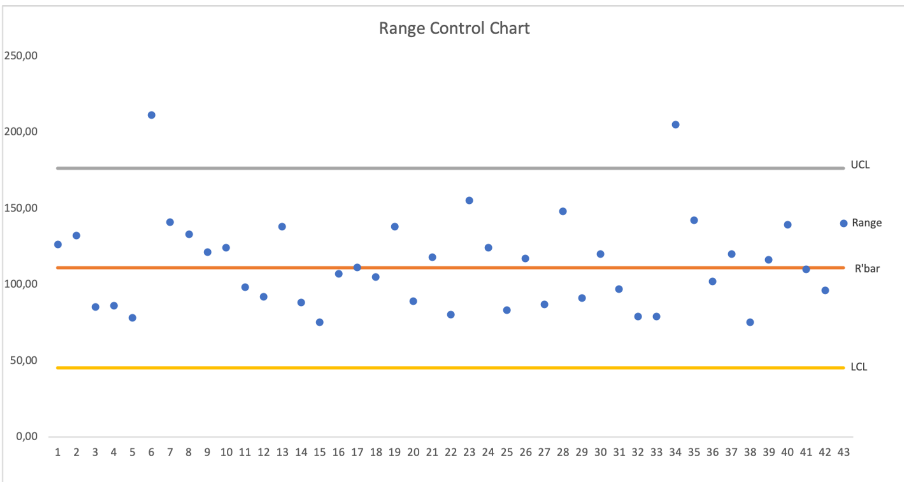

Figure 5.9: *Range control chart of surgery time of 20 observations distributed on the annual working weeks in 2018.*

The Range charts in figure 5.9 show two plots who are above the UCL of 175.05 minutes indicating that assignable variation occurs and the process is therefore out of control. The plots above UCL has a range of 211 minutes in week 6 and 205 minutes in week 34. The assignable variation could be explained by different factors as:. David et al. [2000]

- Surgical Procedure
- Operating Surgeon

- Type of Anesthesia (GA or LA)
- Gender of Patient
- Age of Patient
- Health of Patient

It can be concluded that the process variation of surgeries completed at O6 in 2018 is present when analysing all the types of completed surgeries. Although the product process type can be categorised as low variation and the scope of the analysis is limited to step 3, "surgical procedure" focusing only on the surgical procedure, the spread of surgery time is still present.

5.3.2 Surgery time - 2019

In the following section, a similar analysis as the one in section 5.3.1 is illustrated. Firstly, a mean control chart is illustrated in figure 5.10 to show the central tendency of the surgery time at O6 in 2019. The control chart is based on 20 observations distributed on 42 sample sizes corresponding to the number of working weeks available in 2019.

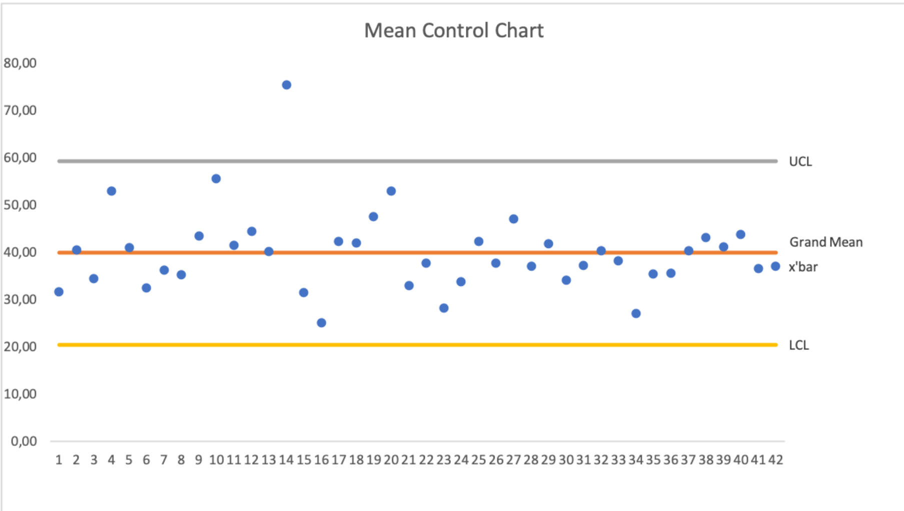

Figure 5.10: *Mean control chart of surgery time of 20 observations distributed on the annual working weeks in 2019.*

As illustrated in figure 5.10, one plot exceeds the UCL limit of 59.3 minutes indicating an unstable process. The plot who exceeds the control limits is categorised as an assignable variation and could be explained by the factors mentioned with the bullet points above. The plots of figure 5.10 illustrate cycle patterns because the plots illustrate a wave with a declining distribution. The process is unstable but, the dispersion has decreased during the period. Stevenson [2012]

Figure 5.11 illustrate the dispersion of the average surgery time in 2019. It is seen that the range between the highest and lowest measurement is widely distributed where week 10 exceeds UCL and week 24 is close to LCL.

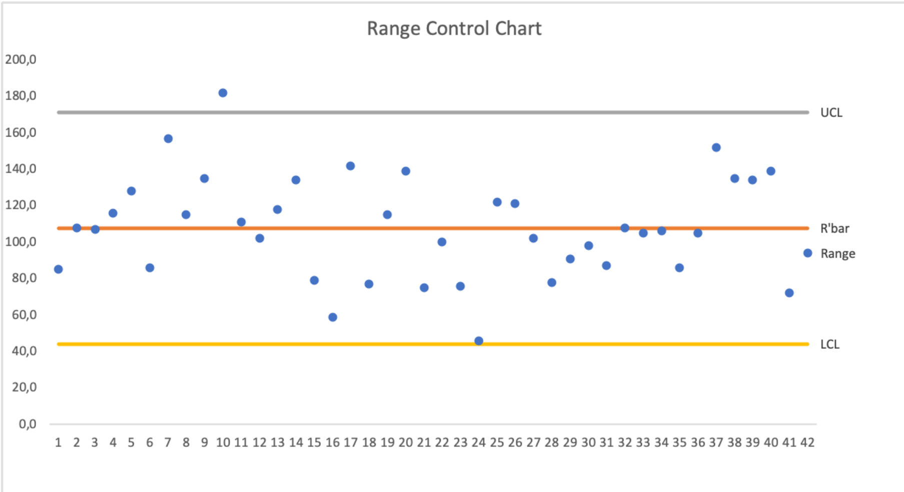

Figure 5.11: *Range control chart of surgery time of 20 observations distributed on the annual working weeks in 2019.*

Based on the dispersion of observations in 2018 and 2019, process variability seems to be present among the surgeries conducted at O6.

In table 5.2 the process variability is distributed on weekly working days to illustrate the number of completed surgeries related and average surgery time related to weekdays. Furthermore, a standard deviation (SD) of each day is used to describe how much data varies around the mean, meaning the larger standard deviation is, the greater the spread of the data. The standard deviation is calculated with the following formula: Agresti [2009].

$$\sigma = \sqrt{\sum (y_i - y_{bar})^2/(n-1)}$$

The average of surgery is illustrated with both mean and median. The median is not affected by outliers as when the mean of the population is calculated.

Day	**No. obs**	**Mean**	**Median**	**SD**	**CV**
Monday:	646	38.11	27	31.57	0.82
Tuesday:	711	33.70	25	26.72	0.79
Wednesday:	650	41.21	26	36.67	0.88
Thursday:	614	40.60	32	30.75	0.75
Friday:	565	37.45	31	27.36	0.73

Table 5.2: *Process variability distributed on sector of surgery.*

As illustrated in table 5.2, the volume of completed patients differentiate between the available days, which could indicate that required surgery time varies among weekdays. However, weekdays have a standard deviation of +26 supporting the argument of variation among surgery time. Based on the standard deviation and mean it is possible to comment if the distribution of variance is deemed as high or low through the calculated coefficient of variation (CV). The CV value is calculated with the following formula, Agresti [2009].

$$CV = sd/mean$$

As a rule of thumb, a CV >= 1 is categorised as high variance while a CV < 1 is categorised as a low variance. The variance of weekdays can not be categorised as high variance because none of the CV-value exceeds or is equal to one.

Even though none of the CV values can be deemed as high variance, it is closer to high variation versus a low variation. Since variation is present it is assumed to be difficult to predict the future surgical duration. The following section looks into how the performance is affected by the present process variability to investigate how O6 is able to cope with the dispersion of surgery time.

5.4 Current Performance

A commonly shared mentality within the sector of healthcare is that a surgical duration is unpredictable. The fallacy rests on the idea that any task is a complex series of steps and the duration of one step dependent on the preceding step. Consequently, the duration of the whole procedure is deemed “unpredictable”, Pandit [2019]. The mentality could originate by the findings in section 5.3, showing that process variability is present within a department who only conducts elective surgeries with product process deemed as a low variation. As a result of the shared mentality of surgical duration being unpredictable historical data is used to analyse how the process variability and mentality reflect the current ability to estimate future surgery time.

The performance of O6 is measured based on the capacity utilisation rate of the operating theatres indicating the ability to use the dedicated productive capacity. It is set up a specific productive capacity of the operating theatres however, calculations of the capacity utilisation are made by using the lowest and highest amount of available time-slots. The capacity utilisation is calculated with the following formula: Stevenson [2012]

$$Utilisation = (AO/DC) * 100\%$$

AO is a shortening of ”actual output” and DC is a shortening of ”design capacity”. The design capacity is the maximum designed output rate and since min. four and max. six time-slots are used to analysis the utilisation of the operating theatres. The capacity utilisation calculated with four time-slots is illustrated as CU1 and capacity utilisation calculated with six time-slots is illustrated as CU2. The results of the calculated capacity utilisation of both operating theatres annually are illustrated in table 5.3.

Year	Output	CU1	CU2
2017	1,784	101.36 %	67.57 %
2018	1,542	87.61 %	58.40 %
2019	1,519	86.30 %	57.53 %

Table 5.3: *A illustration of how much 10 and 3 surgery code constitutes of the total distribution*

As illustrated in table 5.3, the capacity is exceeded in 2017 if the calculations with four time-slots are used. Otherwise, the operating theatres are not fully utilised in 2018 or 2019. The non-utilised capacity could be seen as lost production time since patients could have been treated during that time. To analysis, if the non-utilise capacity actually could be used to complete patients figure 5.12 has been created. Figure 5.12 shows the number of days where an operating theatre finishes the last scheduled patient before 1:30 pm from 2017 - 2019 divided into four quarters in a year.

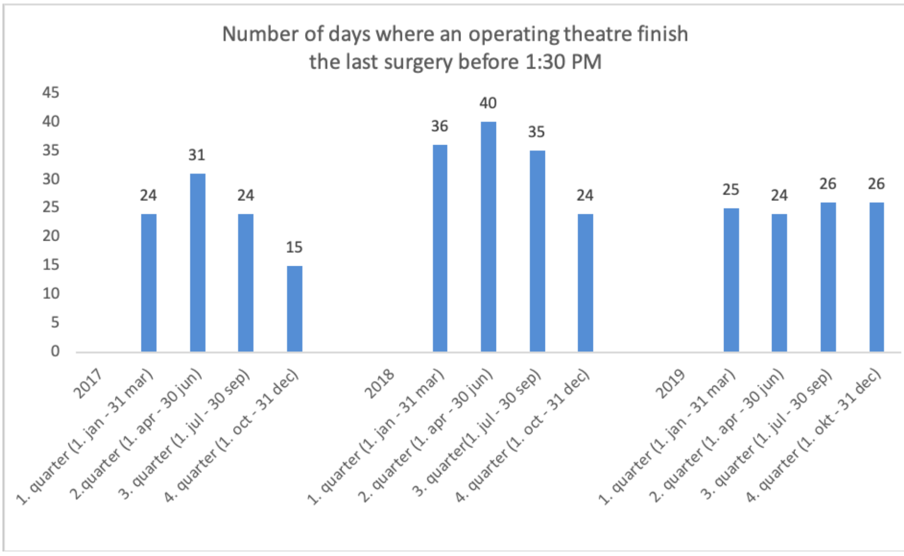

Figure 5.12: *Number of days where the operating theatre complete the last surgery before 1:30 pm*

The number of days finishing before 1:30 pm is used as a performance indicator selected by the management at O6. The performance indicator is selected based on the assumption that an extra patient could have been treated within the non-utilised 90 minutes at the end of a day equivalent to 21.90% non-utilised potential of the operating theatre. Based on figure 5.12, it would have been possible to treat 94 extra patients in 2017, 135 extra patients in 2018 and 101 extra patients in 2019. The number of days finishing before 1:30 pm covers a non-utilised production time equivalent to 5.27-8.75 % lost output from 2017 to 2019. The amount of non-utilised time is an expression of lost production time, as a result, missing accurately predicted surgery time when input at the operating theatres as a control point is missing.

Another cause-effect of the missing accuracy results in extended opening hours of the operating theatre and overtime for the employees. As illustrated in figure 5.13, overtime was required in 44 days in 2017, 48 days in 2018, and 33 days in 2019. When focusing on the days where overtime is conducted in one of the operating theatres it can be concluded that overtime is used in 7.5-10.9 % of the cases from 2017 to 2019.

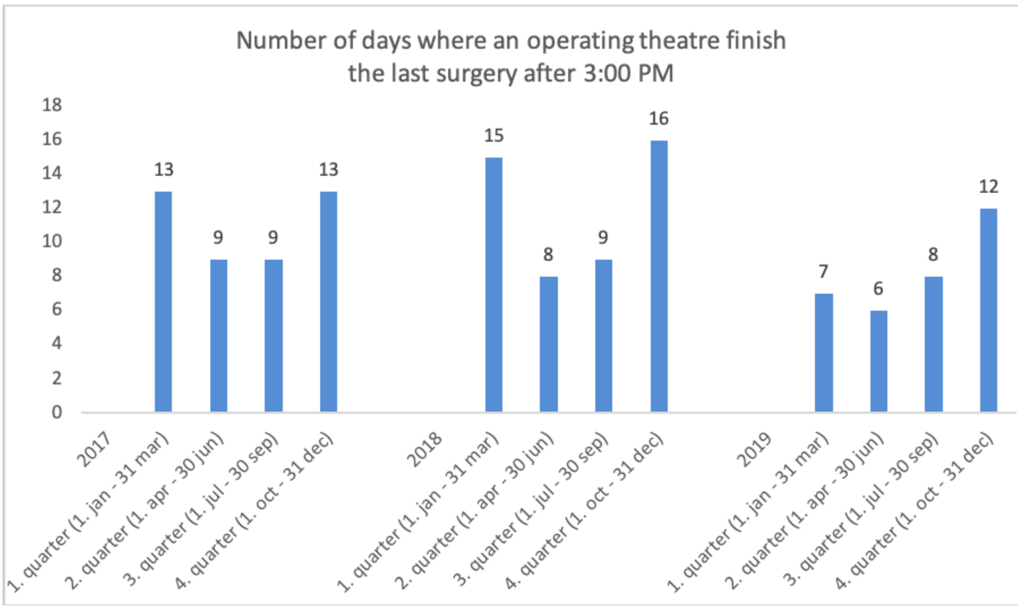

Figure 5.13: *Number of days where the operating theatre complete the last surgery after 3:00 PM*

When overtime is required labor cost increases unless support from the emergency staff is used. The issue of using emergency staff is that it is a scarce resource and should not be used to conduct routine and non-emergency surgeries. Both findings in figure 5.12 and 5.13 indicates that missing accuracy is present and causes a two-part problem. The operating theatres are not fully utilised and overtime is frequently used at O6.

5.5 Future Requirements

The current issue of missing accuracy has been elaborated above and the following section focuses on future cause-effects of the missing accuracy when patients are scheduled.

In 2022, Aalborg UH is fronting a relocation to New Aalborg University Hospital (NAU) located in Eastern Aalborg. At NAU 32 operating theatres are shared among all departments distributed on 28 operating theatres and four hybrid-rooms. The total number of rooms is a minor decline in capacity compared to the current capacity at Aalborg UH. Within the new capacity at NAU, preparation rooms are made to minimise the non-surgery time in the operating theatres. The rooms make it possible to handle the preparation steps in advance, however, it increases the need for accurate estimate surgery time otherwise the preparation would stand idle which is inappropriate if patients are anesthetised or if the equipment has been unwrapped. Leth, A [2019]

Another aspect to consider during the movement to NAU is that none of the operating theatres are directly dedicated to a specific department. Instead, operating theatres are shared and booked by the departments based on their needs related to the expected required surgery time. Therefore, it is important to increase the current accuracy of how patients are scheduled otherwise the entire puzzle of distributing operating theatres among departments at NAU will fall apart. Lack of accuracy will no longer only affect the individual department, but also the subsequent department if an operating room is under or overbooked. The importance of increased accuracy in terms of planning is illustrated in figure 5.14.

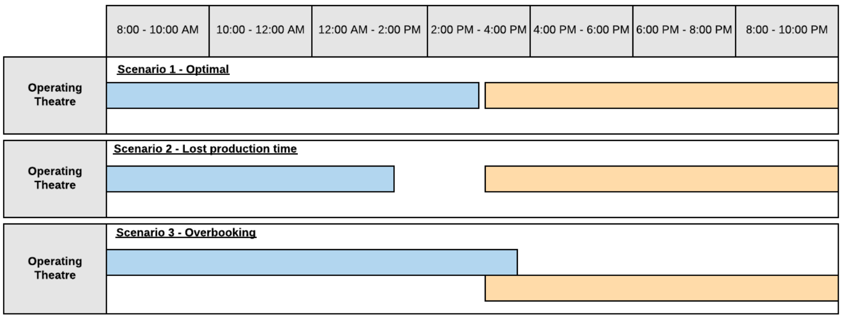

Figure 5.14: *The importance of an increased accuracy illustrated in a Gantt chart showing to different scenarios*

The issue of under or overestimated surgery time is illustrated in figure 5.14 in scenarios 2 and 3. As illustrated in scenario 2 underestimated surgery time will result in other departments starting later than actually possible. If overtime is required it will be conflicting with the scheduled surgeries from other departments as illustrated in scenario 3. As a result of scenario 3, surgeries at other departments will be postponed and possibly create a bull wipe effect of delays through the entire schedule of the room. Otherwise, scheduled surgeries from O6 could end up being canceled if they fear to exceed the planned surgery if scenario 2 is preferred compared with scenario 3. Both cause-effects of missing accuracy is conflicting with the vision and value Aalborg described in 3 and NAU. RN - Projektafdelingen [2010]

Furthermore, the vision of NAU is covered by five aspects, one of them is focusing on Economics. It is stated that NAU should be driven effectively with optimal utilisation of resources across the organisation to utilise the competences of the employees without any idle time during a flow of patients. The utilisation of resources will secure that duties are managed at the lowest effective level of cost and create an opportunity to increase the attention of innovation and research with the purpose to increase employee satisfaction through the released resources. RN - Projektafdelingen [2010]. To meet the vision of NAU related to economics, variability in surgical procedure time needs to be minimised and the utilisation rate of the operating theatres need to increase without using overtime.

5.6 Problem Statement

As elaborated in chapter 3, Aalborg UH emphasises on being a hospital with the patient at the center as a part of their vision. The vision and the current planning approach at O6 are conflicting because the vision emphasises individual patient treatment, however, the planning approach is based on a standard approach and surgical duration is estimated based on gut feelings based on tacit knowledge by the Secretary and Operating surgeon. As illustrated in chapter 5, the current planning approach leads to under- and overestimation of required surgery time Currently, it results in lost production time as a result of the in-lighted capacity utilisation of the operating theatres equivalent to lost productivity of 5.27-8.75 % relative to volume from 2017 to 2019.

As elaborated in section 5.5, the accuracy of estimated surgery time becomes even more important when Aalborg UH is moved to NAU where operating theatres not are fixed to the departments anymore. It can be concluded that the aspect of accurate planning procedures becomes even more important. The following investigations seek to disprove the mentality of surgical being unpredictable and increase the accuracy estimated surgical duration with the purpose to increase the capacity utilisation as formulated in the problem statement:

> ***Problem Statement: Is it possible to predict the surgical duration and increase the accuracy estimated surgery time of patients at O6 with the aim of increasing the utilisation rate of the operating theatres without using overtime?***

How to increase capacity utilisation 6

Surgeries are assumed to be unpredictable and lack of accurate estimated surgery time causes lost production time and increases labor cost at O6. The chapter seeks to disprove the commonly shared attitude of surgical procedures being unpredictable. The purpose is to increase the ability to estimate future required surgery time to increase the current capacity utilisation of the operating theatres within the fixed opening hours. Further, increased accuracy of estimated surgery is required when Aalborg UH move their location to NAU.

6.1 Surgical Duration

Accuracy of predicted surgical duration is a crucial point to increase capacity utilisation of the operating theatres without using overtime. To estimate future surgical duration a five-factor model illustrated below is used as guidance for future analysis. The formula is developed based on a case study consisting of 46,322 surgical cases over a seven-year period. The sequence of the five different factors is listed by their importance, starting with the Operating surgeon as the most important source. David et al. [2000]

$$Ln(ST) = Surgeon + Anesthesia + ASA + Gender + Age + Error$$

The formula is used as inspiration to drive the following chapter but, firstly variability among the different conducted procedure codes is investigated in the following section to analysis the variation within each procedure code.

6.1.1 Surgical Procedure Variability

During the period from primo 2017 to ultimo 2019, 4,845 surgeries was distributed on 50 different procedure codes conducted by 70 different operating surgeons. The following analysis is based on historical data from primo 2018 to ultimo 2019 because data registrations from 2017 were not available.

The characteristics of procedure codes who have been conducted +10 times are investigated and listed in table 6.1. The table includes volume, number of operating surgeons (OS) who has conducted the procedure code, minimum (min) & maximum (max) time, and median & mean time of the surgical duration. Furthermore, a standard deviation of each procedure code is calculated with the purpose of showing how the observations vary around the mean.

Pr. code	No. obs	OS	Min	Max	Median	Mean	SD
Athletics:							
KNCT99:	38	12	9	94	33	36.87	23.37
KNFK99:	27	8	2	128	37	38.96	25.62
KNGA11:	141	11	8	137	24	30.77	22.07
KNGD11:	872	16	5	103	22	25.17	13.51
KNGE15:	19	6	9	74	19	25.89	16.31
KNGE45D:	248	4	20	248	92	93.92	31.19
KNGE45F:	16	3	93	178	113.5	119.5	22.24
KNGF31:	56	7	7	63	23	25.34	13.56
KNGH41:	32	8	13	94	29.5	31.44	17.07
KNGH72B:	22	4	8	148	106.5	96.27	37.00
KNGH91:	11	3	11	51	21	25.64	10.76
KNGK19:	19	5	16	142	33	42.26	30.58
KNGK99:	37	13	14	192	39	54.41	38.64
KNGM09:	11	4	16	47	21	28.36	11.62
KQBE10:	212	24	4	111	26	30.57	19.10
Children:							
BLXC1:	19	3	2	33	7	9.42	7.50
KQDH10:	23	10	10	95	16	21.52	17.93
KNFK99:	27	8	2	128	37	38.96	25.62
KNCU49:	98	24	5	69	29	31.21	14.51
KNDT99:	39	15	4	250	23	34.08	40.66
Feet:							
KNGF11:	214	12	7	92	20	22.80	13.05
KNGH46:	24	5	39	105	67	69.67	18.82
KNGH49:	17	4	11	223	33	50.29	50.39
KNHK57:	65	6	24	120	63	65.57	21.64
KNHL39:	20	6	4	122	31.5	38.30	28.34
KNHT99:	327	22	3	136	33	40.61	28.61
KNHU49:	158	35	3	140	37	41.92	26.73
Traume:							
KNFU49:	21	10	24	145	44	53.33	31.76
KNGU39:	79	29	4	75	21	24.66	16.77
KNGU49:	106	32	10	205	34	43.68	30.42
Tumor:							
KQBE10:	212	24	4	111	26	30.57	19.10

Table 6.1: *Characteristics of the procedure codes conducted +10 times from primo 2018 to ultimo 2019. All measurements are listed in minutes except SD.*

In total 30 different surgical procedures have been completed within the two year period, meaning that 40% of the total number of procedure codes has been conducted less than ten times. The 30 surgical vary in terms of volume covering a range from 11 to 872 cases both from the athletic section. The most frequently conducted procedure code (KNGD11) covers 28.49 % of the total output from 2018 - 2019.

The number of operating surgeons varies from 3 to 35 different surgeons and as argued in the five-factor formula is the operating surgeon the one who affects the duration the most. The median and mean are used to illustrate the central tendency of the surgical procedure. As illustrated in table 6.1 the central tendency varies from 16 minutes to 113.5 minutes based on the median value. The central tendency varies from 21.5 minutes to 119.5 minutes based on the mean. The standard deviation of each sample size is calculated based on the following formula: Agresti [2009]

$$\sigma = \sqrt{\sum (y_i - y_{bar})^2/(n)}$$

The calculated standard deviation indicates that process variability among surgeons is present at O6. All most every procedure codes have a standard deviation of +10. All procedures have wide standard variation which makes the mean or median not appropriate to estimate future surgery time based on a procedure code. The wide value of the standard deviation makes the process of prediction ever more uncertain.Pandit [2019]

The process variability of the most frequently conducted procedure code (KNGD11) is visualised in figure 6.1 as a control chart including UCL and LCL of +/- 2 and 3 standard deviations. The control limits are used to visualise the range of time that is required if approximately 95.44% probabilities covered by +/- 2 standard deviation, and 99.73% probabilities covered by +/- 3 standard deviations. Agresti [2009]

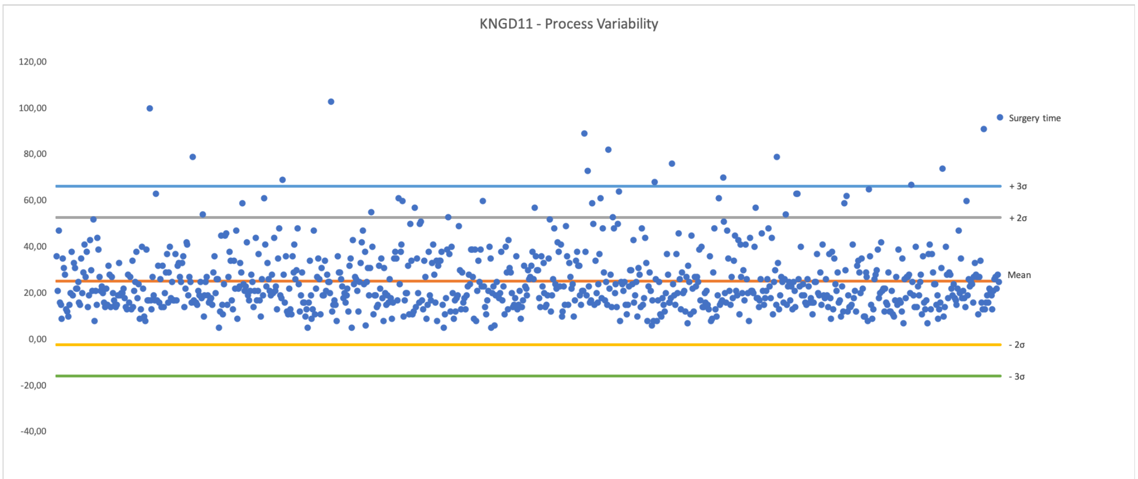

Figure 6.1: *A control chart of KNGD11 with UCL and LCL of +/- 2 and 3 standard deviation.*

Both control limits of figure 6.1 are exceeded by the observations and the process could be categorised as unstable as a result of the assignable variation. The characteristics of assignable variation at +/- 3 standard deviations are cased by six different surgeons distributed on 66.67 % male patients within the ages of 17-71. If the illustrated variation of KNGD11 surgeries is accepted and used as input when future KNGD11 surgeries are scheduled, it would require a time frame of 66.38 minutes related to the surgical duration if 99.73 % probabilities should be covered. If surgeries with a higher standard deviation as KNGE45D having a standard deviation of 32.19 the range of required time would be even more. The advantage of using a UCL and LCL of +/- 3 standard deviation is that it would be possible to complete the schedule surgeries with 99.73% certainty within the scheduled time frame. The disadvantages are that process variability still remain and an accurate estimate of the surgical duration would not be achieved.

The following section analysis the impact of the operating surgeon by using minor samples size to estimate the surgical duration from a statistic perspective. The characteristics of procedure code in proportion to the specific operating surgeon are investigated to clarify how it would affect the process variability.

6.2 Variance Among Surgeons

Variation among surgeons related to required surgery time seems to be present through historical data, and the hypothesis of variation among surgeons are supported by information provided by the employees at O6. The hypothesis of surgeons not having the same mean is expressed as hypothesis testing by the following null hypothesis and alternative hypothesis.

$$H_0 : \mu_1 = \mu_2 = \mu_3 = ...\mu_k$$
$$H_1 : \mu_1 \neq \mu_2 \neq \mu_3 \neq ....\mu_k$$

The hypothesis is tested by using a single-factor ANOVA test used to determine whether there are any statistically significant differences between the means of all the surgeons who have conducted KNGD11 surgeries.

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
A690	184	4201	22,831522	129,0479627
A8RM	153	4226	27,620915	163,6448228
CMTJ	2	39	19,5	0,5
IC7S	93	2253	24,225806	185,502805
MNJ4	74	3002	40,567568	209,7282488
NKR0	50	818	16,36	47,45959184
RWF4	24	879	36,625	177,375
XC28	2	116	58	72
Y3GJ	222	4762	21,45045	158,565407
YZ6T	50	1024	20,48	58,66285714

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	32937,656	9	3659,7395	24,65901594	9,426E-38	1,8909565
Within Groups	125261,29	844	148,41385			
Total	158198,95	853				

Figure 6.2: *A F-test of the operating surgeon who has conducted KNGD11 more than once.*

As illustrated in figure 6.2 the average between the surgeons vary. Furthermore, the variance illustrates how much the values of the stochastic variables differentiate on average from the mean. In the second table "ANOVA" the F-test-size is illustrated with "F" showing a value of 24.65. The F-value is compared with "F crit" showing a value of 1.89. Since the value of F is higher than F-crit the null hypothesis is rejected supported by the P-value who exceeds 5% and significant difference among surgeons could be concluded. Agresti [2009]

To visualise the variance among surgeons who have conducted a KNGD11 surgery more than ten times, a boxplot is used as descriptive statistics of numerical values. The boxplot illustrates the value of min & max, upper & lower quartiles, and median in figure 6.3.

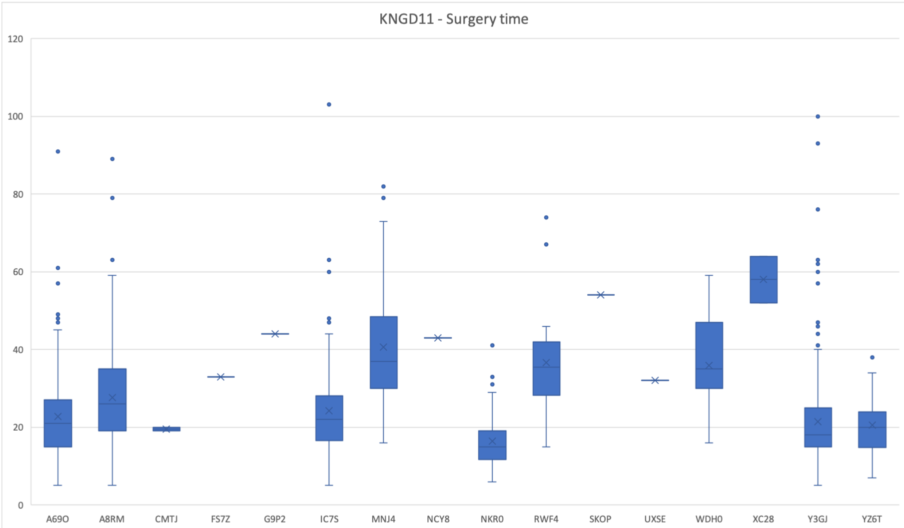

Figure 6.3: *A distribution of time required to complete KNGD11 across 16 different operating surgeon illustrated in a boxplot*

The boxplot makes it possible to compare the values of the 16 surgeons, where it can be seen that variations of surgery time is present at all values. The process variability compared with the population is summarised in table 6.2. The table illustrates the mean, standard deviation, standard error of the mean, and volume of each operating surgeon. In the bottom of table 6.2 the value of KNDG11 population is listed.

Surgeon	**Mean**	**SD**	**Standard Error of Mean**	**Cases**
A690	22.83	11.36	-2.35	184
A8RM	27.62	12.79	2.24	153
CMTJ	19.50	0.71	-0.59	2
FS7Z	33	x	0.58	1
G9P2	44	x	1.39	1
IC7S	22.23	13.62	-0.68	93
MNJ4	40.57	14.48	9.80	74
NCY8	43	x	1.32	1
NKR0	16.36	6.89	-4.61	50
RWF4	36.21	13.36	4.00	24
SKOP	54	x	2.13	1
UXSE	32	x	0.51	1
WDHO	35.87	11.81	3.07	15
XC28	58	8.49	3.44	2
Y3GJ	21.45	12.59	-4.49	222
YZ6T	20.48	7.66	-2.46	50
KNGD11:	25.17	13.51	x	872

Table 6.2: *Process variability of KNDG11 among operating surgeons.*

Based on table 6.2 it can be concluded that time varies among the surgeon. The difference related to mean with 38.5 minutes between the 16 surgeons and the range of variation around the mean do also vary between the surgeons. However, it does also seems to vary within the surgeries conducted by the surgeon self. Furthermore, the standard error of means is used to describe how fare the sample mean deviate from the population mean and is calculated with the following formula, Agresti [2009]:

$$z - score = (x - \mu)/(\sigma/\sqrt{(n)})$$

The calculated z-score shows how many standard errors there are between the sample mean and the population mean. The standard error of mean varies from -4.61 to +9.80 standard error among surgeons. The variation indicates that the surgical duration is highly affected by the surgeon and the mean of the population would not be suitable to schedule future patients. Based on table 6.2, there seems to be no connection between the number of completed surgeries and the time required. Seven surgeons have completed a KNGD11 surgery +49 times, but only 57.14% of the surgeon's mean is below the mean of the population.

Based on the findings above, a solid argument of occurrences of variance among surgeons is a factor to consider at O6 if the accuracy of estimated surgery time should increase. Furthermore, the analysis could indicate that the variance of the surgeries conducted by the surgeon it-self seems to bee presented.

6.3 Process Variability of Operating Surgeon.

The standard deviation for each surgeon illustrates that variation of the surgeries conducted by the surgeon varies in terms of time. The standard deviation among surgeons varies from 0.71 standard deviations at CMTJ to 14.48 standard deviation at MNJ4 as illustrated in table 6.3. Furthermore, the min. and max. value of the z-score is used to illustrate the individual variance of the surgeon it-self.

Surgeon	**Mean**	**SD**	**z-score (min)**	**z-score (max)**	**CV**
A690:	22.83	11.36	-1.57	6.00	0.49
A8RM	27.62	12.79	-1.77	4.80	0.46
CMTJ	19.50	0.71	-0.71	0.04	0.03
IC7S	22.23	13.62	-1.41	5.78	0.61
MNJ4	40.57	14.48	-1.70	2.86	0.11
NKR0	16.36	6.89	-1.50	3.58	0.42
RWF4	36.21	13.36	-1.62	2.81	0.36
WDHO	35.87	11.81	-1.68	1.96	0.32
XC28	58	8.49	-0.71	0.71	0.14
Y3GJ	21.45	12.59	-1.31	6.24	0.58
YZ6T	20.48	7.66	-1.76	2.29	0.37

Table 6.3: *Process variability of KNDG11 among operating surgeons*

The z-score is used as a numerical measurement to illustrate the number of standard deviation the surgeons has performed below or above their individual mean and is calculated by using the following formula: Agresti [2009]

$$Z - score = (x_i - x_{bar})/\sigma$$

A positive z-score occurs when an observation is above the mean and a negative is below the mean. As illustrated in figure 6.3, all surgeons perform below and above their own mean. However, the range of standard deviation illustrated with the z-score (max) is higher than the z-score (min). The variance among the operating surgeons is widely distributed, and only surgeon CMTJ and XC28 have a short-range between the min and max value covering less than 1.5 standard deviations. An explanation of the low z-score of CMTJ and XC28 could be that only two surgeries have been conducted by both. Even though the range between the min and max value seems as a huge gap, none of the surgeons would be categorised as high variance based on the coefficient of variation (CV). Furthermore, a tendency is that in almost every cases the range between min and max value of the z-score increases proportional to the number of completed surgeries. Experiences with the procedure code do not seem to reflect the amount of time required since the highest CV-values is seen by surgeons who frequently conduct the KNGD11 surgeries. A control chart with +/- 2 and 3 standard deviations is illustrated in figure 6.4 to visualise process variability of a randomly picked surgeon.

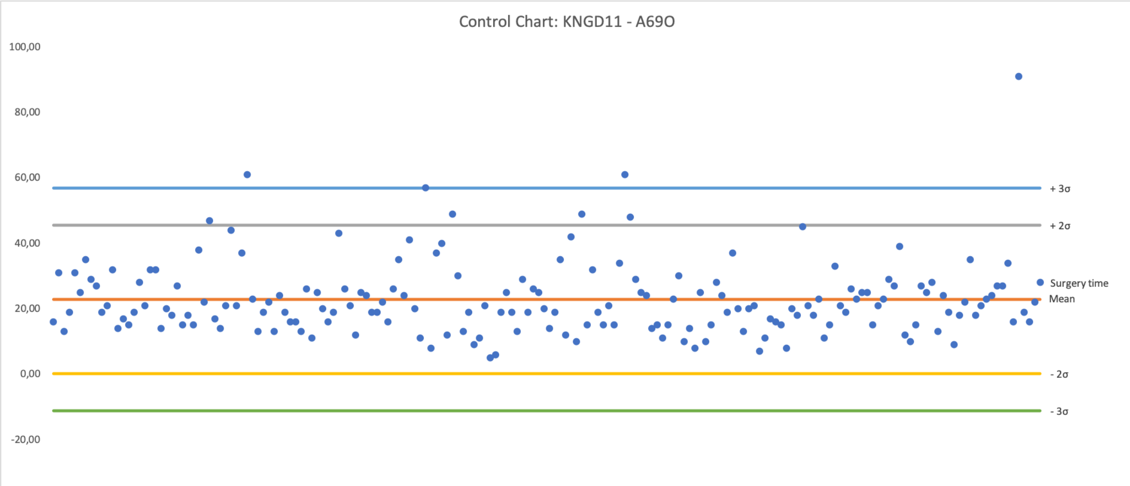

Figure 6.4: *A control chart illustrating +/- 2 and 3 standard deviations of the surgical procedure code KNGD11 managed by the operating surgeon A69O.*

As illustrated in figure 6.4, four observations exceed the UCL of +3 standard deviation. The characteristics of the assignable variation are investigated to identify the causes of extended surgery time. Based on data it can be seen that 50% of the patients are female and the four cases are covered by 23-70 years old, but the female patients are elder than male patients. The assignable variation is covered by ASA I and II, but 50% of the ASA score is unknown.

In table 6.4 standard deviations of +/- 2 and 3 are illustrated to show the range of time required if future surgeries are estimated based on the meantime of the operating surgeon covering 95.44% and 99.73% of the probabilities. Five of the surgeons (FS7Z, G9P2, NCY8, SK0P, UXSE) who have completed the KNGD11 surgery are not included because they have only completed the surgery once, and a standard deviation can not be calculated.

Surgeon	Mean	SD	SD+2	SD-2	SD+3	SD-3
A690:	22.83	11.36	45.55	0.11	56.91	-11.25
A8RM	27.62	12.79	53.21	2.04	66.00	-10.76
CMTJ	19.50	0.71	20.91	18.09	21.62	17.38
IC7S	22.23	13.62	51.47	-3.01	65.09	-16.63
MNJ4	40.57	14.48	69.53	11.60	84.01	-2.88
NKRO	16.36	6.89	30.14	2.58	37.03	-4.31
RWF4	36.21	13.36	62.94	9.48	76.30	-3.88
WDHO	35.87	11.81	59.49	12.24	71.31	0.43
XC28	58	8.49	74.97	41.03	83.46	32.54
Y3GJ	21.45	12.59	46.81	-3.88	59.48	-16.55
YZ6T	20.48	7.66	35.80	5.16	43.46	-2.50

Table 6.4: *Process variability of KNDG11 surgeries among operating surgeons.*

Table 6.4 is based on a statistical process control perspective based on a mathematical approach. The LCL control limits who are below 5 minutes do not reflect reality, because it stated by the employees at O6 to be unrealistic. At least 5 minutes are required to complete KNGD11 surgeries. A range of 5-20.91 minutes is required to cover 95.44 % probabilities 5-21.61 are required to cover 99.72 % probabilities to cover the surgery time of CMTJ. CMTJ covers the shortest range of time as a result of the lowest CV-value listed in table 6.3. The required time interval could be acceptable if the surgical duration is considered unpredictable. However, if the same approach were accepted to cover IC7S operations with the highest CV value of 0.61, an interval of 5-51.47 and 5-65.09 minutes would be required, while the average operation time is 22.23 minutes. By using such a large amount of time to secure the probabilities, a cause-effect will be an even greater amount of unused capacity in the operating room.

A similar analysis is made of the other procedure codes illustrated in table 6.1. Based on the findings of KNGD11 surgeries, process variability seems to be a tendency among the operating surgeons but, also due to the surgical duration of the individual surgeon.

6.3.1 Summary of process variability

Based on the information covered in appendix C section C.1 it can be concluded that process variability remains throughout the remaining procedure codes even though procedure codes are proportional to a specific operating surgeon. As mentioned above, a control chart with UCL and LCL defines the range of acceptable variations, but if the scheduling approach is based on the control chart it will affect the utilisation rate of the operating theatres negatively as a result of the range of minutes within the control limits. The mean is also not an appropriate approach because the value of the standard deviation is too high leading to under- and over coating of the operating theatres.

In the following section, the impact patient characteristics as gender, age, ASA, BMI, and type of anesthesia are investigated with the purpose to increase the number of factors taken into account. The aim is to decrease the process variability even more if sample size is made specific.

6.4 Variability From Other Factors

In the following section the impact of the last four factors for the calculation shown at the beginning of chapter 6 is investigated. Relevant patient characteristics as age, gender, and physical health are often correlated with the required surgery time and could be relevant to include if the accuracy of estimated surgery time should increase. Hillier [2012]. The five-factor calculations stated that the difference of gender affects the surgical duration, however, an F-test is used to analysis of variance among female and male patients is present at O6. The dispersion of female and males patients is formulated by the following null hypothesis:

$$H_0 : Female = Male$$

$$H_a : Female \neq Male$$

The null hypothesis is rejected as a result of the F-test illustrated in figure 6.5. As illustrated in figure 6.5, that the F-value (1.344) exceeds F-critical (1.168), which illustrates that analysis error or uncertainty of female and male patients are not equal.

	Male	*Female*
Mean	26,446089	22,949192
Variance	216,92982	161,40019
Observations	473	433
df	472	432
F	1,3440493	
P(F<=f) one-tail	0,0008904	
F Critical one-tail	1,1680765	

Figure 6.5: *The variance of time required during the preparation phase due to female vs. male patients*

The F-test supports the five-factor calculations empathising that gender is relevant to consider if future surgery time should be estimated. Since the variance of the gender is present, female and male patients would be analysed individually and related to Age, Anesthesia, ASA category, and BMI in proportion to surgical duration procedure codes who have been conducted +49 times. The distribution of time required to complete KNGD11 surgeries related to the above mentioned patient characteristics is illustrated in figure 6.6.

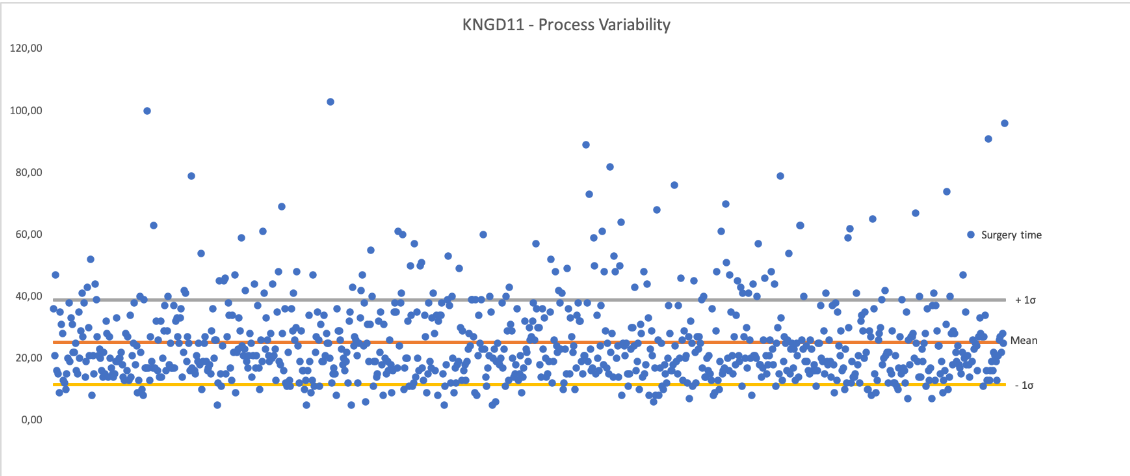

Figure 6.6: *A control chart with +/- 1 standard deviation of KNGD11 illustrating the process variability across operating surgeons.*

A control chart with +/- 1 standard deviation as control limits is used to distinguish between patient characteristics with the purpose to analysis patterns of patients who are below, between or above +/- 1 standard deviation. The distribution of the population is divided into three sample sizes related to, Gender, ASA category, BMI, and Anesthesia is illustrated in table 6.5 with the purpose to detect patterns of surgeries who is categorised as being in stable or unstable. The unstable process could either cause a shorter or extended surgery time compared with observations who is stable.

	Category	Population	Sample 1	Sample 2	Sample 3
Gender:	Female	46.57 %	34.19 %	52.05 %	48.02 %
	Male	53.43 %	65.81 %	47.95 %	51.98 %
ASA cat.:	ASA I	29.63 %	23.08 %	24.66 %	31.33 %
	ASA II	18.19 %	12.82 %	19.18%	19.03 %
	ASA III	1.60 %	0.00 %	2.74 %	1.76 %
	ASA IV	0.17 %	0.00 %	0.00 %	0.15 %
	Unknown	50.23 %	64.10 %	53.42%	47.73 %
BMI:	Gr. 1	0,69 %	1,71 %	1.37 %	0.44 %
	Gr. 2	15,38 %	10,26 %	12.33 %	16.25 %
	Gr. 3	17,80 %	16,24 %	17.81 %	18.45 %
	Gr. 4	15,84 %	7,69 %	16.44 %	17.13 %
	Unknown	50,29 %	64.10 %	52.05 %	47.73 %
Anesthesia:	GA	47.94 %	35.04 %	46.58 %	50.37 %
	LA	1.72 %	0.85 %	1.37 %	1.90 %
	Unknown	50.11 %	64.10 %	52.05 %	47.73 %

Table 6.5: *The percentage distribution of KNGD11 patients relative to four categories: Gender, ASA, BMI and Type of anesthesia*

As illustrated table 6.5, three of the categories has +50% missing registrations, shown by the subcategory ”unknown”. The high number of missing registrations adversely affects the ability to make a completely reliable analysis, but nevertheless, it will still be possible to draw parallels between the sample sizes.

Table 6.5 illustrates the percentage distribution of the four factors within the areas of inspection. The three sample sizes are selected based on the control limits from figure 6.6. The population of KNGD11 is divided into patients above +1 sd (sample 1), below -1sd (sample 2) and, between +/-1 sd (sample 3). The percentage distribution indicates that the distribution of patient characteristics are not equally distributed among random- and assignable variations. The gender of the population is almost equally divided, however, the ASA category of treated patients is primarily categorised as ASA I and ASA II. The ASA category indicates that patients treated at O6 primarily are normal healthy patients or with mild systemic disease, ASA House of Delegates/Executive Committee [2019]. The Body Mass Index (BMI) is distributed into four categories, but the patients relative to KNGD11 surgeries are primarily categorised as ”Normal weight” to ”Obese” The American Cancer Society medical and editorial content team [2016], and the frequent conducted type of anesthesia is general anesthesia (GA). As illustrated in table 6.5, the percentage distribution differentiate among the sample sizes. The assignable variation illustrated with sample 1 and 2 is compared with the random variation covered by sample 3 is elaborated in section 6.4.1 and 6.4.2.

6.4.1 Above +1 standard deviation (sample 1)

The difference between the assignable variation of sample size 1 compared with the random variation at sample size 3 is illustrated in figure 6.7. The observations who exceed + 1 standard deviation are those who have an extended surgical duration based on the calculated mean of the population. In total 118 cases exceed the standard deviation of +1, consisting of 13.52 % of the population. To visualise the differences between Sample 1 and Sample 3, changes in the percentage distribution are colored. If the percentage distribution of sample 1 is less than sample 3 it is marked with green and if sample 1 is above sample 3 it is marked with red.

Gender			ASA category			BMI			Anesthesia		
Female	-13,84	%	ASA I	-8,26	%	Less than 18,5:	1,27	%	GA	-15,32	%
Male	13,84	%	ASA II	-6,21	%	18,5 - 24,9	-6,00	%	LA	-1,05	%
			ASA III	-1,76	%	25 - 29,9	-2,21	%	Unknown	16,37	%
			ASA IV	-0,15	%	30 or more	-9,44	%			
			Unknown	16,37	%	Unknown	16,37	%			

Figure 6.7: *The percentage distribution of patient characteristics who exceed +1 standard deviation*

As illustrated in figure 6.7 the percentage distribution of females patients has decreased in sample 1 and male patients are over-represented if the surgery duration is extended. Furthermore, the percentage distribution of patients having a BMI of less than 18.5 has increased slightly. All other characteristics have decreased as a result of the increased number of unknown registrations. The distribution of age is investigated and listed in table 6.6. The age distribution is illustrated by the percentage distribution for samples 1 and 3 and the last column " Difference " illustrates the changes for sample 1 compared to sample 3.

Group of age	Sample 1	Sample 3	Difference
0-10 years:	0.00 %	0.59 %	-0.59 %
11-20 years:	11.02 %	7.22 %	+3.80 %
21-30 years:	18.64 %	12.67 %	+5.98 %
31-40 years:	15.25 %	13.99 %	+1.26 %
41-50 years:	16.95 %	21.80 %	-4.85 %
51-60 years:	21.19 %	23.86 %	-2.67 %
61-70 years:	14.41 %	15.91 %	-1.50 %
71-80 years:	2.54 %	3.83 %	-1.29 %
81-90 years:	0.00 %	0.15 %	-0.15 %
Total:	100 %	100 %	

Table 6.6: *A percentage distribution of group of age of the patients who is exceed +1 standard deviation compared with the percentage distribution of sample 3.*

As illustrated in figure 6.6, the percentage distribution is higher within the group of age from 11-40 years in sample 1 compared with sample 3. Based on the findings in section 6.4.1 it seems possible to detect the pattern of patient characteristics relative to gender and age linked to assignable variation who exceed +1 standard deviation. In the following section the characteristics of assignable variation of patients below -1 standard deviation, to investigate if similar patterns could be drawn.

6.4.2 Below -1 standard deviation (sample 2)

To illustrate the patient characteristics of sample size 2 consisting of 73 observations below -1 standard deviation, consisting of 8.37 % of the population. The observations analysed by sample 2 are the observations who are below the calculated probabilities and are cases where less surgery time has been used. A similar approach as the once used in section 6.4.1 is conducted as illustrated in figure 6.8.

Gender			ASA category			BMI			Anesthesia		
Female	4,03	%	ASA I	-6,67	%	Less than 18,5:	0,93	%	GA	-3,79	%
Male	-4,03	%	ASA II	0,14	%	18,5 - 24,9	-3,92	%	LA	-0,53	%
			ASA III	0,98	%	25 - 29,9	-0,64	%	Unknown	4,32	%
			ASA IV	-0,15	%	30 or more	-0,69	%			
			Unknown	5,69	%	Unknown	4,32	%			

Figure 6.8: *A percentage distribution of assignable variations of the second sample size compared with the sample size 3.*

It can be concluded that the difference of sample 2 compared with sample 3 is less than sample 1 proportional to gender, however, increased percentage distribution of females seems present. Furthermore, it can be seen that the number of ASA I patients decreases compared with sample 3. This indicates that a lower surgical duration is required when healthy or patients with mild systemic disease are treated. The distribution could be misleading as a result of the percentage distribution of the unknown. A minor increased distribution of BMI 1 patients categorised as under-weighted and BMI 2 decreases the most as a cause-effect of increased unknown registrations.

The distribution of age is listed by groups in table 6.6. The age distribution is illustrated by the percentage distribution for samples 2 and 3 and the last column " Difference " illustrates the changes for sample 2 compared to sample 3.

Group of age	**Sample 2**	**Sample 3**	**Difference**
0-10 years:	0.00	0.59	-0.59 %
11-20 years:	4.11	7.22	-3.11 %
21-30 years:	21.92	12.67	+9.25 %
31-40 years:	6.85	13.99	-7.14 %
41-50 years:	23.29	21.80	+1.49 %
51-60 years:	21.92	23.86	-1.94 %
61-70 years:	15.07	15.91	-0.84 %
71-80 years:	6.85	3.83	+3.02 %
81-90 years:	0.00	0.15	-0.15 %

Table 6.7: *A percentage distribution of group of age of the patients who is below -1 standard deviation compared with the percentage distribution of sample 3.*

The distribution of age is higher within the group of age from 21-30, 41-50, and 71-80 years. The assignable variation among the second sample size can not be related to young or elder patients since 11-20, 31-40, and 51-60 decreases. The findings table 6.6 and 6.7 shows a tendency of patients within the range of 21-30 and 31-40 years has the highest variation based on the percentage distribution compared with the random variation in sample 3. Based on the findings in section 6.4.1 and 6.4.2 process variability seems to be present when focusing on patient characteristics. To analysis if it a common tendency among the remaining 11 procedures the following section summarises the findings.

6.4.3 Summary of patient variation

The findings of the remaining 11 procedure codes are listed in appendix C section C.2 are summarised in this section. The variation detected by focusing on gender is the first to cover, but before the patterns are pretended it is important to have the point of issues of the missing registration in mind because since it could have affected the results. It is especially critical due to the ASA category, BMI, and type of anesthesia.

- **Gender:**
  - In 81% of the cases the percentage distribution of females in sample 2 exceed the percentage distribution of sample 3
  - In 54 % of the cases the percentage distribution of females in sample 1 exceed the percentage distribution of sample 3
  - The percentage distribution of males do not exceed the percentage distribution of sample 3 in sample 2, but it exceed the percentage distribution of sample 3 in 34% of the cases in sample 1.

Based on the findings related to gender it can be concluded that the percentage distribution of female patients exceeds the patient distribution in both samples 1 and 2. The scope of process variability is broader when focusing on females versus male patients. Furthermore, it is recognised that a higher distribution of female patients is handled within a shorter surgical duration than male patients.

- **ASA category:**
  - All ASA categories exceed the percentage distribution of sample 3 at least once in sample 1.
  - In sample 2, ASA I and ASA II is the only one with a lower percentage distribution than sample sample 3, but ASA I is the only one that exceed the percentage distribution of sample 3.
  - The percentage distribution of ASA III and ASA IV exceeds the percentage distribution of sample 3 at sample 1.
  - Patients categorised as ASA III and ASA IV is rarely represented in sample 2.

The patients handled at O6 are primarily covered by ASA I and ASA II patients, and the percentage distribution of patients categorised as ASA III does not exceed 6% of the population while ASA IV patient covers less than 2% of the population. There seems to be none clear tendency of ASA score covered by sample 1 because an increased and decreased percentage distribution of ASA score is present at the 10 procedure codes. Only a minor increased percentage distribution of ASA III and ASA IV patients is present in proportion to an increased surgical duration at some of the procedure codes. Further, it is seen that a shorter surgical duration in almost every case is related to patients with an ASA score of ASA I or ASA II. In 36% of the cases focusing on assignable variation below -1 standard deviation ASA I is over-represented.

- **BMI:**
  - All BMI categories are present to be either above or below the percentage distribution of sample 3 in sample 1. In some cases more than one BMI category vary from sample 3 at the same time.
  - BMI 1 do not differentiate from the percentage distribution of sample 3 in sample 2.
  - In sample 2, the percentage distribution of BMI 3 is lower than the percentage distribution of sample 3 in 54% of the cases.

All groups of BMI are handled at O6, but the highest distribution is covered by BMI 2 and 3, categorised as ”normal weight” or ”overweight”. The distribution of having a high or low BMI is not directly relative to the surgical duration, but it can be argued that there is a minor tendency of BMI 3 and BMI 4 patients are rarely in proportion to a shorter surgical duration. BMI category 3 and 4 is the once that vary the most. In 63.63% of the cases, the percentage distribution of assignable variation changes compared with the percentage distribution of random variation. The percentage distribution of BMI varies in 50% of the cases.

- **Type of Anesthesia:**
  - In 36% cases the percentage distribution of GA exceeds the percentage distribution of sample 3 in sample 1.
  - The percentage distribution of LA do not differentiate from sample 3 in sample 1.
  - In 20% of cases the percentage distribution of GA and LA exceeds the percentage distribution of sample 3 in sample 2.

Most of the surgeries are conducted with GA anesthesia among all three samples. In 40% of the cases, GA increases as a result of decreased LA anesthesia, but primarily caused by increased data registration. GA surgeries could be relative to extended surgery time, while both GA and LA surgeries are proportional to shorter surgery time. The mentioned issue of missing registration could have affected the results of GA surgeries with an extended surgery time. Furthermore, it is seen that the quality of registrations increases with the assignable variation below -1 sd, but none of the types can be linked to the surgery time since both types increase.

- **Age:**
  - All groups of ages exceed the percentage distribution of sample 3 at least once in sample 1 among the procedure codes.
  - All groups of ages has a lower percentage distribution than sample 3 at least once in sample 2 among the procedure codes .

- The group of 11-20 year old patients are the one that exceed the percentage distribution of sample 3 frequently in sample 1. The group exceed the percentage distribution in 45% of the cases.
- The group of 31-40 year old patients are the once that as lower percentage distribution than sample 3 in sample 2. The group has a lower percentage distribution in 54% of the cases.

The age of the patients at O6 is covered by 0-90 years. The most frequent group of age in terms of volume is covered by the group within 51-60 years, followed by 11-20, 21-30, and, 41-50 years. Based on the age distribution between the procedure codes, there appears to be a tendency that extended surgical duration is proportion to patients at 11-20 years, while the age distribution 31-40 years seems to be related to a lower surgical duration.

Based on the conclusions in section 6.4, it seems relevant to include patient characteristics beyond the surgery surgeon if the accuracy of estimated future surgery time should increase. The following section combines the influence of surgery surgeons and patient characteristics to investigate whether a combination of the factors can reduce process variation and disprove the mentality of surgical duration is unpredictable.

6.5 Connection Between Process Variability

Based on the findings in section 6.2 and 6.4 both perspectives are combined to see if the factors constitute an overall parameter to consider when future surgeries are scheduled. To secure validity and a representative analysis reflecting reality only surgeons who have conducted the surgery +49 times will be taken into account.

6.5.1 Operating surgeon with a positive standard error of mean

The operating surgeon, MNJ4, is the operating surgeon with the largest standard error of mean related to KNGD11 surgeries as illustrated in table 6.2. Meaning, MNJ4 is the operating surgeon with the highest sample mean fare from the population mean. Table 6.8 illustrates the percentage distribution of Gender, ASA score, BMI, and type of anesthesia of the patient handled by MNJ4 to investigate if it could be used as an explanation of the value amount of time used on surgeries. The percentage distribution of the characteristics of the surgeries conducted by MNJ4 is compared with the characteristics of the population.

OS: MNJ4	Characteristics	Population (%)	Sample (%)
Gender:	Female	46.57 %	41.18 %
	Male	53.43 %	58.17 %
ASA cat.:	ASA I	29.63 %	10.81 %
	ASA II	18.19 %	14.86 %
	ASA III	1.60 %	0 %
	ASA IV	0.17 %	0 %
	Unknown	50.23 %	74.32 %
BMI	BMI 1	0.69 %	0 %
	BMI 2	15.38 %	4.05 %
	BMI 3	17.80 %	13.51 %
	BMI 4	15.84 %	8.11 %
	Unknown	50.29 %	74.32 %
Anesthesia	GA	47.94 %	24.32 %
	LA	1.72 %	1.35 %
	Unknown	50.11 %	74.32 %

Table 6.8: *The percentage distribution of the four categories, Gender, ASA, BMI and Type of anesthesia relative to the operating surgeon MNJ4.*

As illustrated in figure 6.8, the percentage distribution of male exceeds the population of KNGD11 with 4.74%, which support the findings of section 6.4. Beyond gender, it is seen that only ASA I and ASA II patients are treated, but no further conclusion drawn as an explanation of why MNJ4 has the highest standard error of the mean, besides the skill level of the operating surgeon.

The percentage distribution of assignable variation and random variation of KNGD11 surgeries conducted by MNJ4 is illustrated in table 6.9. The characteristics of MNJ4 surgeries are divided into three sample sizes similar to the analysis used to detect patient characteristics above. Sample 1 consist of assignable above the UCL and sample 2 consist of assignable variation below LCL. Sample 3 consists of random variation within UCL and LCL.

OS: MNJ4	Characteristics	Sample 1(%)	Sample 2 (%)	Sample 3(%)
Gender:	Female	27.27 %	22.22 %	48.15 %
	Male	72.73 %	77.78 %	51.85 %
ASA cat.:	ASA I	18.18 %	11.11 %	9.26 %
	ASA II	9.09 %	33.33 %	12.96 %
	Unknown	72.73 %	55.56 %	77.78 %
BMI	BMI 2	0.00 %	11.11 %	3.70 %
	BMI 3	18.18 %	11.11 %	12.96 %
	BMI 4	9.09 %	22.22 %	5.56 %
	Unknown	72.73 %	55.56 %	77.78 %
Anesthesia	GA	27.27 %	44.44 %	20.37 %
	LA	0.00 %	0.00 %	1.85 %
	Unknown	72.73 %	55.56 %	77.78 %

Table 6.9: *Comparison of assignable variation and random variation of KNGD11 surgeries conducted by MNJ4.*

The variation frequently occurs when male patients are treated since they are over-represented in both sample 1 and sample 2. Furthermore, it can be seen that ASA I and BMI 3 patients are over-represented in sample 1. In sample 2, ASA II and BMI 4 patients are over-represented when the assignable variation is compared with random variation. The group of the age of the patient completed by MNJ4 is compared with the population of in table 6.10. The distribution of age managed by MNJ4 is primarily covered by the range of age from 21-60 years old, similar to the distribution of the population.

	Population		**Sample(MNJ4)**	
Group of age	Cases	Percentage	Cases	Percentage
0-10 years:	4	0.46 %	0	0.00 %
11-20 years:	65	7.45 %	5	6.76 %
21-30 years:	124	14.22 %	12	16.22 %
31-40 years:	118	13.53 %	10	13.51 %
41-50 years:	186	21.33 %	17	22.97 %
51-60 years:	204	23.39 %	17	22.97 %
61-70 years:	136	15.60 %	8	10.81 %
71-80 years:	34	3.90 %	5	6.76 %
81-90 years:	1	0.11 %	0	0.00 %
Total	872	100.00 %	74	100.00 %

Table 6.10: *Percentage distribution of age according to completed KNDG11 surgeries by MNJ4*

The age group of 44-59 years is the one that covers the highest percentage distribution consisting of 37.03% of sample 3, while the patients aged 74-89 years consist of 3.70 % as the lowest percentage distribution. In Sample 1, patients less than 23 years are not present, while 23-46-year-old patients covered 63.64% of the patients requiring extended surgery.

Based on the results of the variations among the operating surgeon and patient characteristics it has been possible to clarify an explanation of the high standard error of mean. The process variation of surgeries conducted by MNJ4 is the third-lowest as illustrated with the CV value of 0.11 in table 6.3, but extended surgery time is required.

6.5.2 Operating surgeon with a negative standard error of mean

A similar analysis is made of the operating surgeon NKR0, who is the one with the lowest standard error of mean as illustrated in table 6.2. Meaning, NKR0 is the operating surgeon with the highest sample mean fare from the population mean. Table 6.11 illustrates the percentage distribution of Gender, ASA score, BMI, and type of anesthesia of the surgeries conducted by NKR0 compared with the population to investigate if that could explain the amount of time spent on surgeries.

OS: NKR0	Characteristics	Population (%)	Sample (%)
Gender:	Female	46.57 %	56.00%
	Male	53.43 %	44.00%
ASA cat.:	ASA I	29.63 %	12 %
	ASA II	18.19 %	2 %
	ASA III	1.60 %	2 %
	ASA IV	0.17 %	0 %
	Unknown	50.23 %	82 %
BMI	BMI 1	0.69 %	0 %
	BMI 2	15.38 %	4 %
	BMI 3	17.80 %	6 %
	BMI 4	15.84 %	6 %
	Unknown	50.29 %	84 %
Anesthesia	GA	47.94 %	18%
	LA	1.72 %	0%
	Unknown	50.11 %	84%

Table 6.11: *The percentage distribution of the four factors: Gender, ASA, BMI and Type of anesthesia relative to the operating surgeon NKR0*

As illustrated in figure 6.11, the percentage distribution of female patient increases compared with the population, which supported the findings of section 6.4. The quality of data proportional to NKR0 is rather low which makes it difficult to draw any further conclusion to the calculated standard error of mean.

The percentage distribution of assignable variation and random variation of KNGD11 surgeries conducted by NKR0 is illustrated in table 6.12. The characteristics of NKR0 surgeries are divided into three sample sizes similar to the analysis used to detect patient characteristics above. Sample 1 consist of assignable above the UCL and sample 2 consist of assignable variation below LCL. Sample 3 consists of random variation within UCL and LCL.

OS: NKR0	Characteristics	Sample 1(%)	Sample 2 (%)	Sample 3(%)
Gender:	Female	85.71 %	66.67 %	48.65 %
	Male	14.29 %	33.33 %	51.35 %
ASA cat.:	ASA I	14.29 %	16.67 %	10.81 %
	ASA II	14.29 %	0.00 %	0.00 %
	ASA III	0.00 %	0.00 %	2.70 %
	Unknown	71.43 %	83.33 %	86.49 %
BMI	BMI 2	0.00 %	0.00 %	5.41 %
	BMI 3	14.29 %	0.00 %	5.41 %
	BMI 4	14.29 %	16.67 %	2.70 %
	Unknown	71.43 %	83.33 %	86.49 %
Anesthesia	GA	28.57 %	16.67 %	13.51 %
	LA	0.00 %	0.00 %	0.00 %
	Unknown	71.43 %	83.33 %	86.49 %

Table 6.12: *Comparison of assignable variation and random variation of KNGD11 surgeries conducted by NKR0.*

The variation compared of the meantime relative to NKR0 surgeries often occurs when female patients are treated since they are over-represented by sample 1 and 2. As a result of the high amount of unknown registrations, a comparison of assignable variation and random variation is not conducted of the following section are not elaborate. Sample 1 and 2 would be based on a fragile database, since 71.43 % is unknown registrations at sample 1 and 83.33 % is unknown in sample 2.

The ages of patients completed by NKR0 is compared with the population in table 6.13. The distribution of the age handled by NKRO is primarily covered within the group 41-70 years old. The distribution of ages is conflicting with the findings in proportion to age elaborated in section 6.4, where a tendency of female patients within the group of age 21-30 seems to be below -1 standard deviation.

	Population		**Sample(NKR0)**	
Group of age	Cases	Percentage	Cases	Percentage
0-10 years:	4	0.46 %	0	0.00 %
11-20 years:	65	7.45 %	4	8.00 %
21-30 years:	124	14.22 %	5	10.00 %
31-40 years:	118	13.53 %	4	8.00 %
41-50 years:	186	21.33 %	11	22.00 %
51-60 years:	204	23.39 %	10	20.00 %
61-70 years:	136	15.60 %	14	28.00 %
71-80 years:	34	3.90 %	2	4.00 %
81-90 years:	1	0.11 %	0	0.00 %
Total	872	100.00 %	50	100.00 %

Table 6.13: *Percentage distribution of age relative to completed KNDG11 surgeries managed by NKR0*

The characteristics of surgeries handled by NKR0 supports the tendency of the surgical duration is affected by the skill level of the operating surgeon and the gender of a patient. The gender of patient and skill level of NKR0 could be argued as an explanation of the standard error of mean at -4.61. Based on the results of combining the impact of the surgery surgeon and the patient's characteristics, this appears to be a solid and systematic approach that could be used to support the planning process at O6.

Based on the findings in section 6.3, 6.4, and 6.5 it can be concluded that there is a synergy between surgical duration, operating surgeon, and patient characteristics. In the following section a systematic planning procedure that include both procedure code, operating surgeon and patients characteristics are presented.

6.6 Scheduling Principles

It can be concluded that variation among surgeons and patients are present at O6, it is relevant to include these factors when future surgery time is estimated. The scheduling process would then base the estimation on only relevant factors and not characteristics of the entire population. Based on the descriptive analytics underlying trends and causes have been clarified which makes it possible to recommend the following scheduling principles illustrated in figure 6.9 based on a solid foundation.

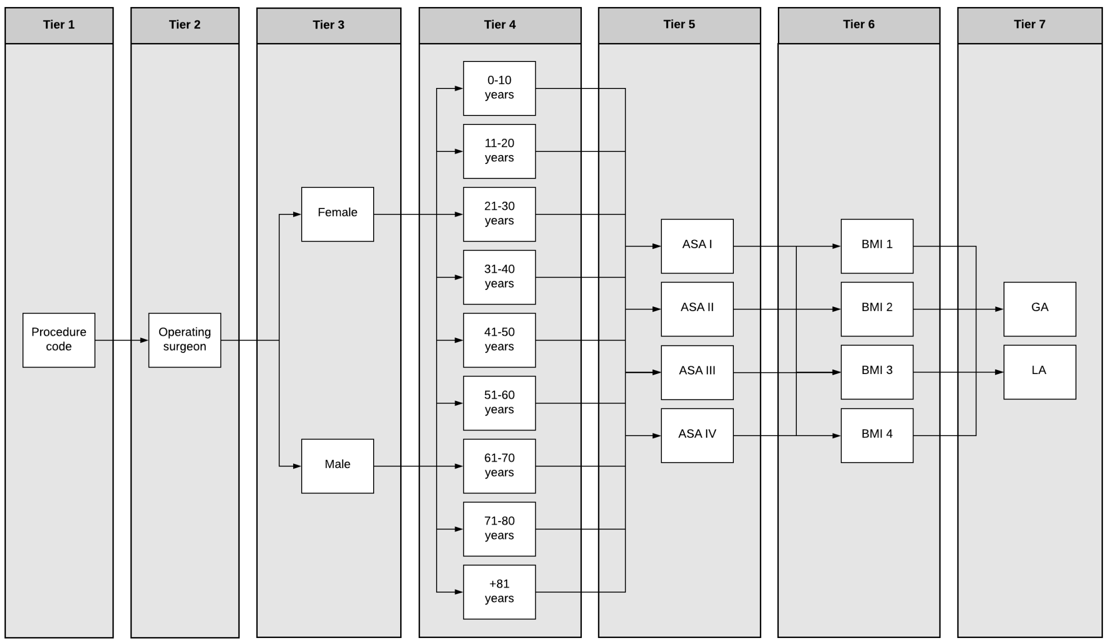

Figure 6.9: *Scheduling principles at O6.*

By using the scheduling structure illustrated in figure 6.9, the future surgical duration is estimated based on a systematic approach by using minor sample size defined specific parameters. Throughout the analytics, the variation of data quality is acknowledged as an issue that makes it difficult to estimate surgery on a solid foundation of data. It is therefore recommended that an operating surgeon still should be include when surgery times are predicted, especially when it is based on fragile data. Often, experienced surgeons can predict the surgical duration within an acceptable range, and by using the planning tool these estimates would be supported by historical data from the descriptive analytics and rather accurate estimations could be made. Pandit [2019]

An e.g. of how the new scheduling principles should be applied and how it affects the variation is illustrated in table 6.14. The scheduling principles are based on KNGD11 surgeries conducted by the operating surgeon, A690, on female patients within the group of the age of 51-60 years. The four first characteristics are covered by T1-T4 before the patients will be distinguished by ASA score, BMI, and Type of anesthesia.

	Min	**Median**	**Mean**	**Max**	**Sd**	**CV**
T1 - KNGD11:	5	22	25.25	103	13.69	0.61
T2 - A690:	5	21	22.83	91	11.36	0.49
T3 - Female:	5	21	23.13	91	12.33	0.53
T4 - 51-60y.:	11	21	26.35	91	16.03	0.60
T5 - ASA I:	16	18.50	18.50	21	2.38	0.12
T6 - BMI 1:	16	18.50	18.50	21	2.38	0.12
T5 - ASA II:	12	25	33.63	91	25.14	0.74
T6 - BMI 1:	32	x	x	32	x	x
T7 - GA:	32	x	x	32	x	x
T5 - ASA II:	12	25	33.63	91	25.14	0.74
T6 - BMI 2:	19	20	20	21	1.41	0.07
T7 - GA:	19	20	20	21	1.41	0.07
T5 - ASA II:	12	25	33.63	91	25.14	0.74
T6 - BMI 3:	12	29	39.40	91	31.15	0.79
T7 - GA:	12	25	26.50	44	13.58	0.51
T7 - LA:	91	x	x	91	x	x

Table 6.14: *Scheduling principles relative to a KNGD11 procedure code conducted by A690 on female patients within the ages of 51-60 years old.*

As illustrated in table 6.14, the variance of a KNGD11 surgery has a CV-value of 0.61 in tier 1 with a range of 98 minutes. By using the characteristics of the surgeon and patient from tier 1 to tier 4 the variance proportional to time decreases as illustrated with the decreased range of 80 minutes and CV-value of 0.60. The characteristics relative to T1-T4 are then distributed into minor sample sizes from T5-T7 as long as data is available. A radical impact of taking surgeon and patient characteristics into account can be seen at ASA I and ASA II + BMI 2 where the standard deviation is less than 2.5 and the variance is almost 0. Even though none of the tiers could be categorised as high variance it is relevant to consider how process variability could be decreased with the purpose to increase the accuracy of estimated surgery time. However, the new scheduling principles make it possible to illustrate where process variation is assumed to be present and take it into account. By recognising the possible variation, it is possible to develop a daily program that takes into account the variation between all patients, rather than having a program where there can be great variation among all the surgeries throughout the day.

6.7 Preparation & Awaken

So far the analytics has focused on the surgical duration, and how it could be predicted. As illustrated in figure 5.5, actions before and after the surgery is started is required. The specific operating principles in proportion to Preparation and Awaken is illustrated in appendix A in section A.2

The current summons template illustrated in appendix B section B.1 and B.2 include the preparation and awaken phase. In section B.1, a summons template used by all sectors besides Athletics is illustrated. The template focus on when the surgery is started, as the only information, meaning that specific preparation and awaken time is not allocated but included at surgery time. In the new summons template used by the athletic sector, the patient flow is divided into minor steps with fixed time slots. 15 minutes are allocated to preparation at "Skopi" operations, while 30 minutes is allocated at "ACL" operations. To handle the awakening time 15 minutes are allocated at both types of operations. In total, either 30 or 45 minutes is allocated to cover the changeover time between when the surgery is completed until the next surgery starts depending on the type of surgery. The time spent of preparation is analysed in the following section with the purpose to demonstrate if the fixed time intervals used summons template reflects reality.

The time required in proportion to preparation and awaken are investigated in the following section. Firstly, an F-test is used to test if variance among female and male patients also is relevant relative to the preparation and awaken phase. To test if variance among gender is present, the following null hypotheses are tested:

$$H_0 : Female = Male$$

$$H_a : Female \neq Male$$

The result of the F-test is illustrated in figure 6.10. It can be seen that F (1.105) do not exceed F-critical (1.140) meaning that the null hypothesis is accepted. The variance among female and male patients are equal and would be investigated as once throughout the section.

	Female	*Male*
Mean	39,4054487	39,8587127
Variance	251,599392	227,58378
Observations	624	637
df	623	636
F	1,10552427	
P(F<=f) one-tail	0,10416633	
F Critical one-tail	1,14016351	

Figure 6.10: *The variance of time required during the preparation phase due to female vs. male patients*

6.7.1 Preparation

The time spent during preparation before the surgery is illustrated in table 6.15 by the mean and median value. Furthermore, the variation among each sector of surgery is highlighted by the standard deviation and CV-value.

Sector of surgery	Mean	Median	sd	cv
Athletics:	36.02	34	14.22	0.39
Children:	35.83	34	15.12	0.42
Feet:	36.56	34	16.66	0.46
Trauma:	32.72	32	15.88	0.49
Tumor:	31.88	29	16.06	0.50

Table 6.15: *Average time and process variability relative to preparation among each sector of surgery.*

None of the processes can be categorised as high variation based on the calculated average, but all values except for the median at Tumor exceeds the fixed 30 minutes. The average value varies with max. five minutes between the surgeries and variation illustrated with the standard deviations and CV-values are rather close. Furthermore, the variation within the sector of surgery is analysed based on athletics patients illustrated in figure 6.16.

Sector of surgery	Mean	Median	sd	cv
0-10 years:	41.35	36	15.79	0.38
11-20 years:	37.02	34	15.58	0.42
21-30 years:	39.19	38	14.52	0.37
31-40 years:	35.57	35	13.57	0.38
41-50 years:	34.97	33	13.25	0.38
51-60 years:	33.26	30	13.13	0.39
ASA I:	35.56	32.5	10.71	0.30
BMI 2:	34.64	31	9.79	0.28
BMI 3:	36.04	32	11.48	0.32
BMI 4:	37	39	10.38	0.28
ASA II:	35.76	34	14.25	0.40
BMI 2:	34.54	30	15.62	0.48
BMI 3:	39.39	37.5	16.85	0.43
BMI 4:	36.35	35	11.88	0.33
ASA III:	32.83	30	16.78	0.51
BMI 3:	30.67	35	15.95	0.52
BMI 4:	19.67	21	6.11	0.31
ASA IV:	21.5	21.5	2.12	0.10
ASA - unk.:	31.54	27.5	13.16	0.42
61-70 years:	34.31	32	14.07	0.41
71-80 years:	34.1	35	14.44	0.42
+80 years:	44.67	46	9.07	0.20

Table 6.16: *Average time and variations within the Athletic sector distributed into age group.*

It can be concluded that variation among the group of age is present, but the highest range of variance occurs at the lowest and highest group of age. The patients within the ages of 11-80 have more or less the same average value of time, but the variance is still present as illustrated by the standard deviations and CV-values. The variance relative to additional patient characteristics is illustrated in the age group of 51-60 years. The average value and variations drop the most proportional to ASA IV patients, and only minor differences are seen within the other categorise. When the BMI score is included it changes the mean and variation changes compared with the age group and ASA score. However, variance among the sector of surgeries and within each sector of surgery do not vary a lot, but it should still not negligible if the duration should be estimated precisely. By using the available historic data it is possible to estimate both preparation and surgical duration based relevant and specific parameters.

When the surgery is completed, time is required to handle the awakening phase. The phase covers the time required after the surgery is finished until the patient at consciousness and able to return to the recovery area. As elaborated above, 15 minutes are allocated to manage the awakening phase.

6.7.2 Awaken

The time spent managing the wake phase after surgery is illustrated in table 6.17 across the five sectors of operations relative to average time. Also, the variance among the sector of surgeries is shown by the standard deviation and CV-value.

Sector of surgery	Mean	Median	sd	cv
Athletics:	11.09	9	8.98	0.81
Children:	40.99	39	17.75	0.43
Feet:	10.48	8	9.76	0.93
Trauma:	10.78	8	10.80	1.00
Tumor:	8.72	7	9.20	1.06

Table 6.17: *Average time and process variability in proportion to awaken phase among each sector of surgery*

The time required to handle the awakening phase has minor variance among athletics, feet, trauma, and tumor however, the average value proportional to children is four times higher than the others. Based on the average values the fixed time-frame of 15 minutes seems to be either an under- or overestimation of reality. Furthermore, the standard deviation in athletics, feet, and tumor is less than 10 standard deviations, which makes it possible to estimate the required time by a relatively small margin and still within an acceptable probability. Besides, the variation within the sector of Athletics relative to the age group is illustrated in figure 6.18

Sector of surgery	Mean	Median	sd	cv
0-10 years:	17.43	17	8.55	0.49
11-20 years:	11.64	9	8.86	0.76
21-30 years:	11.58	10	8.85	0.76
31-40 years:	9.58	8	6.57	0.69
41-50 years:	11.32	9	10.09	0.89
51-60 years:	10.36	9	9.56	0.92
ASA I:	11.23	8.5	13.76	1.23
BMI 2:	15	8	24.20	1.61
BMI 3:	9.37	9	5.45	0.58
BMI 4:	13.14	8	18.30	1.39
ASA II:	10.53	9	9.1	0.86
BMI 2:	13.15	8	16.33	1.24
BMI 3:	9.72	10	8.56	0.88
BMI 4:	10.57	10	5.51	0.52
ASA III:	12.67	11	4.46	0.35
BMI 3:	15	14	5.57	0.37
BMI 4:	9.67	10	0.57	0.05
ASA IV:	7.5	7.5	6.36	0.85
ASA - unk.:	9.05	8	8.13	0.82
51-60 years:	10.36	9	9.56	0.92
61-70 years:	11.24	9	9.45	0.84
71-80 years:	10.83	10	6.30	0.58
+80 years:	6	6	1.41	0.24

Table 6.18: *Average time and variations within in proportion to the Athletic sector distributed into group of age.*

It can be concluded that only minor differences occur across the group of age within the Athletic sector, however, the results of table 6.18 support the findings of the table 6.17 related in proportion to children. The awaken phase extended in proportion to time when younger patients are treated. Furthermore, it can be seen that some of the variables that affect the sample size of e.g. ASA I and ASA III are caused by minor groups within the same size and not a result of variation of all the minority groups as illustrated by BMI score.

Based on the finding in section 6.7, it can be concluded that the time required before the surgery is higher than the time required after the surgery in every case expect within the sector of children based average value. Children are, in general, a group of patients where extended time is required after the surgery. The currently fixed time-slots used to cover preparation and awaken do not reflect reality, and variation within a sample size could be caused by variation of minor groups within the sample size and do not necessarily reflect the entire sample size.

Therefore, the systematic approach used through the new planning principles should also reflect the approach to how preparation and waking time are estimated. It is recognised that variation is not directly eliminated, but the systematic approach makes it possible to include the variation in the planning process. The estimates based on historical data are not insignificant if the current accuracy of the estimated surgery time is to be increased. It also makes it possible to estimate the operation time based on only relevant parameters that reflect the specific surgeon and patient type and not a rough estimate for the entire population.

6.8 Decision Support System

Lack of accurate estimates of future surgical duration is present at O6, and new planning principles have been investigated throughout the report to increase capacity utilisation without using overtime. Historical data investigated as Descriptive analytics aim to understand the current situation and understand the underlying trends and causes of occurrences based on a consolidation of data, Ramesh et al. [2014]. The obtained knowledge-based descriptive analytics makes it possible to use forecasting techniques as a part of the scheduling process to support the Secretary and Operating surgeon who handles the process currently. Forecasting is a technique that assumes that the underlying causal system occurred in the past will continue to exist in the future based on descriptive analytics. The underlying structure of the recommended forecasting approach is based on a time-series forecast technique. Time-series forecasting simply attempts to project experience identified in time-series observations into the future based on historical data with the assumption that the future will be similar to the past, Stevenson [2012]. The structure of the decision support system is illustrated in figure 6.11,

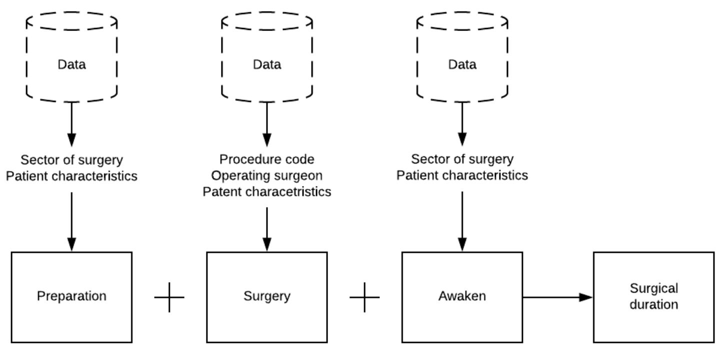

Figure 6.11: *The structure of a decision support system used to predict future surgical duration.*

The time required to handle the preparation and awaken phase is estimated based on historical data relative to the sector of surgery and patient characteristics, and the surgery time is based on procedure code, surgeon, and patient characteristics. The total surgical duration in proportion to time is a combination of the time required through the three phases as illustrated in figure 6.11.

An example of the outcome of the new forecasting approach is presented in table 6.19. The table illustrates the output based on the seven tiers where the level of detail increases proportionally with the number of tiers. The table focuses on KNGD11 surgeries in female patients within the age group 51-60, performed by surgery surgeon A690. The forecasted number of treated patients is illustrated as three examples: F1, F2, and F3.

Cat.	Mean	sd	F1	F2	F3
T1 - KNGD11:	25.17	13.51	6,3	5.1	4.5
T2 - A690:	22.83	11.36	6.6	5.4	4.7
T3 - Female:	23.13	12.33	6.4	5.4	4.6
T4 - 51-60y.:	26.35	16.03	6.8	5.9	5.2
T5 - ASA I:	18.5	2.38	7.5	7.1	6.8
T6 - BMI 2:	19	2.65	7.2	6.9	6.6
T6 - BMI 3:	17	x	7,2	x	x
T6 - BMI 4:	14	x	6.9	x	x
T5 - ASA II:	33.63	25.14	6.1	5.3	4.7
T6 - BMI 2:	23	x	6.0	x	x
T6 - BMI 3:	20	1.4	6.2	6.1	6.0
T6 - BMI 4:	39.4	31.5	5.9	4.9	4.2
T5 - ASA III:	11	x	8.1	x	x
T5 - ASA IV	34	x	6.7	x	x

Table 6.19: *An illustration of how the number of possible treated patients is affected by different tiers and scope of probabilities (sd). The underlying structure and applied algorithms are illustrated in appendix D section D.1.*

In table 6.19, the sample size consisting of T1-T4 is divided into minor groups illustrated with T5-T7 based on the ASA category, BMI score, and type of anesthesia. The three forecasting techniques covered by F1, F2, and F3 illustrate how the range of included probabilities affects the number of possible patients treated. The different probabilities are covered by calculated control limits as illustrated below:

- Patient 1: Calculated mean related to tier x + changeover time covered by +/- 0 standard deviation (50 %)
- Patient 2: Calculated mean related to tier x + changeover time covered by +/- 1 standard deviation (68.26 %)
- Patient 3: Calculated mean related to tier x + changeover time covered by +/- 2 standard deviation (95.45 %)

As illustrated in table 6.19, the composition of tiers affect the number of possible treated patients. The changes among in proportion to the number of treated patients are especially seen when minor sample sizes are used to distinguish between the ASA category in T5. The difference between ASA I and ASA II consist of 1.4 patient, and an even higher range is covered in proportion to ASA II and ASA III. However, it should be acknowledged that the conclusion related to the time of ASA III patients is based on fragile data foundations since only one patient fits the characteristics since no standard deviation can be calculated. In 2019, the daily average of the treated patient was 3.52 and as illustrated in table 6.19 is it possible to increase the daily average in almost every case as a result of increased accuracy-related to KNGD11 even though the calculations are based on F3 forecasting covering the highest probability. A similar table related to the remaining four sectors of surgeries based on the frequently conducted procedure code is illustrated in appendix D section D.2. The results similar calculation of the other sectors supports the findings elaborate above in almost every case showing that increased accuracy of estimated surgery time results in increased productivity at O6.

Furthermore, it is recommended that sequence principles be included in the planning process. Sequencing principles should operate as predefined rules used to prioritise in which order patients are tackled, Slack [2013]. The sequential principles related to O6 should be driven by Due date of patients and Resource constraints. Patients should be sequenced based on the due date as the most important principle, to secure that none of the patients exceed the 30 days patient guarantee as stated by law. The resource limitation ensures that LA patients are scheduled as the last patient to release anesthetic resources as their professionalism is not required when LA anesthesia is used.

Solution 7

The following chapter should be seen as a pitch of the findings of the report and elaborates on the advantages and opportunities from an objective perspective.

7.1 Increased Productivity

The issue of non-utilised capacity seems to be a tendency at O6 and the cause-effect of missing accuracy results in under- and over coating of operating theatres as illustrated in table 7.1.

	2017	**2018**	**2019**
Patient Output:	1,784	1,542	1,519
Finish before 1:30 PM:	94	135	101
Overtime:	44	48	33

Table 7.1: *The number of completed patients and the number of days who finish before 1:30 PM and when overtime has been required from 2017 - 2019.*

In 2019, one of the operating theatres finishes the last patient before 1:30 pm in 45.91% cases of the annual working days equivalent to a lost production time of 21.41% in proportion to the daily capacity. The 21.41% non-utilised capacity could have been used to complete at least one patient which would have increased the annual productivity with 6.65 % measured in volume in 2019. Furthermore, it can be concluded that within 15% of the days overtime has been used at one of the operating theatres.

The issue of under- and over coating of the operating theatres illustrates a two-sided problem. Currently, the cause-effect of under- and over-coating results in non-utilised capacity and overtime internally. When Aalborg UH changes location to NAU lack of accuracy affects other departments since operating theaters are not allocated to a specific department anymore. It is difficult to elaborate further on how the forecasting technique affects productivity, as the surgical duration is affected by five different factors that could be combined as illustrated in figure 5.4. Furthermore, the number of different combinations support the argument of having a data-driven planning procedure since it is inhumane to consider all the combinations as a human being. Schenkman, L. [2009]

Also, the strategic and tactical level should consider the range of probabilities covered when patients are scheduled. As illustrated in table 6.19 and appendix D section D.2, the number of scheduled patients is affected by the range of probabilities as illustrated with

F1, F2, F3. All three forecasts illustrate the number of treated when the capacity is fully utilised. However, it is recommended to implement F2, since the range of probabilities covered by F3 is too conservative and would result in non-utilised capacity. F1 cover 50% of the probabilities as a too fragile foundation in proportion to Planning. F1 could lead to increased overtime or increased use of emergency staff at the end of the day relative to the current setup, and disrupt the planning of other departments when the location is moved to NAU. The three forecasts are calculated as a decimal number since the calculations aim to utilise the capacity fully. Depending on the covered probabilities by F1, F2, F3 it could be considered if the number should be rounded to positively or negatively.

7.2 Performance Objective

The benefits of an increased accuracy estimated surgery duration proportional to relevant performance objectives. The performance objectives are used as a summary to illustrate the advantages of a time-series forecast technique at O6.

7.2.1 Quality & Dependability

Quality and dependability are combined because these performance objectives are closely related to each other when focusing on increased accuracy of estimated surgery time. Quality is defined as inversely proportional to variability from a statistic process control perspective, Stevenson [2012]. The overall variability is not eliminated, but process variability decreases as a result of using minor sample sizes based on the characteristics of the five-factor model, rather than focusing on the population. The variation among procedure codes, surgeons, and patients is clarified and included in the planning process, which makes it possible to decreased uncertainty and thereby increase the dependability of treatment at O6.

Furthermore, the accuracy of estimated surgical duration makes it possible to base the summons template on the relevant characteristics and not fixed times-slots. It will make it possible to make exact arrival time and decrease waiting time in the arrival area. Decreased waiting time is assumed to affect the patients positively since waiting time is considered as an inactive time where the patient could perform personal requests. The decreased idle time used before the surgery is assumed to increase the quality of service from a patient perspective.

Additionally, by estimating the surgical duration related to the specific patient, but also the operating surgeon, and not the population the new planning principles embrace the foundation of Aalborg UH of being a hospital with the patient at the center.

7.2.2 Cost

The increased accuracy of estimated surgical duration relative to a financial point of view could be highlighted from different perspectives. The benefits related to cost is illustrated in the following section where different aspect is elaborated. Firstly, cost proportional to increased capacity utilisation is in-lighted.

Capacity Utilisation

Cost is associated with capacity utilisation and as illustrated in table 7.1, non-utilised occurs in 45.91 % of the cases in 2019. By using the new planning procedure, the time-series forecast technique makes it possible to create the most optimal case-mix. The case-mix could either be made based on only one type of procedure code or combining different types. The case-mix is selected to utilise the entire opening hours as the calculations show in table 6.11.

Trade of patients

Trading of patients is a disadvantage and a cause-effect of the current capacity utilisation. When the trade of patients is conducted it affects Aalborg UH negatively financial. Trade of patients increases the initial cost with 40-50% if the patients are sent to another Region and 10-20% if the patients are sent to the Private sector compared with the internal offer price. It is not possible to detect the exact amount of money spent on the trading of patients relative to O6. Trading of patients is accumulated at Special-level, as Central OP and not in proportion to departments. However, 1,930,681 DKK is used on trading between Central OP and other Regions or the Private sector in 2019. It is assumed that patients from O6 have contributed to the cost related to the trading of patients and if the productivity increases it would affect the contribution positively from a financial perspective. Furthermore, elective surgeries make up a substantial portion of the revenue at Aalborg UH, which makes an increased utilisation of the operating theatres even more important. Stewart, A [2020]

If the available capacity at O6 cannot be met by demand at O6, the new planning principles make it possible to highlight when operating rooms are not fully utilised. Subsequently, the released capacity is assumed to be sufficient to handle other operations managed by the Central OP, thereby reducing the number of outsourced patients.

Labor cost

The obvious factors relative to overtime are increased labor costs or compensation time as a cause-effect of overtime. In 2019, overtime was continued for 33 days annually. By estimating future operating time and matching the estimated operating time with the available capacity over time, it would have been possible to achieve cost savings of 139,690.89 DKK. The calculations are based one hour overtime in proportion to the average salary of an operating-nurse and surgeons, Jobindex [2020]. Additionally, fixed cost should also be added to the calculation to cover all relevant cost relative to overtime if all cost should be covered. It has not been possible to clarify the amount of fixed cost associated to an operating theatre but, the probabilities of an extended amount of cost savings is present if fixed cost is added to the calculation.

Furthermore, the new planning principles include the type of anesthesia and distinguish between GA or LA anesthesia. GA is when the patient is in full anesthesia and LA is only local anesthesia. The type of anesthesia is relevant to when resources are scheduled. GA surgeries require anesthetic nurses and LA does not. Currently, LA patients could be placed anywhere during a day which results in anesthetic nurses at the operating theatre is standing idle. The planning procedure should, therefore, include GA and LA anesthesia to increase the efficiency of resources. It could be considered to make a case-mix of only LA surgeries without compromising with sequence principle Due Date or place LA anesthesia at the end of a day. The purpose is to release resources rather than having it standing idle. It will reduce labor costs related to cost from an O6 perspective and anesthetic resources could be added to central OP if required.

Evaluating Proposals 8

The following sections evaluate how the problem statement is covered during the project and whether the solution is possible at Aalborg UH combined with considerations about future actions. Furthermore, the impact of constraints, conditions, and assumptions, and how it might have affected the result is evaluated.

8.1 Data Awareness

The collected data related to patient flow is only used to visualise the process flow of a day on a dashboard, without any further information. The visualisation of the process flow is rarely used to evaluate the daily work on the operational level and has no clear function or purpose. The visualisation is primarily used to clarify whether the day can be considered a " Good " or " Bad " day, based on individual preferences, as explanatory information as procedure code, surgeon, and patient characteristics, etc. are not included. During the project, awareness and possibilities related to statistical process control have been in-lighted where random variations and assignable variation is used to find explanations of process variability. The increased information level makes the scheduling process data-driven and less dependent on tacit knowledge and personal opinions. The explanation of process variability allows optimisation to be sought, as variation can be explained based on assignable variation and challenge current surgical approaches and begin to use continuous improvement processes as a learning process to develop tomorrow's treatment as one of the core values at Aalborg UH. Aalborg University Hospital [2019]

If the new planning principles should be operated successfully, the issues related to missing and incorrect data registrations need to be taken into account. Incorrect data has been removed from the extracted data files and the remaining data is validated by staff members at O6. The corrections of data have not been translated into the ERP system. Therefore, it is required that a significant effort is put into cleaning data and finding a way to increase the quality of future data registrations to make data value-adding in the future.

8.1.1 Decreased uncertainty

Process variability was recognised as a trend at O6, but the degree of uncertainty was not exactly acknowledged at O6. Some of the experienced employees at O6 have obtained tacit knowledge that allows them to predict whether if the summons template would be ahead, behind, or on time, even before the program was not yet started. These assumptions were based on experience, but not used to challenge the current planning method. The missing accuracy was instead accepted even though some employees stated that optimisation could be relevant to consider. The tacit knowledge acquired by experienced employees is formalised as a report to establish an argument of changes that are required based on performance facts. The argument is based on already collected historical data, by dividing the population into minor sample sizes. Based on the fact that the current scheduling approach causes under- and over coating of the operating theatres it supports the argument of using a data-driven decision supporting system. By using data the scheduling becomes transparent and not hidden through embedded knowledge by employees and preferences. Furthermore, it should be acknowledged that the impact of the characteristics of Tier 1 - Tier 7 as illustrated in figure 6.9 is impossible to manage by the human brain. Schenkman, L. [2009]

8.2 Further pitfalls

The scope of the report is limited to the parameter included in the five-factor model, however, causative affected by other factors has not been investigated. Further aspects as quality of surgery, the number of re-operations related to process variability, and required surgery time could have been investigated. Besides, the impact of the orthopedic- and anesthetic nurses seniority in total or at O6, as well as the number of students assigned to the operating room could have been taken into account. Training of students is a part of Aalborg UH and students are sometimes included in the daily work at O6. When students are added it is stated by the employee that expanded surgical duration is required. Students are added to all staff groups at O6 and the number of attached students could vary between the employee. It could have been considered to include some kind of seniority score to highlight the total score of the resources allocated at the operating theatres. Students could then been included by adding a negative value to the seniority score. Non-clinical factors as a weekday, occupancy rate of the department, physical workload, and team-spirit are not analysed throughout the project. These are all factors that also could affect productivity. The physical workload could be an expression of the already mentioned factor covered by the number of students but, it could also be an expression of the number of supplemental duties during a day as supporting other departments or paperwork. Wang et al. [2020].

The cause-effect on increased productivity should be investigated to see how it affects the staff at O6 on a personal level and the surgical duration. Based on theory from Wang et al. [2020], it is argued that the surgical duration increases if more than four surgeries are managed within a day. The theory needs to be challenged because even though the number of surgeries increases it does not result in increased surgery time of the whole day. Also, the type of surgeries administered at O6 is more or less routine surgeries with low variation across procedure codes as illustrated in table 5.1 compared with surgeries types performed at other departments where multiple hours may be required to complete the operation. These are relevant factors to consider before it is determined if an increased number of patients should be treated daily at O6.

8.3 Values of Aalborg UH

The vision of Aalborg UH is to be a hospital with the human at the center both from a patient and employee perspective, Aalborg University Hospital [2019]. It can be discussed if the individual human is in the center when patients and surgeons are measured and treated as one population. Throughout the project sample sizes based on patterns are used to categorise the surgeon and patient by their characteristics. By focusing on the individual characteristics of the person it could be argued than an increased quality related to the vision of Aalborg UH is achieved. Further, by challenging the current working approaches and methodologies it could be argued than the mission of developing the treatment and employee of tomorrow it meets. By tackling the current situation, it is possible to challenge the setup and thus make continuous improvements relative to the severity of the identified problems.

The findings of non-utilised capacity and the ability to administrate financial resources could establish a societal discussion of how the financial assets are managed within the Healthcare sector. As elaborated, in 2019 the specialty Central OP has spent almost 2 mio. DKK on trading patients even though at least 90 minutes in one of the operating theatres are not utilised in 45.9 % of the annual available days. From an economic perspective, it seems unreasonable that surgeries are outsourced to other Regions and the Private sector while 21 % of available capacity is not utilised in 45.9 % of the cases. Furthermore, a cost-benefit analysis could have been used to analysis if the cost spent on trading patients could decrease or be eliminated through in-house surgeries by accepting some degree of overtime. Overtime could be preferred compared to non-utilised capacity as a part of the culture or only when patients are close to exceeding their due date. This would decrease the cost spent of the trading patients, but a cost-benefit analysis would be required to conclude if it would be profitable while having the current utilisation operating theatres in mind.

9 Project Summary

The pressure of the sector of healthcare is increasing since financial savings from the danish government and an increased danish population challenge the sector to increase internal efficiency. Aalborg UH has selected the O6 department to drive and test internal improvements to meet future demand. O6 conducts only elective surgeries covered by five different sectors of surgery: Athletics, Children, Feet, Trauma, and Tumour. O6 is available from 7:30 am to 5:00 pm and the included operating theatres are scheduled to conduct surgeries from 8:00 am to 3:00 pm from Monday to Friday approximately 220 days annually. As a starting point, the current ability to deal with process variability of elective surgeries was investigated driven by the following research question:

How is the current the capacity utilisation of the operating theatres at O6?

It could be concluded that a tendency of under- and over coating was present at the operating theatres, based on the number of days finishing before 1:30 pm and days where overtime was required to complete the last patient. When operating theatres complete the last surgery before 1:30 pm, at least 21% of the capacity is non-utilised on a day as a result of undercoating. In 2019, 45.9% one of the operating theatres completed the last patients before 1:30 pm, covering a huge amount of lost production time. Furthermore, overtime was conducted within 15% of the days annually. These are some of the current cause-effect of the inaccuracy of the estimated operating time, but the question of under- and over coating will affect the entire production plan when Aalborg UH is moved to NAU, as operating rooms are shared between other departments. The highlighted issue in proportion to under- and over coating was used to compile the following problem statement:

Is it possible to predict the surgical duration and increase the accuracy estimated surgery time of patients at O6 with the aim of increasing the utilisation rate of the operating theatres without using overtime?

Based on historical data supported by theory it was possible to elaborate a five-factor model focusing on Procedure code, Operating surgeon and Patient characteristics with the purpose to decrease process variability of elective surgeries. By using descriptive analytics it was possible to identify underlying causes of process variability relative to completed elective surgeries. The descriptive analytics made it possible to challenge the current planning approach driven by rough estimations of the population of a procedure code and tacit knowledge by employees. A new and systematic planning procedure was developed to estimate future surgical duration based on minor sample sizes based on specific characteristics relative to Procedure code, Operating surgeon, and Patient characteristics.

By using the new planning procedure it is possible to estimate the required surgery time and match it with the available capacity of the operating theatres from a statistical perspective. The new planning procedure would increase the productivity with 6.65 % and create cost savings of 139,690.98 DKK plus fixed cost in proportion to extended opening hours of the operating theatres based the performance of 2019. Furthermore, increased productivity will decrease the assumed contribution of O6 patients who are outsourced to other regions or the private sector. The drawback of outsourced patients is that the involved cost increases with 10-50 % compared with in-house cost. In 2019, 1,930,681 DKK was used on the trading of patients and the cost could have decreased if O6 patients have contributed, as a result of the increased productivity in terms of volume. Also, the new planning procedure increases the transparency of capacity and resources versus demand, and if the available capacity or resources of the operating theatres exceeds demand it is possible to release the capacity or resources to other departments who also is a part of Central OP with the purpose to manage patients within the due date and decrease the number of outsourced patients.

Reflection 10

The reflection elaborates on relevant considerations in form and how employees should be guided to ensure the successful implementation of the new planning principles. Second, inputs of how the new planning principles can be used as a continuous improvement process and eventually future considerations used to enhance the current digital mentality in Aalborg UH.

10.1 Implementation Phase

The utilisation rate of operating theatres should be maximised and underutilised rooms representing unnecessary costs should be eliminated. However, Operating theaters that are fully booked without any time buffers is unstable and can create a high amount of cost in proportion to uncertainty cost. If minor changes of surgical duration may cause higher costs to cover overtime in working hours or patient deferrals. The management cannot insist on never finishing early and employees cannot insist on never finishing late. Therefore, it is recommended that management and staff in collaboration make these limitations related to finishing late or early. Managers should consider how early they are prepared to let the staff go home early and, the staff should consider how late they are prepared to stay. These considerations cover the tolerance level between the management and employees at O6. Cardoen et al. [2009] Further, the degree of available time slots and time horison may be considered. It is relevant to consider if some time slots should remain available in case of emergency patients or if only elective patients should be managed at O6, Hillier [2012]. Currently, time slots are available in emergency cases to occur or if patients from Central OP should be handled to release scare resources,

10.1.1 Change Management

Change management should be considered if the new planning procedure should be implemented successfully. Theoretically, optimisation is based on two factors: Competition and Desire to optimise the use of available resources. Both aspects depend on the management's ability to communicate why optimisations are required to their employees and make sure that they understand why changes are needed. Schwarz et al. [2011]. Competition is not a direct issue within the sector of healthcare. The highlighted current performance could be used to in-light why changes should be made. Furthermore, requirements relative to the relocation to NAU and aspects of the mission and vision of Aalborg UH could support why optimisation is needed. Additionally, the amount of possible treated patients could be used to set standards that define the boundary between acceptable and not acceptable performance. The standards make it possible to perform detection and inspection as performance indicators to investigate why performance is over or underperforming with the purpose to maintain or increase the quality of the service quality. Stevenson [2012]

The mentality of the employees relative to optimisation could be highlighted through Theory X and Theory Y that focuses on Managers' assumptions of their employees, Cameron and Green [2015]. Theory X argues that the only motivation and alignment of the employee is created by a combination of rewards and punishment. A degree of control is necessary from the management to control their employees since and effort to motivate and convince employees to accept the new planning principles would be required. Theory Y assumes that employees have a need and desire to work. It is assumed that employees appreciate optimisation or at least attend if it seems beneficial without any further incentive. To enable the employee to assess whether there is a need for change, it returns to the aforementioned focus area where the need for change is understandable for employees. However, the process of change is started by making the need for changes understandable for the employees.

Even though managers make an assumption of how Theory X and Theory Y could reflect the mindset of the employees it may be considered how employees attend to react during the process of change. The reaction of employees is illustrated in figure 10.1 focusing on self-esteem a human being.

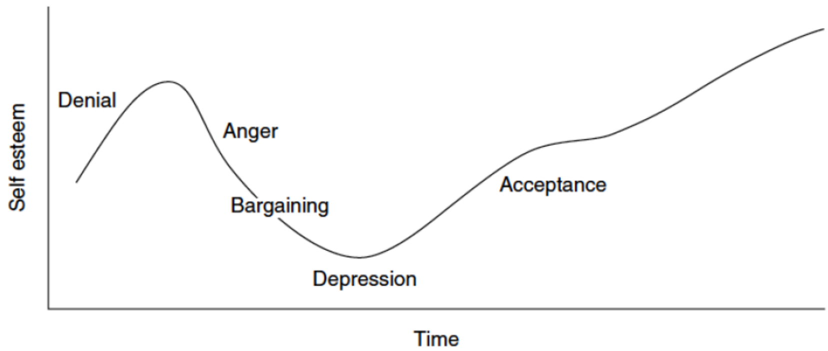

Figure 10.1: *The process of change and adjustment,Cameron and Green [2015].*

When changes are implemented people attempt to feel uncomfortable and the reaction could be illustrated as in figure 10.1. These barriers need to be taken into account by the management because the phases of self-esteem could lead to a performance dip before the last phase of Acceptance is reached.

Forcefield Analysis

A Forcefield analysis is a suitable tool for managers to defined forces who either drive or block the movement towards the goal. A Forcefield analysis focus on the barrier and driving force that should be considered during the phase of implementation used to select a suitable change strategy. The pitfall of the analysis is to determine the size of the forces focusing on which force who is most critical. An initial Forcefield analysis based on rough estimations of forces is illustrated in figure 10.2.

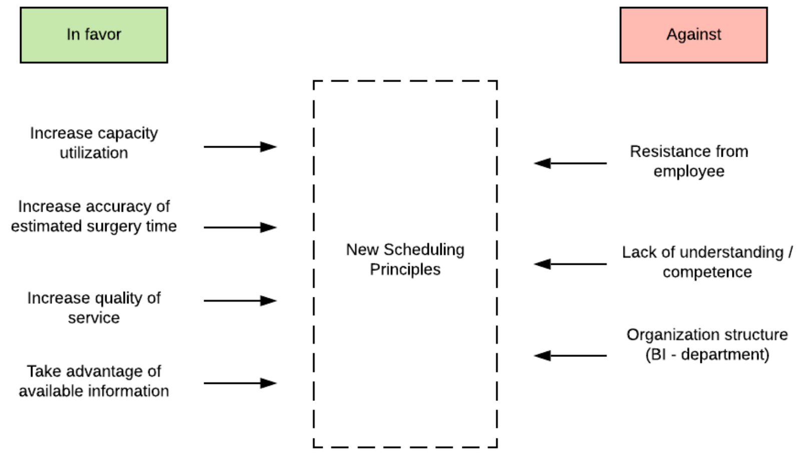

Figure 10.2: *An Forcefiled analysis of rough assumptions of forces that could affect the process of changes,*

The forces covered in the Forcefield analysis is based on assumption and should be elaborated further and more concrete by the management before the Forcefield analysis is used as a part of implementing the new planning procedure. Further, the size of forces needs to be rank based on the insights from the management to cover all forces in the right manner.

10.2 Continuous Process of Improvements

The new scheduling principles are driven by forecasting techniques based on collected quantitative data. Currently, data is handled by the BI department were requests are stated to be handled within 14 working days, but if future surgical duration should be foretasted it is required that transparency of data increases. The data used to set up a forecast model is based on data from different it-systems and translation was required before data from different databases could be combined. Furthermore, the cleaning of data was required to remove outliers and incorrect data to make it useful for analysis. Resources should be allocated to manage the process of obtaining, cleaning, and analysing data since a significant effort often is required if the future surgical duration should be estimated accurately Stevenson [2012].

It is important to acknowledge that if the forecast model should perform within a satisfactory manner it needs to be reexamined continuously. Accurate forecasts are necessary if future surgeries should be estimated successfully otherwise the generate schedules would result in under- or over coating of operating theatres. The complex nature of real-world variables makes it almost impossible to accurately predict future values of these variables because random variation will always be present and residual error will remain even though all factors have been accounted for. The accuracy of forecasted surgical duration should continuously be examined by analysing the forecast error showing the difference between the value of occurrences versus the predicted value. Hence, Error = Actual - Forecast. Since characteristics related to surgeon and patient have been weighted equally throughout the analysis it is recommended to apply Mean Absolute Deviation (MAD) to summarise historical errors. The mathematical algorithm of MAD is illustrated by the following formula: Stevenson [2012]

$$MAD = \sum(Actual_t - Forecast_t)/(n)$$

The calculation illustrates the average absolute forecast error within any given period (t). The MAD shows the accuracy of the estimated surgical duration versus reality as the last phase to secure a sufficient forecast technique, Stevenson [2012]. This is a relevant aspect to consider because it will present information on capacity utilisation and illustrate if the tendency of under- and over coating return used as a Performance indicator.

10.3 Digital Transformation

A digital transformation within the sector of healthcare seems to be far from reality. However, aspects in proportion to digitalisation and the involved opportunities are still relevant to consider. The purpose of this project is to increase the accuracy of the scheduled patient based on data. Currently, data is captured through manual registrations and the value of data is rarely applied. To elaborate on the digital maturity of Aalborg UH figure 10.3 is used to evaluate the current situation.

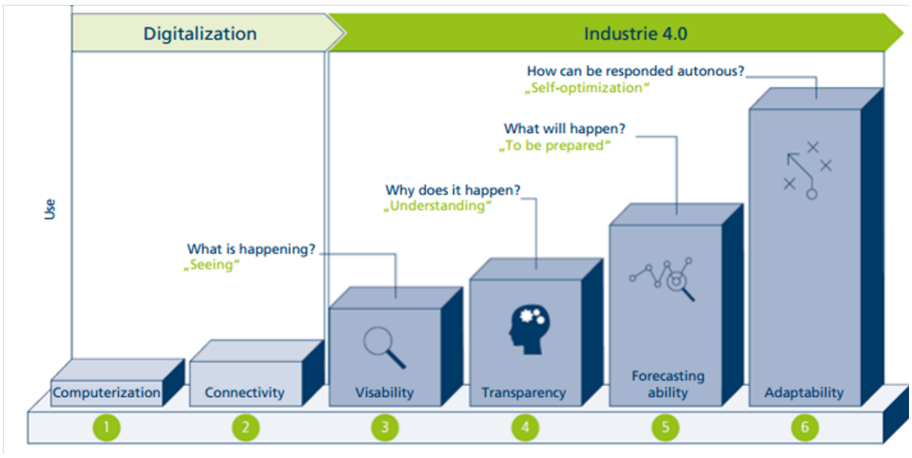

Figure 10.3: *Stages of Industry 4.0 development path Schuh et al.*

Data registrations are manually typed into Bookplan conducted by the orthopedic nurses at the operating theatres, where four registrations are made during a surgical duration. Patients characteristics are typed into the national Anesthesia database and written on paper by the anesthetic nurses. All registrations are handled manual and linked to decentralised system isolated and not able to interact with each other. The procedure of how data is captured refers to stage 1, Computerisation, where information technologies are isolated and digital interfaces are used to type data registrations manually, Schuh et al..

Since data is captured manual issue as human errors as elaborated in chapter 4 need to be considered, and automation of data registrations should be considered to increase the quality of data and release duties of the orthopedic- and anesthetic nurses.

As elaborate, connections between the different IT-system has been applied through the execution of the report referring to step 2, Connectivity. It can be concluded that connectivity of the IT-system is possible which makes it possible to elaborate on what is happening through descriptive analytics as illustrated in step 3, Visibility. However, it can be argued that visibility through the mentioned dashboard even though the current level of information is rather low. Based on statistical process control it has been possible to investigate assignable variation used to understand why things are happening as illustrated with step 4, Transparency, Schuh et al..

The possibilities of increasing the digital maturity level seem to be present based on the executed report, however, an effort is required before it can be implemented at Aalborg UH. As a result of the current digital maturity level of Aalborg UH and the fact that Aalborg UH and AAU are collaborating on the prospect of Healthcare Excellence, it could be considered to included Innovation Factory North (INF) as a third party, or as a decentralised prospect.

As a result of the digital maturity of Aalborg UH combined by the fact that Aalborg UH and Aau are collaborating on Healthcare Excellence, it could be considered to include Innovation Factory North (IFN) as a third party or as another decentralised prospectus. INF aims to map, test, develop skills, and implement available technologies related to industry 4.0 based on a data-driven approach, Aalborg University [2020]. IFN has developed a 360 digital maturity assessment as illustrated in figure 10.4 as a road map of a digital transformation process.

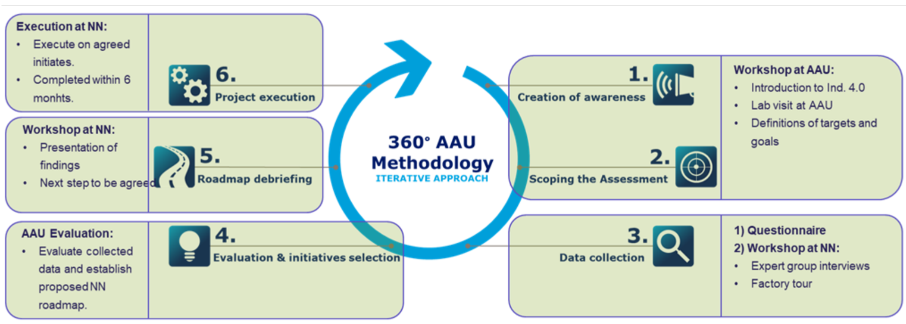

Figure 10.4: *Assessing Digital Maturity: The 360 Digital Maturity Assessment. Colli et al. [2018]*

Furthermore, a digital maturity assessment based on the 360DMA maturity model reference table could be used to understand the current maturity level and required future actions. The assessment generates an overview of strengths and weaknesses at Aalborg UH related to Industry 4.0. Through the identified maturity level, it is possible to create awareness used as foundations of a discussion relative to suitable improvements. Furthermore, the tool could be used to translate some of the embedded knowledge and make it explicit and create a common understanding of the current abilities at Aalborg UH. This will create an understanding of the as-is situation, which will make it possible to select short, medium, and long term achievement. Colli et al. [2018]

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Resources and Operating Principles A

A.1 Resources at the Operating Theatres

In figure A.1, an overview of resources at the two operating theatres are illustrated. The Anesthetic doctor & nurse and the Orthopedic nurse placed between the operating theatres supports both operating theatres.

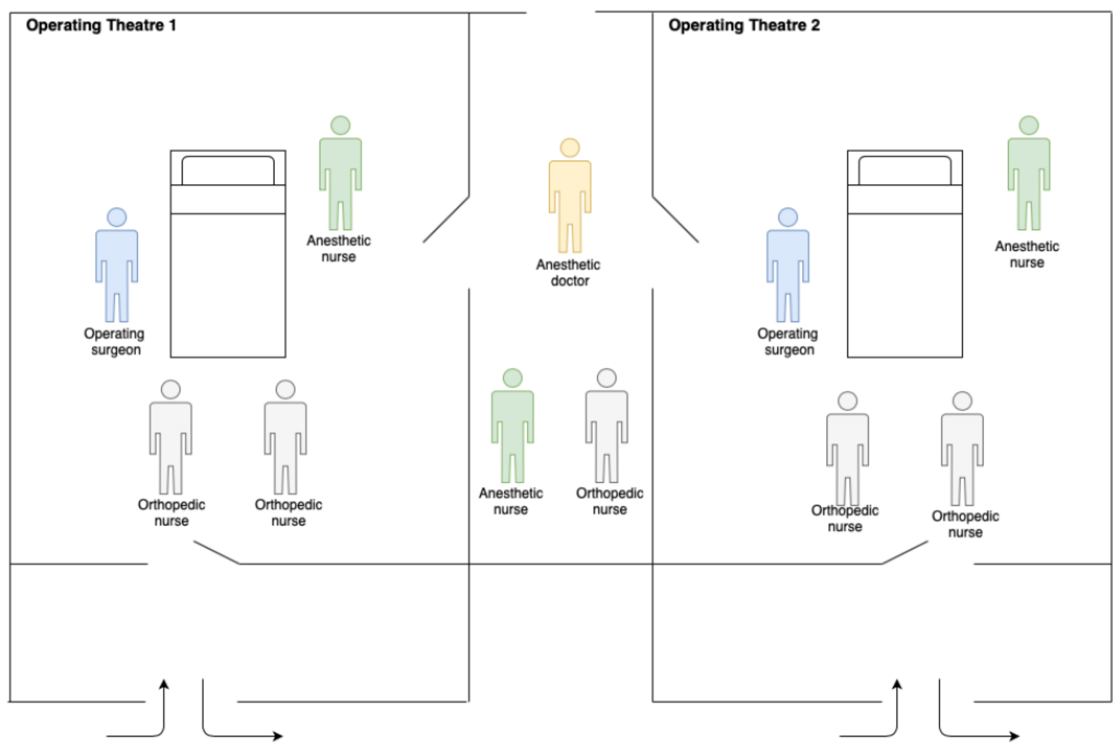


Figure A.1: *Operating Principles at O6 illustrated at each professionalism during a patient flow.*

Furthermore, two PACU nurses are taking care of the patient in the arrival area before and after the surgery. Supplementary resources like Cleaning staff and Hospital porter are a part of the daily operating, however, none of them are fixed to O6 and handle other duties at other departments.

A.2 Operating Principles

The operating principles of the resources in proportion to a patient flow at O6 are illustrated in figure A.2. Each resource is illustrated by color clarified before duties are listed.

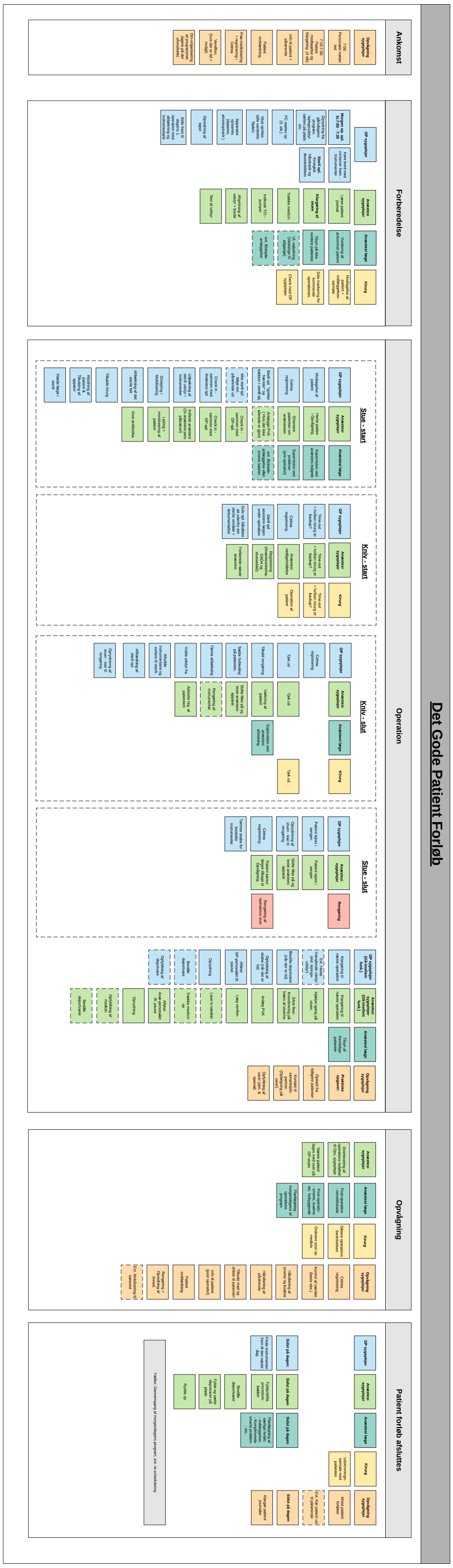


Figure A.2: *Operating Principles at O6 illustrated at each professionalism during a patient flow.*

Scheduling Approach B

B.1 Planning Approach

A standard summon template used at O6 across the sector of surgery. The summon template illustrates in table B.1 is used when four patients are scheduled and table B.2 is used when five patients are scheduled. ”Patient arrival” is the time where the patient is scheduled to arrive at O6 and ”Surgery start” is the scheduled time of when the surgery should start at the operating theatre. As elaborated in chapter 3, the operating theatres at O6 are available from 8:00 AM meaning, that 20 minutes is available at the operating theatre to prepare and anesthetize the patient. The time categorised as ”surgery time” covers the scope of time between surgery start until the next surgery start.

	Patient arrival	**Surgery start**	**Surgery time**
Patient 1:	7:30 AM	8:20 AM	75 min
Patient 2:	7:40 AM	9:35 AM	135 min
Patient 3:	11:00 AM	11:50 AM	60 min
Patient 4:	12:00 AM	12:50 AM	130 min

Table B.1: *Schedule when four patients are treated*

	Patient arrival	**Surgery start**	**Surgery time**
Patient 1:	7:30 AM	8:20 AM	75 min
Patient 2:	7:40 AM	9:35 AM	75 min
Patient 3:	10:00 AM	10:50 AM	75 min
Patient 4:	11:30 AM	12:05 AM	75 min
Patient 5:	12:00 AM	13:20 AM	100 min

Table B.2: *Schedule when five patients are treated*

In both types of schedules, 400 minutes are scheduled to be used on surgeries, meaning that 20 minutes of the total openings hours are not accounted for in the schedule. The missing 20 minutes are used as a buffer of time to cover possible delays or disruptions during the day. Table B.1 and B.2 illustrates two fixed approaches summons template used by the secretary and an operating surgeon to schedule future patients. Furthermore, resource planning of employees is related to the opening hours of the operating theatre and, patient characteristics are not taken into account.

B.2 New Approach - Athletics

In figure B.1, B.2 and B.3 a new summons template used by the sector of Athletics is illustrated. The template is implemented in February 2020 unfortunately, has it not been possible to test the new summons template because of the limitations caused by COVID-19. The new template distinguishes between "Skopi" or "ACL" surgeries which has an impact on how many patients should be scheduled. The summons template do not take the individual operating surgeon or patient characteristics into account. Furthermore, the information level of the summons template has an increased information level categorised as minor categories of when a patient should enter the next stage during treatment.

Skabelon for indkaldelse og afvikling af Artroskopier og ACL i SDK pr 1. marts 2020

SDK 1: Mandag, Onsdag og Torsdag (ingen ACL)						
OP-type	Mødetid	OP-stue ind	OP start	OP slut	Retur Opv	Udskrivelse
Skopi	7.30	8.00	8.15	8.45	9.00	11.00
Skopi	7.40	9.00	9.15	9.45	10.00	12.00
Skopi	9.30	10.00	10.15	10.45	11.00	13.00
Skopi	10.30	11.00	11.15	11.45	12.00	14.00
Skopi	11.30	12.00	12.45	13.15	13.00	15.00
Skopi	12.30	13.00	13.15	13.45	14.00	16.00

SDK 2: Mandag, Onsdag og Torsdag (ingen ACL)						
OP-type	Mødetid	OP-stue ind	OP start	OP slut	Retur Opv	Udskrivelse
Skopi	7.30	8.00	8.15	8.45	9.00	11.00
Skopi	7.40	9.00	9.15	9.45	10.00	12.00
Skopi	9.30	10.00	10.15	10.45	11.00	13.00
Skopi	10.30	11.00	11.15	11.45	12.00	14.00
Skopi	11.30	12.00	12.45	13.15	13.00	15.00
Skopi	12.30	13.00	13.15	13.45	14.00	16.00

Figure B.1: A summons template used within the sector of athletics

SDK 1: Mandag, Onsdag og Torsdag (med 1 ACL)						
OP-type	Mødetid	OP-stue ind	OP start	OP slut	Retur Opv	Udskrivelse
ACL	7.30	8.00	8.30	9.45	10.00	12.00
Skopi	9.00	10.00	10.15	10.45	11.00	13.00
Skopi	10.30	11.00	11.15	11.45	12.00	14.00
Skopi	11.30	12.00	12.15	12.45	13.00	15.00
Skopi	12.30	13.00	13.15	13.45	14.00	16.00

SDK 2: Mandag og Onsdag (med 1 ACL)						
OP-type	Mødetid	OP-stue ind	OP start	OP slut	Retur Opv	Udskrivelse
Skopi	7.30	8.00	8.15	8.45	9.00	11.00
ACL	7.40	9.00	9.30	10.45	11.00	13.00
Skopi	10.30	11.00	11.15	11.45	12.00	14.00
Skopi	11.30	12.00	12.15	12.45	13.00	15.00
Skopi	12.30	13.00	13.15	13.45	14.00	16.00

Figure B.2: A summons template used within the sector of athletics

SDK 2: Tirsdag (ingen ACL)						
OP-type	Mødetid	OP-stue ind	OP start	OP slut	Retur Opv	Udskrivelse
Skopi	8.30	9.00	9.15	9.45	10.00	12.00
Skopi	8.40	10.00	10.15	10.45	11.00	13.00
Skopi	10.30	11.00	11.15	11.45	12.00	14.00
Skopi	11.30	12.00	12.15	12.45	13.00	15.00
Skopi	12.30	13.00	13.15	13.45	14.00	16.00

SDK 2: Tirsdag (med 1 ACL)						
OP-type	Mødetid	OP-stue ind	OP start	OP slut	Retur Opv	Udskrivelse
ACL	8.30	9.00	9.30	10.45	11.00	13.00
Skopi	8.40	11.00	11.15	11.45	12.00	14.00
Skopi	11.30	12.00	12.15	12.45	13.00	15.00
Skopi	12.30	13.00	13.15	13.45	14.00	16.00
GRÅ FELTER BOOKES FORELØBIGT IKKE UDEN GODKENDELSE VED OPERERENDE LÆGE						

Figure B.3: A summons template used within the sector of athletics

Surgeon and Patient characteristics C

C.1 Variation relative to Operating Surgeon

In the following process variability among operating surgeons at O6 is listed. In each table, the mean value, standard deviation, and volume of the procedure code before the operating surgeon who has conducted the procedure code will be listed below. The covered value of the operating surgeon is the mean, standard deviation (SD), z-score minimum value, z-score maximum value, standard error of mean, and volume. The operating surgeon who was categorised as unknown is not included in the tables.

Surgeon	**Mean**	**SD**	**z(min)**	**z(max)**	**Standard Error of Mean**	**Cases**
BLXC1	9,42	7,50	x	x	x	19
BG0D	16	x	-0,87	3,00	0,88	1
SJXW	9	8,01	-0,22	16		
KNCT99	36,87	23,37	x	38		
BG0D	38,75	20,77	-1,29	0,93	0,16	4
DG4T	94	x	x	x	2,44	1
EYDS	61	x	x	x	1,03	1
GWPU	28,71	18,12	-1,09	2,00	-0,92	7
KG1Y	54,40	28,54	-1,28	1,21	0,34	5
NQ92	35	x	x	x	-0,08	1
SJXW	19	19,14	-0,90	1,40	-0,05	4
UGSW	35	x	x	x	-0,08	1
WDH0	13	x	x	x	-1,02	1
WSXL	38,67	26,69	-0,89	1,77	0,19	6
YN91	46	x	x	x	0.39	1

Table C.1: *XX Calculations are illustrated in appendix* **??**

Surgeon	Mean	SD	z(min)	z(max)	Standard Error of Mean	Cases
KNCU49	31,21	14,51	x	x	x	98
B0TY	47	16,97	-0,71	0,71	0,77	2
BCJY	25,33	17,67	-1,15	0,66	-0,23	3
BG0D	28,83	7,05	-0,97	1,87	-0,07	6
DG4T	29	x	x	x	-0,15	1
DS5J	33,6	16,52	-1,49	1,17	0,07	5
EF2V	21	x	x	x	-0,70	1
EYDS	40,5	10,61	-0,45	0,71	0,45	2
FS7Z	30,67	8,39	-1,15	0,64	-0,02	3
G4VS	48	x	x	x	1,16	1
GWPU	25,23	9,20	-1,65	2,69	-0,09	22
HUC6	39,5	9,19	-0,71	0,71	0,40	2
KG1Y	37	x	x	x	0,40	1
NCY8	59	5,66	-0,71	0,71	1,35	2
NQ92	42	x	x	x	0,74	1
PFFQ	34	x	x	x	0,19	1
PP9H	51	x	x	x	1,36	1
PWE1	22	x	x	x	-0,63	1
Q6T7	54	17,58	-1,14	0,74	0,91	3
SJXW	28,65	13,68	-1,51	2,07	-0,04	17
U0MK	27,5	7,78	-0,71	0,71	-0,18	2
UGSW	46	x	x	x	1,02	1
WSXL	26,11	19,09	-1,05	2,14	-0,12	9
YN91	29	x	x	x	-0,15	1
KNDT99	34,08	40,66	x	x	x	39
BG0D	23	12,08	-0,83	1,41	-0,54	4
FS7Z	19,67	4,04	-0,91	1,07	-0,61	3
GWPU	15,43	7,72	-1,48	1,63	-1,21	7
HMV3	73	60,81	-0,71	0,71	1,35	2
HUC6	13	x	x	x	-0,52	1
MH23	26	x	x	x	-0,20	1
MNJ4	27,5	12,02	-0,71	0,71	-0,23	2
NCY8	32	x	x	x	-0,05	1
PFFQ	14	x	x	x	-0,49	1
PP9H	22	x	x	x	-0,30	1
SJXW	20	4,24	-0,71	0,71	-0,49	2
U44S	46,5	31,82	-0,71	0,71	0,43	2
WSXL	26,67	7,09	-1,08	0,89	-0,32	3
YHE8	139,5	156,27	-0,71	0,71	3,67	2
YN91	38	x	x	x	0,10	1

Table C.2: *XX Calculations are illustrated in appendix* **??**

Surgeon	Mean	SD	z(min)	z(max)	Standard Error of Mean	Cases
KNFK99	38,96	25,62	x	x	x	27
BG0D	32,5	6,36	-0,71	0,71	-0,18	2
FS7Z	24	x	x	x	-0,58	1
GWPU	40,5	3,54	-0,71	0,71	0,04	2
KG1Y	72,5	78,49	-0,71	0,71	0,93	2
PFFQ	2	x	x	x	-1,44	1
SJXW	35,71	20,06	-1,68	1,71	-0,03	14
WSXL	42,5	22,23	-0,79	1,46	0,07	4
YN91	65	x	x	x	1,02	1
KNFU49	53,33	31,76	x	x	x	21
BANN	62	x	x	x	0,27	1
BG0D	36	x	x	x	-0,55	1
DG4T	33	2.83	-0,71	0,71	-0,91	2
DS5J	138	x	x	x	2,67	1
E9U0	59	x	x	x	0,18	1
GWPU	40	15,56	-0,71	0,71	-0,59	2
JKQF	44	x	x	x	-0,29	1
NQ92	48	13,98	-0,71	1,29	-0,34	4
WDH0	49	25,46	-0,71	0,71	-0,19	2
WSXL	31	8,49	-0,71	0,71	-0,99	2
YYTO	24	x	x	x	-0,92	1
KNGA11	30,77	22,07	x	x	x	141
A690	31,21	19,42	-1,04	2,67	0,09	19
A8RM	38,10	29,79	-0,88	3,02	1,52	21
FS7Z	49	x	x	x	0,83	1
IC7S	30,73	28,84	-0,72	3,68	-0,01	23
MNJ4	42,29	17,63	-1,09	2,25	1,95	14
NKR0	19,33	10,46	-1,08	1,78	-1,80	12
O5I2	28,67	6,43	-0,73	1,14	-0,17	3
RWF4	35,5	6,36	-0,71	0,71	0,30	2
UXSE	47	x	x	x	0,74	1
XC28	33	x	x	x	0,10	1
Y3GJ	25,44	18,55	-0,78	4,13	-1,55	41
YZ6T	28,67	13,01	-0,97	1,02	-0,17	3

Table C.3: *XX Calculations are illustrated in appendix* **??**

Surgeon	**Mean**	**SD**	**z(min)**	**z(max)**	**Standard Error of Mean**	**Cases**
KNGE15	25,89	16,31	x	x	x	19
A69O	15	3,67	-1,63	1,09	-1,49	5
A8RM	27,33	11,04	-1,12	1,51	0,22	6
IC7S	47	4,24	-0,71	0,71	1,83	2
RWF4	74	x	x	x	2,95	1
Y3GJ	13	3,61	-0,83	1,11	-1,37	3
YZ6T	23	4,24	-0,71	0,71	-0,25	2
KNGE45D	93,92	32,19	x	x	x	248
A8RM	105,38	26,87	-2,10	2,37	3,04	73
IC7S	95,89	29,14	-2,16	1,72	0,40	44
NKR0	62,38	9,34	-1,00	2,85	-3,92	16
Y3GJ	91,38	27,72	-2,57	4,35	-0,76	93
YZ6T	77,41	29,11	-1,94	2,77	-2,41	22
KNGE45F	119,5	22,24	x	x	x	16
A8RM	116,15	18,50	-1,25	1,99	-0,54	13
Y3GJ	178	x	x	x	2,63	1
YZ6T	112	11,31	-0,71	0,71	-0,48	2
KNGF11	22,80	13,05	x	x	x	214
A69O	19,32	8,23	-1,38	3,00	-1,94	53
A8RM	29,6	17,81	-1,10	3,50	3,08	35
FS7Z	28,5	4,95	-0,71	0,20	0,62	2
IC7S	20,76	9,67	-1,32	3,02	-0,84	29
M4F8	57	x x	x		2,62	1
MNJ4	41,83	11,53	-1,46	1,58	5,05	12
NCY8	51	x	x	x	2,16	1
NKR0	12,5	4,06	-1,11	1,60	-2,50	10
RWF4	37,5	10,61	-0,71	0,71	2,52	2
XC28	49	XXX	2,01	2		
Y3GJ	20,21	9,07	-1,46	2,62	-1,16	34
YZ6T	18,30	9,79	-1,15	3,65	-1,98	33

Table C.4: *XX Calculations are illustrated in appendix* **??**

Surgeon	Mean	SD	z(min)	z(max)	Standard Error of Mean	Cases
KNGF31	25,34	13,56	x	x	x	56
A69O	22,25	5,57	-2,02	0,85	-0,64	8
A8RM	35,8	18,74	-1,38	1,45	2,99	15
IC7S	19,62	7,73	-1,37	1,34	-1,52	13
NKR0	17,8	4,55	-1,06	1,14	-1,24	5
RWF4	28,5	4,95	-0,71	0,71	0,33	2
XC28	40	x	x	x	1,08	1
Y3GJ	23,6	12,10	-1,37	2,18	-0,41	10
YZ6T	13,5	6,36	-0,71	0,71	-1,24	2
KNGH41	31,44	17,07	x	32		
A69O	27	15,10	-0,93	1,06	-0,45	3
A8RM	33,6	22,11	-0,71	2,73	0,40	10
IC7S	17	x	x	x	-0,85	1
MNJ4	47,33	25,74	-0,63	1,15	1,61	3
RWF4	35	x	x	x	0,21	1
UXSE	17	x	x	x	1,03	1
Y3GJ	27	17,80	-0,76	1,42	-0,52	4
YZ6T	25,33	9,46	-0,99	1,34	-1,07	9
KNGH72B	96,27	37,00	x	x	x	22
A8RM	107,25	41,43	-2,28	1,04	0,84	8
IC7S	96,5	55,86	-0,71	0,71	0,01	2
Y3GJ	94,13	37,32	-2,31	0,85	-0,16	8
YZ6T	63,67	12,86	-1,14	0,73	-1,53	3
KNGH91	25,64	10,76	x	11		
IC7S	11	x	x	x	-1,36	1
RWF4	51	x	x	x	2,36	1
YZ6T	24,44	7,11	-0,91	1,48	-0,33	9

Table C.5: *XX Calculations are illustrated in appendix* **??**

Surgeon	Mean	SD	z(min)	z(max)	Standard Error of Mean	Cases
KNGK19	42,26	30,58	x	x	x	19
A69O	18	x	x	x	-0,79	1
A8RM	35,57	15,96	-0,79	2,03	-0,58	7
IC7S	72,75	57,87	-0,84	1,20	1,99	4
Y3GJ	35	16,60	-1,14	1,57	-0,53	5
YZ6T	35	9,90	-0,71	0,71	-0,34	2
KNGK99	54,41	38,64	x	37		
B0TY	26	x	x	x	-0,74	1
BG0D	61	42,43	-0,71	0,71	0,24	2
DG4T	26	x	x	x	-0,74	1
FS7Z	26	x	x	x	-0,74	1
GWPU	74,4	36,45	-1,08	1,20	1,16	5
KG1Y	57,56	53,32	-0,70	2,52	0,24	9
NCY8	14	x	x	x	-1,05	1
PFFQ	35	x	x	x	-0,50	1
PP9H	37	x	x	x	-0,45	1
SJXW	26,5	10,61	-0,71	0,71	-1,02	2
TJMA	49,5	2,12	-0,71	0,71	-0,18	2
WDHO	47	21	-0,71	0,71	-0,30	2
WSXL	64,5	45,95	-1,10	1,86	0,74	8
KNGM09	28,36	11,62	x	11		
A8RM	40,5	4,95	-0,71	0,71	1,48	2
IC7S	34,33	13,58	-1,06	0,93	0,89	3
MNJ4	39	x	x	x	0,92	1
YZ6T	17,8	2,17	-0,37	1,48	-2,03	5

Table C.6: *XX Calculations are illustrated in appendix* **??**

Surgeon	**Mean**	**SD**	**z(min)**	**z(max)**	**Standard Error of Mean**	**Cases**
KNGU39	24,66	16,77	x	x	x	79
AH2W	15	x	x	x	-0,58	1
BG0D	53	x	x	x	1,69	1
DS5J	15,33	3,06	-1,09	0,87	-0,96	3
E9U0	50	x	x	x	1,51	1
EF2V	20	4,24	-0,71	0,71	-0,39	2
EYDS	28	x	x	x	0,20	1
FS7Z	13,5	6,36	-0,71	0,71	-0,94	2
G9P2	28	x	x	x	0,20	1
GWPU	51,5	26,71	-1,48	0,69	3,20	4
HUC6	18,5	14,85	-0,71	0,71	-0,52	2
JKQF	25	x	x	x	0,02	1
KFWG	7,5	0,71	-0,71	0,71	-1,45	2
KG1Y	36,44	20,72	-1,42	1,67	2,11	9
M4F8	20,5	9,19	-0,71	0,71	-0,35	2
N4VP	6	x	x	x	-1,11	1
NCY8	20	x	x	x	-0,28	1
NQ92	16,5	9,67	-1,19	1,60	-1,19	6
PFFQ	29	x	x	x	0,26	1
PP9H	24	x	x	x	-0,04	1
PWE1	45	x	x	x	1,21	1
SJXW	16	11,31	-0,71	0,71	-0,73	2
TJMA	16,86	7,78	-1,01	1,30	-1,23	7
U0MK	11,5	0,71	-0,71	0,71	-1,11	2
UGSW	29	13,23	-0,76	1,13	0,45	3
V2S7	26	x	x	x	0,08	1
VDGZ	10	x	x	x	-0,87	1
VW00	10,5	9,19	0,71	-0,71	-1,19	2
WSXL	30,4	19,35	-0,85	1,74	0,77	5
YN91	15	4,24	-0,71	0,71	-0,81	2

Table C.7: *XX Calculations are illustrated in appendix* **??**

Surgeon	Mean	SD	z(min)	z(max)	Standard Error of Mean	Cases
KNGU49	43,68	30,42	x	x	x	106
A69O	32,5	3,54	-0,71	0,71	-0,52	2
A8RM	39,3	28,22	-0,93	2,12	-0,46	10
B0TY	30	x	x	x	-0,45	1
BCJY	39	9,30	-1,51	0,86	-0,34	5
BG0D	74	x	x	x	1,00	1
BRZ4	54	x	x	x	0,34	1
CMTJ	18	x	x	x	-0,84	1
DS5J	51,88	27,30	-1,24	1,47	0,76	8
E9U0	77	x	x	x	1,10	1
F1UP	29	x	x	x	-0,48	1
G9P2	38	x	x	x	-0,19	1
GWPU	56,25	30,35	-0,93	1,08	0,83	4
HUC6	16	x	x	x	-0,91	1
IC7S	20,43	10,88	-0,87	2,17	-2,02	7
KFWG	205	x	x	x	5,30	1
KG1Y	53,50	50,20	-0,71	0,71	0,46	2
MNJ4	39,6	29,36	-0,87	1,21	-0,30	5
NCY8	38	9,90	-0,71	0,71	-0,26	2
NQ92	55,57	40,86	-1,09	1,19	1,03	7
PP9H	21	x	x	x	-0,75	1
Q6T7	53,67	22,50	-1,14	0,73	0,57	3
RWF4	29	x	x	x	-0,48	1
SJXW	58,67	26,03	-1,02	0,97	0,85	3
U0MK	10	x	x	x	-1,11	1
UGSW	44,13	27,49	-0,99	2,32	0,04	8
UJ8B	24	x	x	x	-0,65	1
UXSE	65	64,37	-0,67	1,15	1,21	3
V2S7	61	x	x	x	0,57	1
WDH0	15	x	x	x	-0,94	1
WSXL	34,5	19,26	-1,17	0,91	-0,60	4
Y3GJ	44	20,01	-1,50	1,50	0,03	7
YN91	40,33	24,83	-0,82	1,11	-0,19	3

Table C.8: *XX Calculations are illustrated in appendix* **??**

Surgeon	Mean	SD	z(min)	z(max)	Standard Error of Mean	Cases
KNHG46	69,67	18,82	x	x	x	24
C0XW	81	18,09	-2,05	1,11	1,59	7
CHH4	76	x	x	x	0,34	1
HEL3	55,2	8,04	-1,02	1,59	-1,72	5
N4VP	54	13,59	-1,10	0,88	-1,67	4
O3OX	80,2	18,67	-1,14	1,33	1,25	5
KNHG49	50,29	50,39	x	x	x	17
C0XW	59,67	45,36	-0,76	1,13	0,32	3
HEL3	96	x	x	x	0,91	1
N4VP	31,25	23,13	-0,88	1,29	-0,76	4
O3OX	60,83	79,60	-0,51	2,04	0,51	6
KNHK57	65,57	21,64	x	x	x	65
C0XW	64,94	25,01	-1,00	2,20	-0,12	16
HEL3	64,45	26,84	-1,02	1,81	-0,17	11
N4VP	58,57	28,56	-1,21	1,38	-0,86	7
O3OX	72,61	16,27	-1,70	2,85	1,38	18
S3FV	68,5	6,36	-0,71	0,71	0,19	2
KNHL39	38,30	28,34	x	x	x	20
BG0D	13	x	x	x	-0,89	1
ETHX	46	x	x	x	0,27	1
KG1Y	45,75	52,02	-0,66	1,74	0,53	4
SJXW	39,6	27,49	-1,29	1,29	0,15	10
WSXL	28	x	x	x	-0,36	1
YN91	30	x	x	x	-0,29	1

Table C.9: *XX Calculations are illustrated in appendix* **??**

Surgeon	Mean	SD	z(min)	z(max)	Standard Error of Mean	Cases
KNHT99	40,61	28,61	x	x	x	327
BCJY	36	x	x	x	-0,16	1
BG0D	19,3	9,48	-1,30	1,55	-2,36	10
C0XW	34,17	26,32	-1,18	2,69	-2,07	84
DG4T	25	5,66	-0,71	0,71	-0,77	2
EYDS	45,57	21,95	-1,67	1,48	0,46	7
FS7Z	27	x	x	x	-0,48	1
GWPU	31,11	23,58	-0,77	1,78	-1,00	9
HEL3	40,38	33,74	-1,11	2,77	-0,05	40
HUC6	26,5	17,68	-0,71	0,71	-0,70	2
KG1Y	38,69	25,05	-1,19	1,89	-0,27	16
N4VP	55,24	25,94	-2,01	2,73	2,75	29
O3OX	60,32	32,55	-1,55	2,08	4,19	37
O5I2	10	x	x	x	-1,07	1
PFFQ	16,5	2,12	-0,71	0,71	-1,19	2
PP9H	44	x	x	x	0,12	1
PWE1	36	x	x	x	-0,16	1
S3FV	37,67	6,51	-1,02	0,97	-0,18	3
SJXW	28,1	11,28	-1,16	1,85	-1,96	20
U0MK	23	x	x	x	-0,62	1
VDGZ	63	x	x	x	0,78	1
WSXL	45,74	33,65	-0,97	-0,97	0,78	19
XC28	40,5	13,44	-0,71	0,71	-0,01	2

Table C.10: *XX Calculations are illustrated in appendix* **??**

Surgeon	Mean	SD	z(min)	z(max)	Standard Error of Mean	Cases
KNHU49	41,92	26,73	x	x	x	158
BCJY	42,67	7,77	-1,12	0,82	0,05	3
BRZ4	49,67	36,91	-0,80	1,12	0,50	3
C0XW	34,63	21,71	-1,18	1,77	-1,19	19
CMTJ	60,5	10,61	-0,71	0,71	0,98	2
DG4T	9	x	x	x	-1,23	1
DS5J	40,86	25,29	-1,38	1,43	-0,11	7
E2EV	84	x	x	x	-1,57	1
E9U0	12,33	6,35	-1,15	0,58	-1,92	3
EF2V	32	x	x	x	-0,37	1
EYDS	39	17,78	-1,13	0,79	-0,19	3
F1UP	20	24,04	-0,71	0,71	-1,16	2
FS7Z	21	1,41	-0,71	0,71	-1,11	2
G9P2	52	7,07	-0,71	0,71	0,53	2
HEL3	37	29,83	-0,94	2,55	-0,58	10
HUC6	19	x	x	x	-0,86	1
JKQF	32	14	-1,00	1,00	-0,64	3
KFWG	78,8	37,49	-1,73	0,75	3,08	5
LQWA	41	35,36	-0,71	0,71	-0,05	2
M4F8	61,67	58,11	-0,91	1,07	1,28	3
N4VP	43	8,64	-1,39	0,93	0,08	4
NCY8	53,67	25,48	-0,65	1,15	0,76	3
NQ92	41,7	23,39	-1,27	1,55	-0,04	20
O3OX	54,5	14,01	-0,68	1,46	0,94	4
PFFQ	7	x	x	x	-1,31	1
Q6T7	61	x	x	x	0,71	1
UGSW	39,17	25,95	-1,01	2,27	-0,36	12
UJ8B	55,33	28,75	-1,12	0,79	0,87	3
UXSE	49,25	30,35	-0,93	1,08	0,55	4
VW00	28,33	7,51	-0,98	1,02	-0,88	3
WDH0	31	9,90	-0,71	0,71	-0,58	2
X61H	49	42,57	-0,89	1,08	0,46	3
X91B	23	x	x	x	-0,71	1
XC28	14	x	x	x	-0,71	1
YN91	23	9,54	-0,94	1,05	-1,23	3
YYTO	44	x	x	x	0,08	1

Table C.11: *XX Calculations are illustrated in appendix* **??**

Surgeon	Mean	SD	z(min)	z(max)	Standard Error of Mean	Cases
KQBE10	30,57	19,10	x	x	x	212
A8RM	28,88	10,75	-1,66	1,50	-0,25	8
CMTJ	30,3	14,61	-1,46	1,48	-0,04	10
DG4T	19,33	18,77	-0,60	1,15	-1,56	3
EF2V	20,86	7,52	-1,31	1,22	-1,34	7
F1UP	33,6	14,33	-1,37	1,14	0,36	5
G9P2	40,29	23,46	-1,21	1,35	1,35	7
HUC6	17	11,14	-0,90	1,08	-1,23	3
IC7S	25,09	17,04	-1,12	3,52	-1,38	23
KFWG	37	13,42	-0,97	1,34	0,89	7
M4F8	47,17	40,52	-0,74	1,58	2,13	6
MNJ4	44,83	12,14	-1,22	1,83	1,83	6
NCY8	22,92	13,10	-1,14	2,60	-1,44	13
O5I2	21	x	x	x	-0,50	1
Q6T7	29,42	16,90	-1,33	2,34	-0,21	12
RWF4	24,67	5,03	-0,93	1,06	-0,53	3
UGSW	22,17	11,09	-1,55	1,52	-1,08	6
UXSE	34,14	23,89	-1,09	3,13	1,11	35
WDH0	14,8	9,47	-1,14	1,60	-1,85	5
X61H	34,14	17,37	-1,39	2,29	0,88	22
XB5U	29,6	11,33	-1,47	1,01	-0,11	5
XYSV	47,75	25,42	-0,66	1,47	1,80	4
Y3GJ	27,75	7,80	-0,74	1,44	-0,29	4
YN91	21	5,10	-1,57	0,78	-1,12	5
YZ6T	22,5	9,25	-1,03	1,57	-1,03	6
KQDH10	21,52	17,93	x	x	x	23
BG0D	14,67	4,62	-0,58	1,15	-0,66	3
C0XW	11,4	2,61	-0,54	1,76	-1,26	5
DS5J	45	x	x	x	1,31	1
EYDS	25,5	13,44	-0,71	0,71	0,31	2
GWPU	22	x	x	x	0,03	1
HUC6	23	x	x	x	0,08	1
PP9H	31	x	x	x	0,53	1
Q6T7	14	x	x	x	-0,42	1
SJXW	22	x	x	x	0,03	1
WSXL	36,75	39,04	-0,58	1,49	1,70	4

Table C.12: *XX Calculations are illustrated in appendix* **??**

C.2 Variability relative to Patient characteristics

The following section cove patients characteristics of the assignable variation from sample 1 and 2 compared with the random variation of sample 3. Sample size 1 cover the assignable variation who exceeds +1 standard deviation, sample size 2 cover the assignable variation who is below -1 standard deviaion and, sample size 3 cover the random variation within the control limits of +/-1 standard deviation. The analysis is based on procedure codes who has been conducted +49 times to ensure the validity of the analysis. The constraint of only using surgeries who has been conducted +49 times was suggested by the employees at O6 to ensure that the findings reflects reality. The procedure codes are listed below where the percentage distribution of sample 1 and 2 could either increase, decreased or almost equal to the percentage distribution of sample 3. The analysis will only comment of the characteristics who has increased or decreased, and not comment on the categories who is equal to sample 3.

- **KNCU49**
  - Sample size 1 (Exceed +1 standard deviation)
    * Increased: Male and BMI 1, and Gr. 0-10 years
    * Decreased: Gr. 11-20 years.
  - Sample size 2 (Below -1 standard deviation)
    * Increased: Female, Unknown reg, and Gr.11-20 years.
    * Decreased: BMI 2 and Gr. 0-10 years.
- **KNGA11**
  - Sample size 1
    * Increased: ASA I, BMI 4, GA and Unknown reg. Gr 11-30 years.
    * Decreased: Gr. 51-60 years.
  - Sample size 2
    * Increased: Female, ASA I, BMI 2 and, Gr. 21-30 and 51-60 years.
    * Decreased: ASA II, BMI 3, BMI 4, GA and Gr. 11-20, 31-40, 41, 61-70 years.
- **KNGD45D**
  - Sample size 1
    * Increased: Male, ASA I, BMI 2, BMI 3, GA, Unknown reg. (ASA & BMI) and Gr. 21-30 years.
    * Decreased: Gr. 31-40 years.
  - Sample size 2
    * Increased: Female, Unknown reg and Gr. 31-50
    * Decreased: ASA I, BMI 3, GA and Gr. 11-30.
- **KNGF11**
  - Sample size 1
    * Increased: Male, ASA II, BMI 4 and Gr. 51-70 years.
    * Decreased: ASA I, BMI 1 and Gr. 11-30 & 71-80 years

- Sample size 2
    - Increased: Female, BMI 2, Unknown reg. and Gr.21-30 years.
    - Decreased: ASA I, ASA II, BMI 3 and Gr.51-70 years

- **KNGF31**
  - Sample size 1
    - Increased: Female, ASA II, BMI 2, BMI 3 and Gr.51-60 years
    - Decreased: Unknown reg. and Gr. 21-30 & 41-50 years.
  - Sample size 2
    - Female, Unknown reg. and Gr. 11-20 & 61-70 years.
    - Decreased: BMI 3 and Gr.31-40 & 51-60 years.

- **KNGU39**
  - Sample size 1
    - Increased: Female, ASA I, ASA IV, BMI 1, BMI 2, GA and Gr. 11-20 years
    - Decreased: Unknown reg. Gr-21-80 years.
  - Sample size 2
    - Female, BMI 1, Unknown reg. and Gr. 51-70 years.
    - Decreased: ASA I, ASA II, BMI 3, BMI 4, Gr. 11-20 & 31-50 years.

- **KNGU49**
  - Sample size 1
    - Increased: Female, ASA II, BMI 2, GA and Gr.71-80 supported with minor difference in 11-20 years.
    - Decreased: BMI 3, Unknown reg., Gr.21-30 supported with minor difference in 31-60 years.
  - Sample size 2
    - Increased: Female, ASA I, and BMI 3, GA and Gr. 0-30 years.
    - Decreased: ASA II, BMI 4 and Gr.31-60 supported with minor difference in 61-90 years.

- **KNHK57**
  - Sample size 1
    - Increased: Female, ASA I, ASA III and Gr. 41-50 years supported with minor difference in 61-80 years.
    - Decreased: ASA II and Gr. 21-40 years.
  - Sample size 2
    - Increased: Female, ASA I, BMI 2, GA and Gr. 71-80 years.
    - Decreased: BMI 3 and Gr. 31-40 and 61-70 years.

- **KNHT99**
  - Sample size 1
    - Increased: Female and Gr. 41-60 years.
    - Decreased: BMI 3 and Gr. 11-20 years.
  - Sample size 2

    * Increased: Female, LA, Unknown reg. and Gr.31-40 and Gr. 71-80 years.
    * Decreased: ASA I, BMI 2, GA and Gr. 11-20 and Gr. 51-60

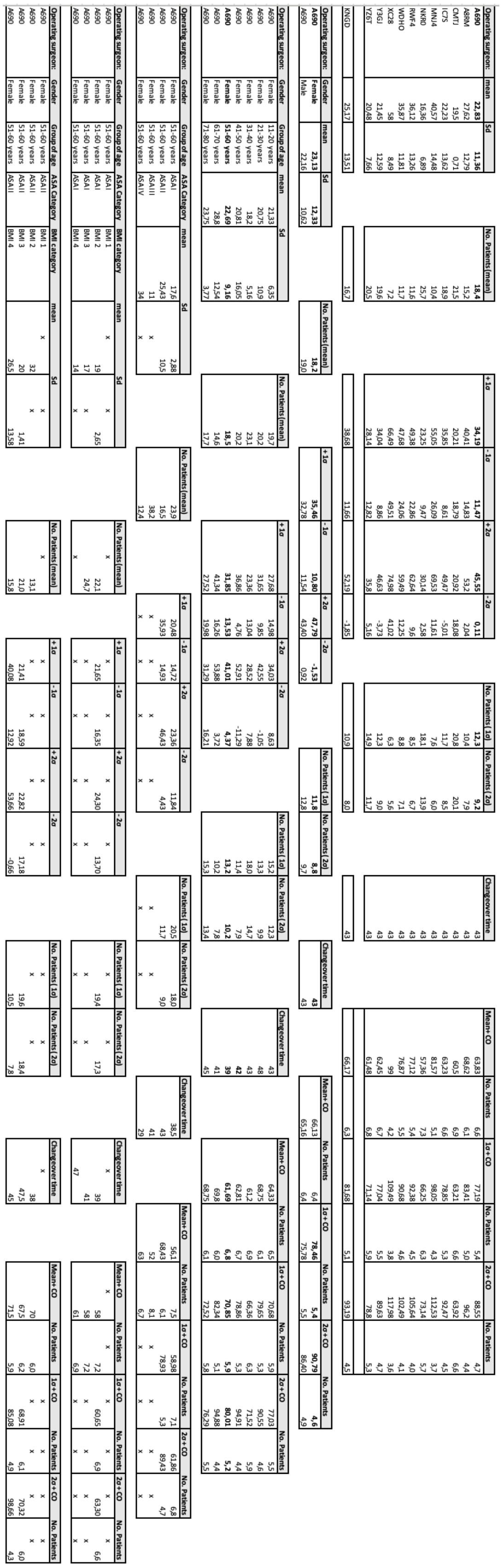
- **KNHU49**
  - Sample size 1
    * Increased: Female, ASA III, BMI 4 and minor difference in Gr.11-30 and 70-90 years.
    * Decreased: ASA II, BMI 2, BMI 3 and minor difference in Gr. 31-70 years
  - Sample size 2
    * Increased: Unknown reg. and Gr. 71-80 years.
    * Decreased: ASA II, BMI 4 and minor difference in Gr. 31-41 years.
- **KQBE10**
  - Sample size 1
    * Increased: Male and minor difference in BMI 2 and Gr. 11-20 & 31-50 years.
    * Decreased: BMI 4 and Gr. 51-60 years.
  - Sample size 2
    * Increased: Unknown reg. and Gr. 41-50 years.
    * Decreased: ASA I, BMI 3 and Anesthesia (cause-effect of increased unknown reg.) and Gr. 61-80 years.

Solution - Increased accuracy

D

D.1 Underlying Algorithms

The systematic methodology and underlying algorithms of the new planning procedure used to increase the accuracy of estimated surgical duration are illustrated in figure D.1. Figure D.1



Operating surgeon:	mean	Sd	No. Patients (mean)	+ 1σ	- 1σ	+ 2σ	- 2σ	No. Patients (1σ)	No. Patients (2σ)	Changeover time	Mean+ CO	No. Patients	1σ + CO	No. Patients	2σ + CO	No. Patients
A690	**22,83**	**11,36**	**18,4**	**34,19**	**11,47**	**45,55**	**0,11**	**12,3**	**9,2**	43	63,83	6,6	77,19	5,4	88,55	4,7
A8RM	27,62	12,79	15,2	40,41	14,83	53,2	2,04	10,4	7,9	43	68,62	6,1	83,41	5,0	96,2	4,4
CMTJ	19,5	0,71	21,5	20,21	18,79	20,92	18,08	20,8	20,1	43	60,5	6,9	63,21	6,6	63,92	6,6
IC7S	22,23	13,62	18,9	35,85	8,61	49,47	-5,01	11,7	8,5	43	63,23	6,6	78,85	5,3	92,47	4,5
MNJ4	40,57	14,48	10,4	55,05	26,09	69,53	11,61	7,6	6,0	43	81,57	5,1	98,05	4,3	112,53	3,7
NKR0	16,36	6,89	25,7	23,25	9,47	30,14	2,58	18,1	13,9	43	57,36	7,3	66,25	6,3	73,14	5,7
RWF4	36,12	13,26	11,6	49,38	22,86	62,64	9,6	8,5	6,7	43	77,12	5,4	92,38	4,5	105,64	4,0
WDHO	35,87	11,81	11,7	47,68	24,06	59,49	12,25	8,8	7,1	43	76,87	5,5	90,68	4,6	102,49	4,1
XC28	58	8,49	7,2	66,49	49,51	74,98	41,02	6,3	5,6	43	99	4,2	109,49	3,8	117,98	3,6
Y3GJ	21,45	12,59	19,6	34,04	8,86	46,63	-3,73	12,3	9,0	43	62,45	6,7	77,04	5,5	89,63	4,7
YZ6T	20,48	7,66	20,5	28,14	12,82	35,8	5,16	14,9	11,7	43	61,48	6,8	71,14	5,9	78,8	5,3
KNGD	25,17	13,51	16,7	38,68	11,66	52,19	-1,85	10,9	8,0	43	66,17	6,3	81,68	5,1	93,19	4,5

Operating surgeon:	Gender	mean	Sd	No. Patients (mean)	+ 1σ	- 1σ	+ 2σ	- 2σ	No. Patients (1σ)	No. Patients (2σ)	Changeover time	Mean+ CO	No. Patients	1σ + CO	No. Patients	2σ + CO	No. Patients
A690	**Female**	**23,13**	**12,33**	**18,2**	**35,46**	**10,80**	**47,79**	**-1,53**	**11,8**	**8,8**	**43**	66,13	6,4	**78,46**	**5,4**	**90,79**	**4,6**
A690	Male	22,16	10,62	19,0	32,78	11,54	43,40	0,92	12,8	9,7	43	65,16	6,4	75,78	5,5	86,40	4,9

Operating surgeon:	Gender	Group of age	mean	Sd	No. Patients (mean)	+ 1σ	- 1σ	+ 2σ	- 2σ	No. Patients (1σ)	No. Patients (2σ)	Changeover time	Mean+ CO	No. Patients	1σ + CO	No. Patients	2σ + CO	No. Patients
A690	Female	11-20 years	21,33	6,35	19,7	27,68	14,98	34,03	8,63	15,2	12,3	43	64,33	6,5	70,68	5,9	77,03	5,5
A690	Female	21-30 years	20,75	10,9	20,2	31,65	9,85	42,55	-1,05	13,3	9,9	48	68,75	6,1	79,65	5,3	90,55	4,6
A690	Female	31-40 years	18,2	5,16	23,1	23,36	13,04	28,52	7,88	18,0	14,7	43	61,2	6,9	66,36	6,3	71,52	5,9
A690	Female	41-50 years	20,81	16,05	20,2	36,86	4,76	52,91	-11,29	11,4	7,9	**42**	62,81	6,7	78,86	5,3	94,91	4,4
A690	**Female**	**51-60 years**	**22,69**	**9,16**	**18,5**	**31,85**	**13,53**	**41,01**	**4,37**	**13,2**	**10,2**	**39**	**61,69**	**6,8**	**70,85**	**5,9**	**80,01**	**5,2**
A690	Female	61-70 years	28,8	12,54	14,6	41,34	16,26	53,88	3,72	10,2	7,8	41	69,8	6,0	82,34	5,1	94,88	4,4
A690	Female	71-80 years	23,75	3,77	17,7	27,52	19,98	31,29	16,21	15,3	13,4	45	68,75	6,1	72,52	5,8	76,29	5,5

Operating surgeon:	Gender	Group of age	ASA Category	mean	Sd	No. Patients (mean)	+ 1σ	- 1σ	+ 2σ	- 2σ	No. Patients (1σ)	No. Patients (2σ)	Changeover time	Mean+ CO	No. Patients	1σ + CO	No. Patients	2σ + CO	No. Patients
A690	Female	51-60 years	ASA I	17,6	2,88	23,9	20,48	14,72	23,36	11,84	20,5	18,0	38,5	56,1	7,5	58,98	7,1	61,86	6,8
A690	Female	51-60 years	ASA II	25,43	10,5	16,5	35,93	14,93	46,43	4,43	11,7	9,0	43	68,43	6,1	78,93	5,3	89,43	4,7
A690	Female	51-60 years	ASA III	11	x	38,2	x	x	x	x	x	x	41	52	8,1	x	x	x	x
A690	Female	51-60 years	ASA IV	34	x	12,4	x	x	x	x	x	x	29	63	6,7	x	x	x	x

Operating surgeon:	Gender	Group of age	ASA Category	BMI category	mean	Sd	No. Patients (mean)	+ 1σ	- 1σ	+ 2σ	- 2σ	No. Patients (1σ)	No. Patients (2σ)	Changeover time	Mean+ CO	No. Patients	1σ + CO	No. Patients	2σ + CO	No. Patients
A690	Female	51-60 years	ASA I	BMI 1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
A690	Female	51-60 years	ASA I	BMI 2	19	2,65	22,1	21,65	16,35	24,30	13,70	19,4	17,3	39	58	7,2	60,65	6,9	63,30	6,6
A690	Female	51-60 years	ASA I	BMI 3	17	x	24,7	x	x	x	x	x	x	41	58	7,2	x	x	x	x
A690	Female	51-60 years	ASA I	BMI 4	14	x	x	x	x	x	x	x	x	47	61	6,9	x	x	x	x

Operating surgeon:	Gender	Group of age	ASA Category	BMI category	mean	Sd	No. Patients (mean)	+ 1σ	- 1σ	+ 2σ	- 2σ	No. Patients (1σ)	No. Patients (2σ)	Changeover time	Mean+ CO	No. Patients	1σ + CO	No. Patients	2σ + CO	No. Patients
A690	Female	51-60 years	ASA II	BMI 1	x	x	x	x	x	x	x	x	x	x			x	x	x	x
A690	Female	51-60 years	ASA II	BMI 2	32	x	13,1	x	x	x	x	x	x	38	70	6,0	x	x	x	x
A690	Female	51-60 years	ASA II	BMI 3	20	1,41	21,0	21,41	18,59	22,82	17,18	19,6	18,4	47,5	67,5	6,2	68,91	6,1	70,32	6,0
A690	Female	51-60 years	ASA II	BMI 4	26,5	13,58	15,8	40,08	12,92	53,66	-0,66	10,5	7,8	45	71,5	5,9	85,08	4,9	98,66	4,3

Figure D.1: *Operating Principles at O6 illustrated at each professionalism during a patient flow.*

D.2 New Planning Procedure

D.2.1 Sector of surgery - Children

Cat.	Mean	sd	Patient1	Patient2	Patient3
T1 - KNCU49:	31.21	14.51	6.2	5.7	5.2
T2 - GWPU:	25.23	9.2	5.9	5.2	4.7
T3 - Female:	21.33	6.84	6.2	5.7	5.2
T4 - 0-9:	33.33	36.89	5.3	3.6	2.7
T5 - ASA I:	17.67	4.93	6.6	6.1	5.7
T5 - ASA - unk.:	19.53	8.33	6.4	5.7	5.1
T4 - 10-19:	24.5	9.19	6.0	5.3	4.7
T5 - ASA I:	25.67	5.13	5.9	5.5	5.1
T5 - ASA - unk.	22.67	6.66	6.1	5.6	5.1

Table D.1: *An illustration of how the number of possible treated patients is affected by the different tiers and scope of covered probabilities (sd). The number of treated patients is calculated by dividing available time with required time related to the specific tier*

D.2.2 Sector of surgery - Feet

Cat.	Mean	sd	Patient1	Patient2	Patient3
T1 - KNHT99:	30.96	19.1	7.4	5.6	4.4
T2 - COWX:	34.17	26.32	7.0	4.9	3.7
T3 - Female:	43.18	30.05	6.1	4.2	3.2
T4 - 50-59:	48.69	33.38	5.6	3.9	3.0
T5 - ASA II:	78	16.83	4.9	3.5	3.1
T6 - BMI 2:	65	x	4.6	x	x
T6 - BMI 3:	92	x	3.6	x	x
T6 - BMI 4:	78	22.63	4.0	3.3	2.8
T5 - ASA - unk.:	38.92	32.02	6.5	4.3	3.3

Table D.2: *An illustration of how the number of possible treated patients is affected by the different tiers and scope of covered probabilities (sd). The number of treated patients is calculated by dividing available time with required time related to the specific tier*

D.2.3 Sector of surgery - Trauma

Cat.	Mean	sd	Patient1	Patient2	Patient3
T1 - KNGU49:	43.68	30.42	5.1	3.7	2.9
T2 - A8RM:	39.3	28.22	5.7	4.1	3.2
T3 - Female:	47.29	30.5	5.1	3.7	2.9
T4 - 10-19:	48.5	38.69	5.0	3.4	2.6
T5 - ASA I:	48.5	38.69	5.0	3.4	2.6
T6 - BMI 1:	76	x	3.8	x	x
T6 - BMI 2:	21	x	7.5	x	x

Table D.3: *An illustration of how the number of possible treated patients is affected by the different tiers and scope of covered probabilities (sd). The number of treated patients is calculated by dividing available time with required time related to the specific tier*

D.2.4 Sector of surgery - Tumor

Cat.	Mean	sd	Patient1	Patient2	Patient3
T1 - KKQBE10:	30.57	19.1	5.8	4.6	3.8
T2 - USXE:	34.14	17.37	5.5	4.5	3.8
T3 - Female:	37.32	26.22	5.3	4.0	3.2
T4 - 30-39:	37	33.70	5.3	3.7	2.9
T5 - ASA II:	13	x	7.5	x	x
T5 - ASA - unk.:	37	33.17	5.3	3.7	2.9

Table D.4: *An illustration of how the number of possible treated patients is affected by the different tiers and scope of covered probabilities (sd). The number of treated patients is calculated by dividing available time with required time related to the specific tier*