MASTER

The design of a nurse capacity planning to create flexibility and improve the workforce division

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The design of a nurse capacity planning to create flexibility and improve the workforce division

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Nurse planning, patient demand, nurse supply, flexibility, workforce division, workload, simulation

Abbreviations

LOS: Length of stay

FTE: Fulltime equivalent

IC: Intensive Care

VBA: Visual Basic for Applications

ED: Emergency Department

OT: Operating Theatre

Preface

This master thesis is the final step in finishing my master Operations Management & Logistics at the Eindhoven University of Technology. This thesis also marks the end of my wonderful period as a student. Before moving on to my thesis, I would like to thank everyone who contributed to this period.

In particular I would like to thank my first supervisor Nico Dellaert for his guidance throughout the thesis project. He supported me by giving me input for new ideas at moments I got stuck. The feedback and advice he gave me were very useful to improve my thesis project. Lastly I would like to thank Nico for giving me the opportunity to conduct my thesis in the Healthcare sector, which turned out to be a very interesting sector for me to conduct my thesis in. I also would like to thank my second supervisor Leander van der Meij for his feedback and critics on my thesis.

From the Elkerliek, I would like to thank Stan Janssen for giving me the opportunity to conduct my thesis at the Elkerliek hospital. Besides the opportunity of conducting my thesis at the Elkerliek I also learned a lot from Stan on the processes, politics and change management within the hospital sector and I really liked his extraordinary passion for Healthcare. Lastly I would like to thank the operational excellence team and sector managers for making my time at the Elkerliek even more pleasant.

At last, I would like to thank my family and friends. At first my family for supporting and motivating me during my student time in all possible ways. Furthermore, I would like to thank Iris for always be there to discuss what was on my mind. Lastly I would like to thank my student house 't Slotje, my hockey team De Joepies and my study friends for making my student life a tremendous period.

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Management summary

Nurses are considered to be the most important factor in both the hospital costs and the patient satisfaction (Yankovic & Green, 2011). The labor costs for nursing care account for approximately 25% of the total hospital operating budget and even increase in percentage over the last several years due to the increasing complexity of care and the decreasing length of stay (Kane & Siegrist, 2002), (Graf et al, 2003). Furthermore does the quality of care provided by the nurses directly influences the patient satisfaction (Mckee et al., 2012). These 2 examples emphasize the importance of accurate nurse planning.

This research is conducted at the Elkerliek hospital in Helmond and focuses on nurse planning at the regular inpatient departments of the Elkerliek. The research is conducted since the Elkerliek hospital experiences several problems regarding the nurse planning and satisfaction of nurses in the inpatient clinics. The first problem that arises is that the workload of nurses varies largely throughout time. These fluctuations are caused by the variability in patient arrivals and nurse availability. The lack of attention paid to these fluctuations often causes a mismatch between patient demand and nurse capacity, resulting in large workload fluctuations. The second problem is regarding the planning process of the departments, the development of the planning is done at once and has no revision moments build in. This makes the planning process very static. Thirdly, there is no standard process in which the strategic planning of the Elkerliek is translated into tactical nurse planning and operational nurse planning for departments. This results in non-uniform tactical and operational planning processes and different quality outputs of the actual schedules developed. Lastly, the flex-department, which helps departments to fulfill their nurse planning, is not able to deliver all the requested nurses from the departments since it is not optimally aligned to the departments.

These problems eventually lead to dissatisfaction of the nurses: during peak moments the workload will be too high, thereby increasing the burden experienced by nurses. During decreased workload the nurses are recovering from the periods of increased workload, and therefore hardly perceive the decreased workload as relaxing. The above results in the following research question:

'How to optimize flexibility and more equally divide workforce within the nurse rostering process of the inpatients clinics within the Elkerliek hospital?'

The research design consists of 3 different elements, which combined will answer the research question. Since the flexibility creation and the workforce division is done at strategic and tactical nurse planning, the elements to answer the research question focus on the strategic and the tactical nurse planning.

Mathematical model

The mathematical model is developed based on the probability distribution of the patient arrivals, LOS and the Newsboy equation and is used to estimate the amount of annualized nursing hours needed per department. The annualized nursing hours needed per department are used as input for the simulation model, the second element of the research. Furthermore, explores the mathematical model the flexibility strategy of cross-nursing. To do so, four clusters containing several combinations of departments are set up. From the mathematical model it is concluded that shared planning of the nurses, based on the patient demand and LOS, results in a smaller difference between the upper and lower bound, and suggests less fluctuations. Therefore cross-nursing decreases the amount of nurses needed to cover the occupancy rate and results in smaller fluctuations in nurse planning of the Elkerliek.

Simulation Model

The simulation model, simulates the patient flow and nurse assignment to shifts in the hospital for 5 years. The simulation consists of two elements, the patient arrival process and the nurse assignment process. The nurses' assignment is done based on a new planning design that is developed.

Patient arrival process

The first element of the simulation, simulates patient arrivals per shift at the different department. This is done based on the distribution, standard deviation, mean and seasonality of the different patients per department. As well as the specifications of the different departments, for example, opening weeks/times, reduction weeks, closing weeks/times and hospitalization procedures. Lastly information regarding illness (long and short term) of nurses will be used as input for the simulation model.

Nurse assignment process: Set-up and results of the new planning design

For the second element, the nurse assignment process, a new planning design is developed which consists of 6 planning phases. In this planning design each phase also includes the nurses planned in earlier phases. The planning phases of the design have different planning horizons in order to create flexibility in the nurse planning. To review the effects of each phase for each department, four performance indicators are set: overcapacity, under capacity, relative under capacity and relative overcapacity, all in percentages. These KPI's compare the amount of available nurses per phase with the patient arrivals. Since the simulation primarily focuses on a decrease of under capacity, the KPI's of under capacity and relative under capacity are most important. The other two KPI's were set to compare the overcapacity of the first phase with the final design in phase 6.

In phase 1, nurses are planned to cover 40% of sufficient occupancy rate, meaning that in 40% of all shifts sufficient capacity is available. With the use of the mathematical model this occupancy rate is determined. It is concluded that the overcapacity as well as the under capacity is still high.

In phase 2, nurses are planned according to seasonality of patient specialisms per department throughout the year. It is concluded that a decrease in under capacity in several departments is expected. Especially in departments 1B, 1C and 3B a decrease in under capacity is seen of respectively 4%, 5% and 7%.

In phase 3, nurses are planned based on the OT-schedule of patients. It is concluded that including the OT-schedule in the planning design of nurses especially has effect on the under capacity in the departments that have a substantial percentages of elective patients. Departments 2B, 2C and 2D (short stay and daycare) contain large percentages in elective patients, which cause a reduction in under capacity of respectively 21%, 13% and 35%. Also a large decrease in relative under capacity is measured in these departments.

In phase 4, departments are combined based on three different clusters. Cluster 1 (1B, 1B) and cluster 3 (3A, 3B, 3C, 3D, 4 Alg) show substantial decrease in the under capacity and relative under capacity. At 4Alg for example a decrease in under capacity can be seen of 41% while in 3A and 3B respectively a decrease of 36% and 32% can be reviewed. At these 2 clusters, the relative under capacity also substantially decreases.

In phase 5 and 6, two nurse pools are set up to compensate for the decreased nurse availability caused by long and short term illness of nurses. The results show that both phases cause a decrease in under capacity occurrences and relative under capacity. Especially with the adding of nurses in phase 6 large decrease in the under capacity in the departments is expected.

Lastly it is reviewed if the new planning design changes the overcapacity and relative overcapacity. As expected, it is concluded that the overcapacity and relative overcapacity only changed for a small percentage since the focus is on the under capacity side of the workforce. This small change in overcapacity is caused by the decrease in personnel used during periods which suggest low seasonality demand.

Current planning design versus new planning design: KPI's

In order evaluate the new planning design, the KPI outcomes of the new planning design are compared with the KPI outcomes of the current design. In the current situation one can see, that the percentage of overcapacity is very large while the under capacity is relatively small but still substantial. Comparing these results to the final results (phase 6) of the new planning design, it is concluded that both the under capacity and the overcapacity KPI's are improved in the new planning design (lower under capacity and lower overcapacity) for all the departments. Furthermore, the number of nursing hours used for the current planning compared to the number of nursing hours in the final design of the new planning design is decreased with 23%.

Current planning design versus new planning design: planning horizon

The new planning design contains multiple planning horizons, while the old design contains one planning horizon. Phase 1 and Phase 2, are scheduled 3 months in advance. Phase 3 and phase 5 are scheduled 1 month in advance. Phase 4, is scheduled 1 week in advance and phase 6, is planned 1 day in advance. During the 4 different planning horizons: 3 months, 1 month, 1 week and 1 day before due date, respectively 80%, 7%, 10% and 3% of the nurses are planned. By planning with multiple horizons, flexibility is created for nurse planning. The percentages of nurses planned per planning horizon were used as input for the ranking based questionnaire.

Redesign of flex-department

Based on the two peak moments in which departments request nurses at the flex department: 1 to 6 days prior to the shift, and 31 to 36 days prior to a shift, phase 5 and 6 of the new planning design are developed. The results of phase 5 and phase 6 show a substantial decrease in under capacity. Based on the result, the flex-department can be redesigned. After the redesign, the flex department has two pools, one pool to deal with last minute requests for illness, one pool deals with regular requests (long term illness). It is important to make a clear distinction between the two pools, if there won't be a clear distinction between these two pools, too much personnel is planned for the regular long term illness pool and a shortage in personnel is planned for short term illness.

Ranking based interview

In order to get feedback from nurses on the new planning design a ranking-based-questionnaire is conducted which evaluates the two key elements of the planning design, workforce division (reduction in under capacity) and the planning horizons related to different phases. The questionnaire is conducted among the nurses that develop the nurse planning at the departments. In this questionnaire, the nurses had to rank 6 options extracted from the 6 phases, from most preferred to least preferred. The nurses were also asked to motivate their ranking on both elements of the questionnaire. It is concluded that for the under capacity element, nurses had in common that they all remembered the specific periods of under capacity. In these periods the nurses felt in a hurry, the sense of stress, dissatisfaction and felt exhausted. In the second element, the nurses described that a planning which is developed one day before the actual shift is not desirable since this will interfere in the nurses private life. Once the planning is developed one day in advance, the nurses are not able to, for example, make appointments with their friends or to pick up their children from school. Based on this it is concluded that nurses seek to find a proper balance between the amount of under capacity in their work and the due dates of the planning horizons. The proper balance however varies per nurse, there is no uniform opinion of nurses on this.

Research question

Based on the conclusions of the mathematical model, the simulation model and the ranking-based interview, the research question can be answered. The workload in the Elkerliek can be more equally divided by developing a new planning design which focuses on the reduction of under capacity and incorporating seasonality, OT-schedules, cross-nursing, long term illness and short term illness of nurses. To optimize the flexibility of the nurse rostering process, the new planning design should consist of multiple planning phases with different due dates, cross-nursing strategy, seasonality strategy and the setup of two pools in the flex-department. In the new planning design the trade-off between the decrease in workload and due dates of the planning should be kept in mind to create support from nurses for the design.

Future research

For future research it is recommended to find a proper balance between due dates of the planning design and the workload of nurses. As explained there is no uniform answer on the balancing due dates of the planning horizons and the under capacity. This varies depending on each nurse. An interesting future research suggestion would be to focus on the individual preferences of the nurses and divide them in two groups: nurses that are willing to adjust to the new planning design and the nurses that are not willing to adjust to the new planning design. The design could then be recalculated with the capacity constraint of the individual nurse preferences on willingness to change. It would be an interesting future research to see the results on the under capacity with this constraint. Using this approach all nurse preferences are taken into consideration.

Table of Contents

1. Introduction

1.1 Nurse planning

Nurses are considered to be the most important factor in both the hospital costs and the patient satisfaction (Yankovic & Green, 2011). The labor costs for nursing care account for approximately 25% of the total hospital operating budget and even increase in percentage over the last several years due to the increasing complexity of care and the decreasing length of stay (Kane & Siegrist, 2002), (Graf et al, 2003). Furthermore the quality of care provided by the nurses directly influences the patient satisfaction (Mckee et al., 2012). These 2 examples emphasize the importance of accurate nurse planning.

Developing an accurate nurse planning is however a complex process in which multiple components have to be taken into account. Typically, nurse planning consists of three stages: budgeting, scheduling and daily staffing, which are all interrelated (Brusco, Futch, & Showalter, 1993). The decision-makers at the three different stages often have contradictory objectives such as minimizing the total costs, maximizing the nurses' preferences or equally distribution of workload over nurses, making it more complex to develop an accurate nurse planning (Legrain, Bouarab, & Lahrichi, 2015). Another factor that makes it difficult is the interrelated character of the nurse planning. Due to the interrelated character of the nurse planning, an accurate nurse planning needs to have integrated decision levels (Abernathy et al., 1973). (Lowerre, 1979) even state that optimization of non-integrated nurse planning process can easily yield poor performance.

Besides the complexity caused by contradictory objectives at different stages and the interrelated character, the complexity is also caused by difficulties in matching patient needs with the required number of nurses. This is the result of the stochastic character of both the patient arrivals and Length of Stay (LOS) of patients. As well as the stochastic character of the nurse availability caused by illness, holidays or educational purposes (Kokangul, 2008), (N. Kortbeek, Braaksma, Burger, Bakker, & Boucherie, 2015).

In order to derive a good nurse planning, it is necessary to evaluate the consequences of inaccurate nurse planning. Inaccurate nurse planning is caused by a mismatch of nurse staff rostered in a department and the actual patients in the department. The mismatch can be either a shortage (increased workload) or an overage (decreased workload) of nurse staff compared to the actual patients in the hospital. Literature focuses on the effects of increased workload. This increased workload may have negative effects for either the patients as well as the nurses. Signorile (2001) found that increased workload, specified as inappropriate amount of nurses for the patients within a department increases the treatment time of patients. Under the circumstances of increased workload the service quality offered to patients, the patients' health and even the patients' clinical outcome may be affected (Bonsall & Cheater, 2008). Besides negative effects for the patients, the increased workload may lead to deterioration in the medical staff performance. Aiken et al. (2001) argued that quality of nursing care ratings are significantly associated with the number of patients each nurse has to attend simultaneously. Also in terms of stress, high workload causes a serious negative impact for nurses. Rowe et al. (2006) found that increased workload results in increased stress levels, which eventually result in the decreased staff satisfaction and difficulties in the ability to recruit and retain nursing staff.

1.2 Elkerliek hospital

The research is conducted at the Elkerliek hospital. The Elkerliek hospital is a general hospital with three different locations. The main hospital is situated in Helmond in which long-term care, intensive care, complex operations, outpatient help and emergency care are provided. The other two locations are in Deurne and Gemert. These two locations are smaller and only provide the more simple operations and has an outpatient clinic. In 2017 the total revenues of the Elkerliek were 193 million euro's making the hospital a small-medium size hospital. The focus of this research will be on the regular inpatient clinics of the Elkerliek hospital, which is the situated in Helmond.

The total costs are 183 million euro's which are based on the labor costs, depreciations of assets, medical specialists and other expenditures. Since the hospital is non-profit based, the profit is small (6,8 million euro's).

1.2.1 Patients: numbers and arrivals

In 2017 the Elkerliek hospital had around 14600 inpatient admissions. These inpatients admissions resulted in approximately 72000 patient days, which is the Length of Stay of all patients summed. Looking at the outpatient clinics, the Elkerliek had around 295000 outpatient admissions.

In the Elkerliek hospital the inpatient patients can arrive at the hospital as either an elective patient or an acute patient. The elective and acute patients have different flows within the hospital, this is depicted in Figure 1. Elective patients arrive at the outpatient clinic. Within the outpatient clinic it is decided whether the patient will be hospitalized or is discharged. In case of hospitalization the patient will be assigned to a bed and a ward. There are three types of wards: short stay wards, daycare wards and the "regular wards"/"Long care" wards. Acute patients typically arrive at the First Aid department, from which there are four different flow options; when the patient is hospitalized the patient gets either a surgery or is assigned to a bed in a ward. Thirdly, the acute patients can be send to the outpatient clinic and lastly the patient can be directly discharged. In Figure 1 the green lines depict the possible elective patient flows while the red lines represent the possible acute patient flows. Further analyses of the patient arrivals is done in Chapter 3. The focus of this thesis will be on the inpatient clinics at location Helmond. Therefore the Elkerliek hospital refers to the location in Helmond from now on.

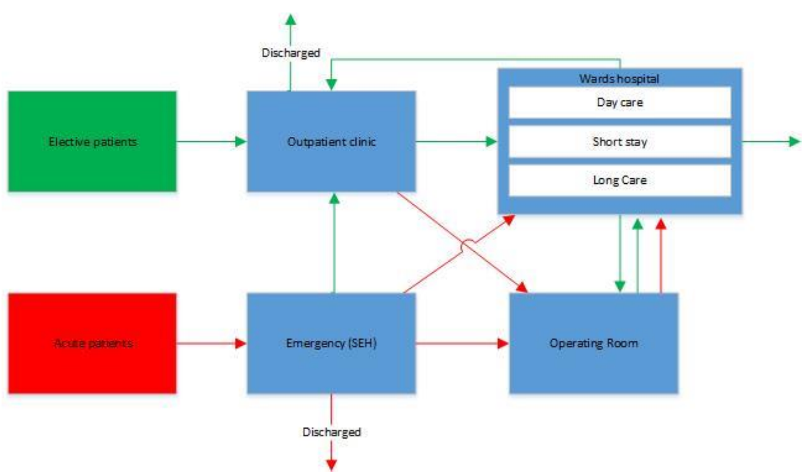

Figure 1: Patient flow in the Elkerliek hospital

1.2.2 Nurse personnel

Based on 2017, 2152 people are employed at the locations Helmond, Deurne and Gemert, resulting in a total of 1277 (FTE) Full Time Employees. The total labor costs of these employees are 88 million, which is almost half of the total expenses of the hospital.

In 2017, the amount of nurse-FTE at the inpatient clinics in Helmond excluding daycare is 185 FTE. This number includes specialized and non-specialized nurses. The nurses together account for almost 37000 nursing shifts. The total amount of nursing hours is 138.0000 for the year 2017.

1.2.3 Challenges regarding nurse planning

Currently the nurses within the inpatient clinics of the Elkerliek hospital face high workload fluctuation throughout time which results in stress and dissatisfaction of work. This is the result of the little attention that is paid to the planning process and the lack of integration of the three planning level. Moreover, due to the lack of integration of the three planning levels, each inpatient department within the Elkeriek has a unique nurse planning with unique planning methods. This results in large fluctuations of quality of the planning. The Elkerliek already set up an internal flex-department that helps departments with the fluctuations in workload. However, there is no permanent structure for the assignment of nurses to departments which has led to frustration and dissatisfaction of departments regarding the flex-department.

1.3 Outline of Report

This report will be structured as follows. Chapter 2 will describe a literature review done on nurse planning. Chapter 3 consists of more elaborate analyses of the current nurse planning at the inpatient clinics as well as the flex-department. In Chapter 4 the research design will be explained, consisting off the problem statement, research objective, methodology, scope and relevance of the research. The next chapter, Chapter 5, will describe the mathematical model, simulation and ranking-based interview that are developed. In Chapter 6 an overview of the results will be discussed. Chapter 7 provides conclusions based on the results. Lastly, Chapter 8 will provide a discussion and future research regarding the research done.

2. Literature Review

In this section findings of a literature review done on topics considered to be relevant for this thesis are summarized. The literature review is divided into two main parts. The first part consists of literature regarding nurse planning, the second part of this literature review will be about workload of nurses.

2.1 Nurse planning

The nurse capacity planning in existing literature generally consists of three layers; strategic, tactical and operational planning (Nikky Kortbeek, Braaksma, Smeenk, Bakker, & Boucherie, 2012), (Vissers, Bertrand, & de Vries, 2001), (Abernathy et al., 1973), (De Vries, Bertrand, & Vissers, 1999)

2.1.1 Strategic nurse planning

At strategic level the total amount of nursing hours needed are determined. In nurse planning literature this is often defined as "Annualized nursing hours". In general, the annualized nursing hours are determined by four factors: patient arrivals (in terms of arrival rate and arrival distribution), length of stay (LOS) of patients, nurse-patient ratios and gross-net nurse ratio (Elkhuizen, 2016).

Patient arrivals and LOS of patients:

The patient arrivals consists of two components: arrival size and the arrival pattern. The arrival size is simply the number of patients arriving in a certain time interval. The arrival pattern represents the way the patients enter the hospital throughout time. Most often the arrival pattern for patients is represented as a Poisson process (Kokangul, 2008). The arrival size and arrival patterns of patients is often determined per specialism (Cheng et al., 2009). Elkhuizen (2016) state that the LOS of stay of patients varies per specialism. To determine the annualized nursing hours they used the average LOS per specialist.

Nurse-patient ratio:

This ratio is defined as the number of patients that one nurse needs to take care. For example: a ratio 1:4 stands for 4 patients that 1 nurse needs to take care of. Since the care needs of patients varies throughout the day, the nurse-patient ratio also changes throughout the day. Patient are likely to need more care during daytime than during nighttime, therefore the ratio is higher during day than during night. Furthermore does the nurse-patient ratio vary per patient specialism, for example, intensive care patients need more care than short stay patients. The ratio is based on the average care a patient per specialism needs, the actual care a patient requires within a specialism changes per patient due to for example age or surgery-complications. Small amount of research is done in which actual care per patient is incorporated. This is because a care system that incorporates the different care needs between single patients within a specialism is a very time consuming and difficult task. Most often, nurse-patient ratios are used (Kortbeek et al., 2012)

Gross-net factor:

The difference between gross and net availability of nurses is caused by four main factors; absenteeism, studying and learning, leave of absence and calamity absence (personal circumstances) (Elkhuizen et al., 2007). These strategies are taken into account for determining annualized nursing hours.

2.1.2 Flexibility in strategic nurse planning

To create flexibility in nurse planning, different flexibility strategies are developed. The most common strategies for creating flexibility on strategic level are, float nurses, annualized hours and supplementary/contract nurses. Float nurses are nurses that have a contract within the hospital and can work on multiple wards within the hospital. The main advantages of float nurses are mitigation in overtime, improvement of quality of care and a reduction in turnover of nurses and a reduction in staffing costs (Inman, Blumenfeld, Ko, 2005). With the use of annualized hours the working time per year of nurses is measured instead of working time per month or day. Therefore the organization can better respond to demand fluctuations of patients by assigning more nurses hours to a specific period and decrease the assigned nursing hours in other periods (Gnanlet & Gilland, 2009). At last the supplementary nurses, nurses hired from other agencies, are a strategy to increase flexibility. This option is also the most expensive option and therefore sometimes less attractive. Most flexibility is created at strategic level, at tactical an operational level, the chosen strategies are implemented.

2.1.3 Tactical nurse planning

At tactical nurse planning level the main goal is to assign the amount of shifts that are to be worked per period and the amount of nurses that need to be assigned to the shifts per period in order to meet the patient demand (Kortbeek et al., 2015). The patient demand, sum of needed patient care in a specific time period, varies throughout time. This means that outcomes of the methods used to achieve this goal vary over time as well or create flexibility to vary over time. According to Van der Veen et al. (2015), 2 commonly used methods to do this are staff formation and capacity planning.

Staff formation is the composition of a nurse team within a hospital or department in terms of nurse-contracts based on the annualized hours set in the strategic planning. Diversification of the staff formation by the use of nurses with different contracts (part-time, flexible contracts, temporary contracts) results in more flexibility for the department or hospital (Kortbeek et al., 2012).

The second method, *capacity planning*, translates strategic planning decisions into designs that are usable as input for operational planning. Decision variables that will be taken into account are: age of nurses in the staff-formation, net-hours availability of nurses and fluctuations in patient arrivals during the different days, weeks or months. These fluctuations in patient arrivals are often caused by seasonality. In the work of Cochran & Roche (2009), at tactical level, the seasonality (daily and monthly) is checked to correctly assign the amount of nurses per shifts. To our knowledge the focus of current literature is not on the tactical nurse planning since only few literature is found on this subject.

2.1.4 Operational Nurse planning

Operational nurse planning is defined as the development of individual nurse timetables based on the required constraints set on the tactical level while satisfying both the preferences of employees and work regulations (Kortbeek et al., 2012). Commonly, the operational nurse planning is split into two parts, the rostering and the re-rostering of the nurses. The rostering of nurses is typically done 2 to 6 weeks up front (Baeklund, 2014). The rostering process is done based on constraints set by the planner which can be either hard or soft. Hard constraints are constraints that need to be met in order to obtain a feasible solution, for example, not working more than six consecutive days in a row. Soft constraints are constraints that can be relaxed when needed, for example preferences of nurses regarding working days. As explained before, scheduling of nurses is done 2 to 6 weeks in advance. However due to fluctuations in demand or supply, the number of nurses needed for a specific shift can change between the time the schedules are created and the due date. Prior to each shift, the amount of nurses that are scheduled for the next 24 hours need to be compared with the actual number of nurses available. In case of shortage of nurses due to for example illness or acute patient arrivals, decisions have to be made to increase the amount of nurses to a sufficient coverage level for each unit or department. According to Bard & Purnomo (2005) this can be done with the use of for example overtime, outside nurses (pool nurses) and floaters. At operational level the flexibility creation focusses on the implementation of the chosen nurse flexibility allocation strategy.

2.1.5 Focus of nurse planning

In conclusion, most literature regarding nurse planning focuses on strategic planning and operational planning. This is also the case for the flexibility strategies in nurse planning. Besides, most papers focus on one level of the nurse planning. As stated before does a nurse planning need to have integrated decision levels in nurse planning to be accurate (Lowerre, 1979). Lastly, most of current literature is cost and patient arrival oriented. This leaves the aspect of workload of nurses very undervalued.

2.2 Workload

Since the challenge within the Elkerliek hospital is partly caused by the perceived workload of nurses, this paragraph will give more insights in the workload of nurses. There are three major components to determine the workload of nurses in a quantitative way; patient arrivals, length of stay and patient acuity (Kortbeek et al., 2012). As stated before, the amount of workload fluctuates during the year due to varying patient arrivals and varying nurse availability resulting in periods of increased and decreased workload. Most literature focuses on the part of in increased workload of nurses. Increased workload may have negative effects for both the patients and the nurses. Signorile (2001) found that increased workload, specified as inappropriate amount of nurses for the patients within a department increases the treatment time of patients. Under the circumstances of increased workload the service quality offered to patients, the patients' health and even the patients' clinical outcome may be affected (Bonsall & Cheater, 2008).

Besides negative effects for the patients, the increased workload may lead to deterioration of the medical staff performance. A frequently used model to measure the effects of increased workload on nurses is the Job Demands Resources model (Demerouti, Bakker, Nachreiner & Schaufeli, 2000). In this model, workload is a component of Job demands which is defined as a set of working conditions that potentially evoke stress-reactions when they overwhelm nurses' personal limits and abilities (Karasek, 1979). Demerouti et al. (2000) found that increased job demands have a strong effect on the feelings of exhaustion which eventually lead to less satisfaction and increased experience of burnout among nurses. This is also supported by the work of Karasek (1979) which state that workload and time pressure, in general, are the most important work-related stressors and a combination is associated with job dissatisfaction. Next to workload (cognitive and physical) as components for job demands, nurses have to deal with multiple other components of work demands that could cause dissatisfaction and exhaustion. Demerouti et al. (2000) state that time pressure, demanding patient contact, environmental conditions and work-shift are also components of the Job demands that potentially evoke-stress reactions. High Job demands does however not automatically lead to dissatisfaction, stress or frustration of nurses. Lepine, Lepine and Jackson (2004) state that the job demands can be divided into challenging job demands and hindrance job demands. Challenging demands are obstacles to overcome in order to learn and achieve (Cavanaugh, Boswell, Roehling, & Boudreau, 2000). In contrast, hindrance job demand are viewed by workers as unnecessarily demands, that prevent workers from personal growth (Cavanaugh et al., 2000). It is found that hindrance demand has a direct negative effect on performance and engagement and an indirect negative effect on motivation. Challenging demands are found to have a positive direct effect on performance and engagement and an indirect positive effect on motivation (van den Broeck, de Cuyper, de Witte, & Vansteenkiste, 2010). To classify job demands as challenging or hindrance is however not very straightforward. Bakker and Sanz-Vergel (2013) suggest that whether a job demand is perceived as challenging or hindrance may depend on the occupational sector as well as the personal perceptions of workers. Despite this, did McVicar (2003) find that work pressure/workload is a major stressor. Also Bakker, Demerouti, Taris, Schaufeli & Schreurs (2003) found that nurse pressure is positively related to exhaustion and negatively related to accomplishments and retention.

In conclusion is it not possible to simply relate high job demands to stress or frustration. This depends on the character of the job demands (hindrance or challenging), occupational sector and the personal perceptions of workers. Despite this, it is found that, in general, nurses perceive work pressure or high workload as hindrance demand.

3. Current situation.

In order to get more insights in the current situation of the Elkerliek hospital, this section will provide a brief analysis. It starts with the outline of the hospital and the departments that will be considered in this thesis, thereafter patient arrival process, nurse planning process and the flex-department process are further analyzed. The focus of the analyses is primarily based on the regular inpatient clinics, since this is the focus of the thesis.

3.1 Departments

The inpatient clinics of the Elkerliek hospital are divided in specialization departments and non-specialization or regular departments. In terms of nurses, the main difference is the type of degree that is required at these departments. Nurses that work at a regular department do not need a specialization degree, while nurses that work on a specialization department need a specialization degree (e.g. Intensive care, Child care department). Since the focus is on the regular departments, the remaining analyses will contain information about these departments and its nurses. In Table 1 an overview of the regular departments is depicted. Despite the fact that the specialisms of patients treated differ, non-specialized nurses take care of these patients. The third column contains the amount of fixed beds on each department. This are the number of beds without the flexible beds which are also available at some months of the year. The 4th and 5th column contain the percentage of acute and elective patients. One can see that at the day-care and short stay departments, almost no acute patients arrive while at departments 3B, 3C, 3D and 4Alg the percentages of acute patients are relatively high.

Department	Patient Specialisms	Bed capacity (fixed)	Elective patients (%)	Acute patients (%)
1B	Surgery, Orthopedics, Urology	20	32%	68%
1C	Surgery, Orthopedics, Urology	20	35%	65%
2B, 2C	Day-care	40	99%	1%
2D	Short stay (<7 days)	23	96%	4%
3A	Cardiology	23	71%	29%
3B	Lung	19	13%	87%
3C	Neurology	14	15%	85%
3D	Geriatrics	16	21%	79%
4Alg	Internal medicine, Stomach, bowels, liver.	32	13%	87%

Table 1: Department information: specialism, bed capacity, elective and acute patients

3.2 Patient arrival analysis

The analysis of patient arrivals for the regular departments are divided in 5 different levels (month-, week-, day-, hour-level).

To get a better understanding of the patient flows of the regular departments, the sum of warm bed minutes per month are depicted in Figure 2 for the years 2016 and 2017**.** Warm bed minutes of a patient is related to the LOS of a patient in the hospital, starting at the hospitalization time and ending at the discharge time. Based on the first visual impression one can see that there is an increase in warm bed minutes during the months January to April, a decrease in warm bed minutes can be observed during the summer months July to September. To get better visualized insights about the departments that cause these fluctuations, the different departments and their warm bed minutes are separated in Figure 19 and included in the appendix. This is the summed warm bed minutes for 2016 and 2017. The decrease in warm bed minutes during the summer period is mainly caused by daycare and short stay departments which is the result from the closing of department 2D and the reduction of the amount of surgeries on 2B and 2C. There can be no specific cause seen for the increase in the period January until March from a specific department. The decrease in warm bed minutes during the summer months and increase during winter months is a general trend in Dutch hospitals.

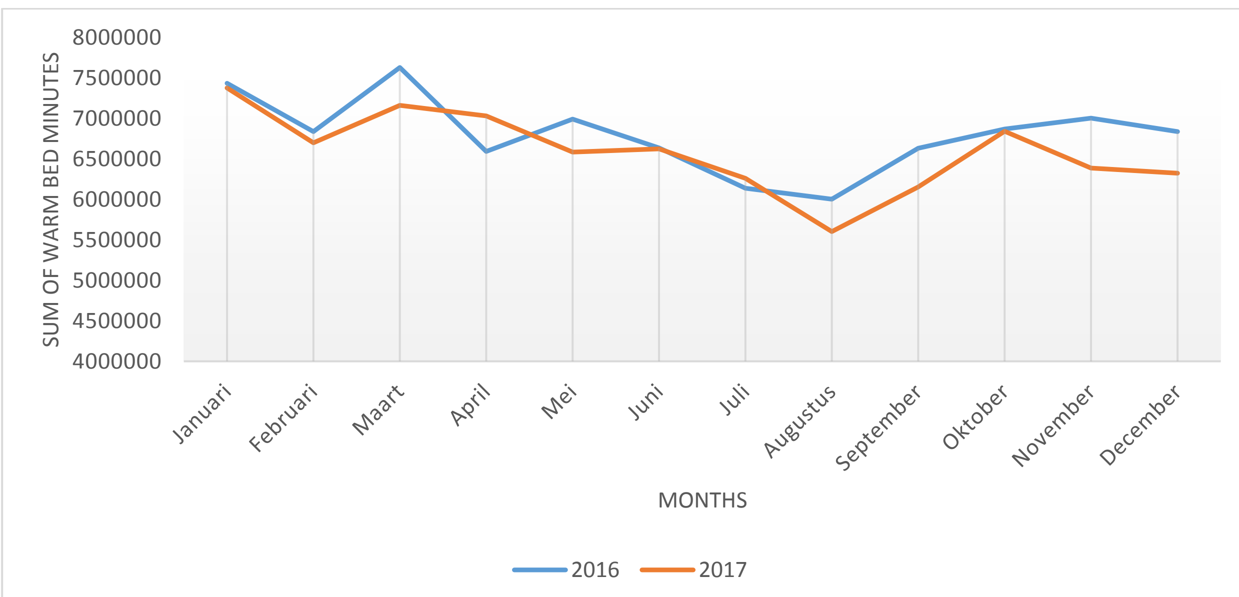

Figure 2: Warm bed minutes on monthly basis for all regular departments combined

The next step is to look at the warm bed minutes of patients on daily level. To illustrate this, Figure 3 shows the amount of warm bed minutes at department 4Alg during the period of 1 January to 1 April. One can see that the total warm bed minutes at daily level strongly fluctuate throughout the time. This supports the literature described in Chapter 2, which says that the patient's arrivals and the LOS have a stochastic character.

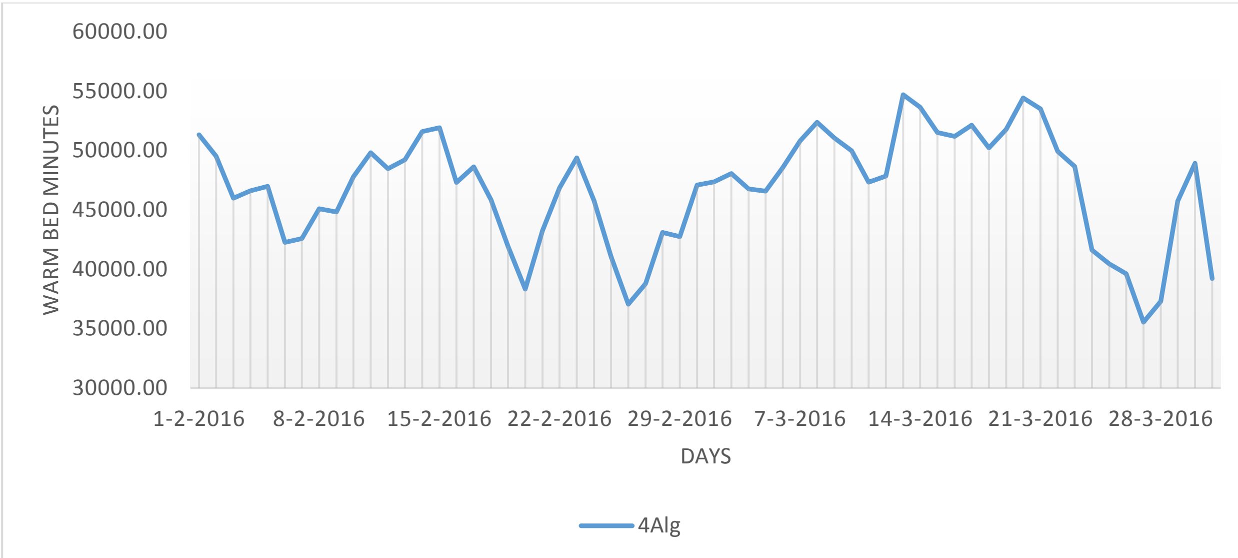

Figure 3: Warm bed Minutes 4Alg on day level

In Figure 20 includes in the Appendix, the difference between the total warm bed minutes per day of the week are visualized. Figure 20 is also based on the summed data of 2016 and 2017. Throughout the week the warm bed minutes increase, once Thursday is reached it starts decreasing. The difference in warm bed minutes during the weekdays is relatively small and the difference between week and weekend-days is bigger, this is caused by the closing of the daycare and short care during the weekend days.

The final step is to look at the differences between warm bed minutes per hour of the day. This is done for the time horizon of two years (2016 and 2017). Figure 4 shows that the warm bed minutes are constant for all the departments except for the daycare departments. This is because the department opens during the morning and closes during the evening again.

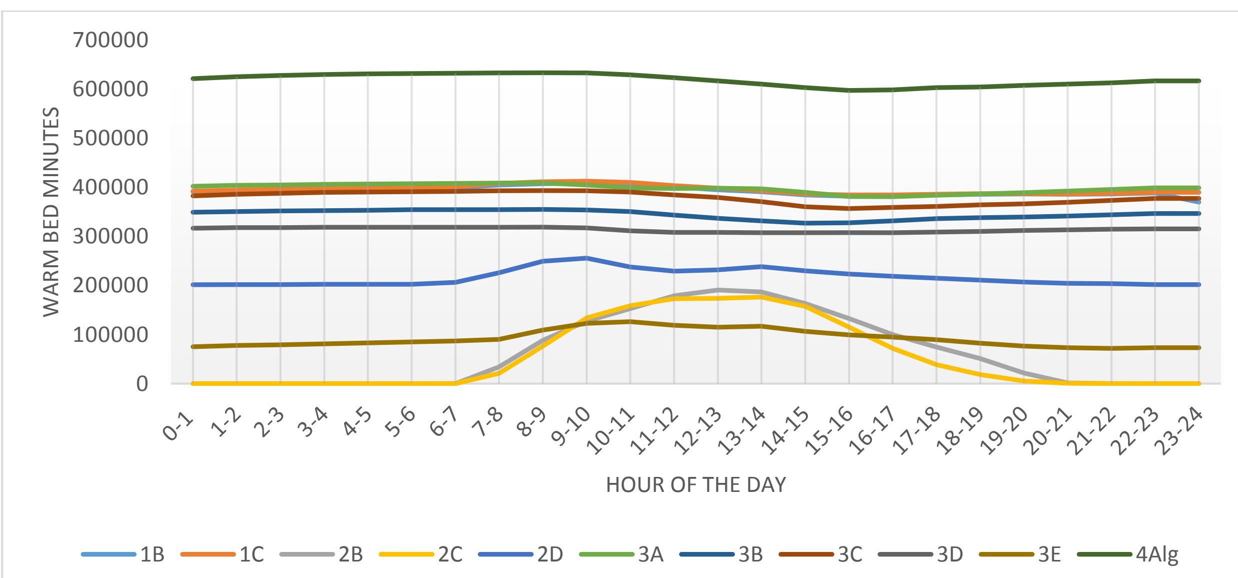

Figure 4: Warm bed minutes on hour level for all regular departments

To get more insights in the actual fluctuations, the size of the fluctuations are determined. This is done with the use of the maximum and minimum values. The fluctuations of the 4 levels (month, days, week/weekend and hour) are depicted in Table 2. As explained, the biggest fluctuations are caused by the short stay and daycare since they close during weekend days (daycare and short stay) and during nights (daycare) at weekdays (daycare). Therefore the numbers of fluctuations in the "weekday" and "Hours" are close to 100%. For the other departments the largest fluctuations are found at month and day level. These findings again support the literature in Chapter 2 that state that fluctuations in patient arrivals complicate the developing of an accurate nurse planning.

Table 2: Fluctuations in percentages of the different layers

Departments	Month (%)	Days (%)	Weekday (%)	Hours (%)
1B	19%	27%	4%	16%
1C	19%	40%	5%	15%
2B	27%	76%	99%	100%
2C	60%	70%	100%	100%
2D	86%	83%	100%	29%
3A	22%	44%	7%	12%
3B	22%	50%	6%	12%
3C	27%	47%	10%	14%
3D	25%	44%	6%	12%
3E	38%	81%	27%	46%
4alg	20%	43%	7%	14%

3.3 Nurse planning analyses

The nurse capacity planning in existing literature generally consists of three layers; strategic, tactical and operational planning (Kortbeek et al., 2012), (Vissers et al., 2001), (Abernathy et al., 2018), (De Vries et al., 1999). Therefore nurse capacity planning analyses are divided into three levels (strategic, tactical and operational).

3.3.1 Strategic nurse planning

At strategic level the amount of nurse capacity needed for the year is determined, this is called annualized nursing hours. In the Elkerliek hospital the annualized nursing hours are based on the expected warm bed minutes per department per year and the gross-net factor and can be divided into 2 steps. The first step is to determine the amount of net nurses needed. To do this the Elkerliek hospital uses a nurse-patient ratio that corresponds to the amount of patients a nurse takes care of simultaneously. This ratio varies during the day and is: 4:1, 7:1 and 10.5:1 during respectively the day-, evening- and night-time. Meaning that for example during the daytime, 1 nurse needs to take care of 4 patients. By multiplying the ratios with the corresponding warm bed minutes per year, the net amount of nursing hours per year are determined. The second step is the multiply the net amount by the gross-net factor to calculate the gross amount (annualized hours) of nurses needed. This factor is 1,183 and is build up out of five elements: absence due to illness, holidays, obligatory holidays, learning days and calamity absence. In Table 3 the percentages for these five factors are depicted. One can see that the biggest factor is caused by the holidays of the employees. The second biggest factor is absence due to illness. The factor obligatory holidays are the holidays that a nurse is obligatory to have, Christmas, Eastern, during reduction weeks etc. The 4th factor is learning days, the Elkerliek organizes educational programs and training days to educate nurses. Lastly calamity absence, this is a factor for personal circumstances. By multiplying the net annualized nursing hours, with the gross-net factor, the actual annualized nursing hours are determined.

Table 3: 5 factors for gross-net nursing hours determination

Factor	Percentages
Absence due to illness	4.17%
Obligatory holidays	1.36%
Holidays	9.07%
Learning days	3.59%
Calamity absence	4.17%
Total	18.3%

The annualized nursing hours are then translated to FTE's per department (department formation). In Table 4 the difference between the predetermined formations based on the calculations above versus actual used formation is depicted for 2016 and 2017. The numbers in red represents an overage of nurses used throughout the year; the number of nurses used are bigger than the predetermined number of nurses. The green numbers represent an underage of nurses used; less nurses used compared to the pre-assigned formation. In a time period of two years, one can see that only one department in 2016 and two departments in 2017 managed to use less nurse FTE's than the amount of nurses that are pre-assigned. The other departments used more FTE's than assigned, fluctuating from 0.16 to 2.33 extra FTE's deployed.

Table 4: Pre-assigned formation versus actual used formation per department

Department	Difference 2016 (FTE)	Difference 2017 (FTE)
1B	2.11	0.63
1C	.16	0.35
2B&2C	.14	0.36
2D	.13	0.32
3B	1.30	2.01
3C	.39	2.33
3D	.16	1.53
4Alg	2.24	0.45

3.3.2 Tactical nurse planning.

At tactical level the formation set at strategic level is translated into different decision rules which are about assigning the correct amount of nurses to shifts and correct number of shifts per day in order to meet the patient demand. In Table 9 in the appendix an overview of the decision rules per department are depicted. Six different decision rules are distinguished which differ per department:

Time to due date: all planners roster for a time horizon of four weeks, except for the period June to August because of the summer holidays. The amount of time between the roster is developed and the due date differs per department, in Table 21 one can see that the shortest time to due date is one month and the longest is 3 months.

Ratio: The nurse-patient ratio which is explained previously is used in the rostering process of all departments except for departments 2B, 2C and 2D.

Peak versus of Off-Peak-season: Since the arrival of patients is not constant over the year, some departments reduce the amount of nurses during off-peak season, while still maintaining the nurse-patient ratio's set. Most department do not reduce the amount of nurses during off-peak season, they consider the patient arrivals to be constant during the year.

Nurses in Training: departments can decide to roster nurses in training (nurses that do not have the nurse degree yet) as extra employee during a shift, thus not included in the fulfillment of the 4:1 patient-nurse ratio. While others roster them as part of the patient-nurse ratio fulfillment (Table 22). Some departments make a distinction between students that just started their studies and students that are close to graduation.

Cross-nursing: Is the exchange of personnel between departments, an overview of the exchange of nurses (cross-nursing) is depicted in Table 5. One can see that there is already some exchange done between departments, there are however no real rules regarding the exchange of nurses. Most often the exchange is done in periods of crisis within a department.

Table 5: Cross-Nursing: exchange of nurses between departments

	1B	1C	2B	2C	2D	3B	3C	3D	4Alg
1B		X							
1C	X								
2B				X					X
2C			X						X
2D	X	X							
3B									
3C									
3D									
4Alg									

Flex-department: Most of the departments use the flex-department to cover the gaps in their rostering. The departments can request up to 10% of their formation size at the flex-department. The actual requests per department however differ, some department request for no personnel at all while others request almost 20%. More detailed analysis will be shown in Chapter 3.4.

CAO-laws: The last rule set is regarding the CAO-laws, these laws protect nurses from for example working to many hours on a day or too much consecutive night shifts. The Elkerliek set internal rules for the CAO rules. These internal rules are a little stricter than the actual CAO laws. Most departments don't use the internal set rules for CAO laws in their rostering process, as depicted in Table 22 in the appendix.

3.3.3 Operational nurse planning.

At operational level the actual rostering of nurses is done. In the Elkerliek hospital each department has one or two nurses that develop the nurse planning within their department with the use of the decision rules set at the tactical level. From now on, these nurses are called planners. The planning itself is made in Cura (employee rostering software), Excel (developed by planner at department) or on paper, depending on the preference of the planner. As explained in the previous section, CAO-laws protect nurses from working for example too many consecutive hours. Most planners don't use the internal rules set at the Elkerliek regarding CAO-laws in their planning process. In order to be able to review the quality of the schedules developed by planners, the schedules are tested on internal set of rules regarding CAO-laws. Since there are dozens of CAO-laws, and therefore internal set rules by the Elkerliek, the three most important internal set rules are chosen and tested on the data of 2016 and 2017:

- Consecutive amount of days worked
- Consecutive amount of hours worked (duration of a single shift)
- Consecutive amount of night shifts worked

Table 23 which can be found in the Appendix shows the amount of consecutive days worked per department in terms of the % of the total per department. The internal rule based on the CAO law state that a nurse is not allowed to work more than 5 consecutive days. As can be seen, only at 1C a substantial amount of employees work 6 or more consecutive days. It can be concluded that despite the fact only a few planners actively use this internal rule the planning of consecutive days is done correctly.

The second CAO-law is the consecutive amount of hours worked. In Table 6 the percentages of the total shifts that are longer than 8 hours are depicted. A lot of shifts have a duration between 8 and 9 hours and also a substantial amount have a duration between 9 and 10 hours. According to the internal set rule based on the CAO-law a regular work shift should be smaller than 9 hours (depending on the length of the break). Therefore this internal set rule is violated very often.

Table 6: Consecutive hours worked

	>8 & < 9	>9 & < 10	>10 & < 11	>11 & < 12
1B	19.0%	1.0%	0.2%	0.0%
1C	17.7%	0.7%	0.1%	0.0%
2B	0.0%	0.0%	0.0%	0.0%
2C	5.5%	2.0%	0.6%	0.1%
2D	14.3%	1.9%	0.6%	0.2%
3A	17.6%	1.3%	0.2%	0.1%
3B	15.6%	1.0%	0.3%	0.1%
3C	17.4%	0.4%	0.1%	0.0%
3D	12.8%	1.3%	0.2%	0.1%
4Alg	18.8%	1.5%	0.3%	0.0%

Lastly the consecutive night shifts are checked. Also for the nights shifts a maximum of 5 consecutive nights is allowed according to the internal set rule. In Table 7 it can be seen that in 2% of the total nightshifts this is not the case. Table 7 shows the amount of consecutive days worked in percentages of the total shifts worked.

Table 7: Consecutive night shifts worked

	Amount of night shifts in a row							
Consecutive days	1	2	3	4	5	6	7	8
Amount of shifts	25%	33%	23%	14%	4%	1%	1%	0%

Summarizing that the internal set rule is violated in two of the three cases, but for a relatively small percentage of the total shifts.

3.4 Flex department analyses

At this moment the flex-department, deals with all the request regarding flexible personnel. The flex-pool of the flex department consists of 23 FTE nurse employees, a combination of specialization and non-specialization nurses. The planners of the flex department assign nurses that are in the flex-pool to departments 1 month prior to the due date. This is done based on the nurse-request from departments. The requests for extra resources can have multiple causes; illness of employees (short and long duration), increase in patients at the departments, holidays of employees and planning mistakes. The department managers can request two types of services: secondment for a period of 3 to 6 months or single-shift request. The secondment request is for long-term illness of employees or a gap in the FTE-formation. A single shift request is a result of the gaps in the schedule due to mistakes or mismatches in the roster of a department. The departments can request for a shift until one day before the schedule is made. For secondment the request is preferably done more up front. The departments can request at most 10% of their formation at the flex-bureau, in practice this is very often violated. The planners at the flex-department plan in two phases. At first all the department requests are planned by the planners (assigning a nurse employee to a department). The remaining flex-nurses are planned up front, this is phase 2. These nurses will be assigned to a specific day without assigning them to a specific department. An analysis is done with data from 1st of

May 2017 until 1st of June 2018 on the current flex-department to get a better overview of the flex-department. In Figure 21 in the Appendix the amount of requests and the accepted requests for a single shift per department per day are depicted. One can see that most requests are done for shifts during weekdays and in specific for Tuesday and Thursday. The numbers on Saturday and Sunday requests are not totally correct since requests that cannot be fulfilled on Saturday or Sunday will likely be switched to a shift request for a weekday. Despite this, the largest amount of requests are for nurses during weekdays. In Figure 22 the requests and the accepted requests per departments are depicted. Most requests come from departments 4Alg and 1c. The fulfillment rate for the flex-bureau is around 89%. Figure 5 depicts the amount of days prior to the shift due date a department requests for a flex-nurse at the flex-bureau. In this Figure only the accepted requests are depicted. Two peak moments can be observed, corresponding to respectively 1 to 6 days prior to a shift and 28 to 37 days prior to a shift. In the current set up, all nurse requests should be done 1 month before the due date of the shift, which is, as can be seen, often violated.

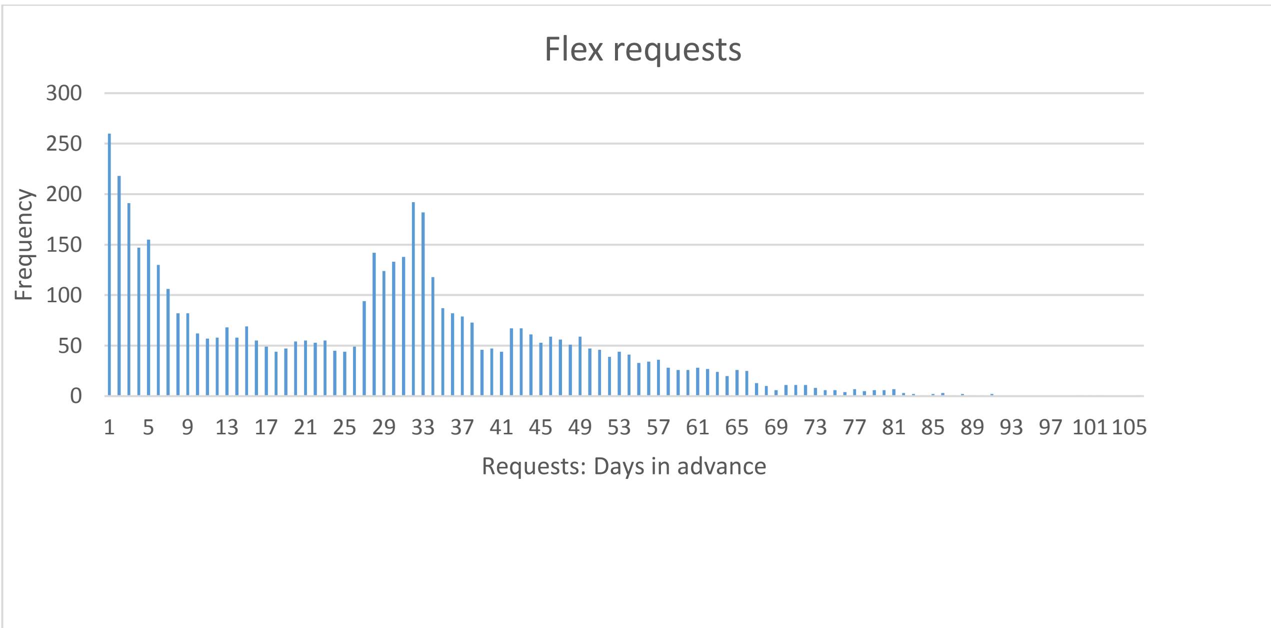

Figure 5: Flex requests: the number request days in between request and due date

At last the reasons for the flex-nurse request are analyzed. There are 14 factors that cause the requests, the most frequent factors are depicted in Table 8. The large percentage of "Gaps is rostering" is caused by the formation set up of each department. Each department has 90% own personnel and 10% flex-department personnel, causing the large percentage of "Gaps in rostering". The harmonica beds are beds that can be used by a department when the normal capacity of beds is not sufficient. This is often used in times of increased patient arrivals. To be able to take care of increased patient arrivals, nurse-personnel is requested at the flex-department. The other two main factors are short and long term illness. Long term illness is typically maternity leave, while short term illness is for example illness due to fever.

Table 8: 4 main reasons for flex personnel requests and their percentages

Reason	Percentage of total
Gaps in rostering	32.62%
Illness (short term)	28.52%
Illness (long term)	10.00%
Harmonica beds (when open)	12.14%

In Figure 6 to 9 the factors that cause the requests are depicted to get more insights in the distribution of the requests. In this Figure only the accepted requests are depicted. One can see that Illness (short term) has a high frequency a few days before the actual shift. Long-term illness has a peak around 30 days in advance. This is also the case for Harmonica beds and Gaps within rostering.

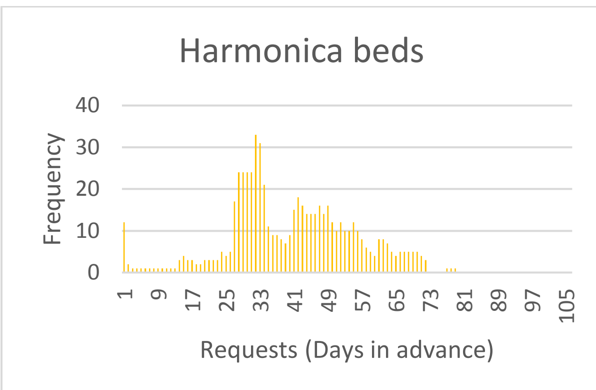

Figure 6: Flex request reason: Harmonica Beds

Figure 7: Flex request reason: Gap in planning

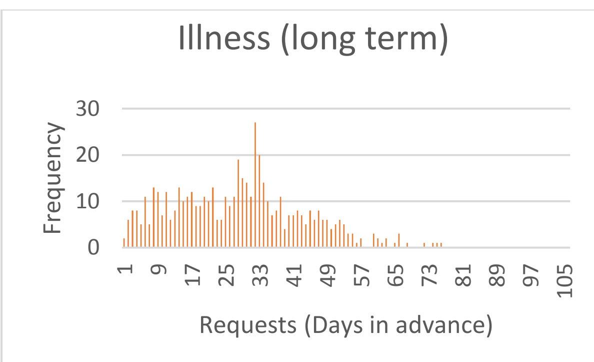

Figure 8: Flex request reason: Illness (long term)

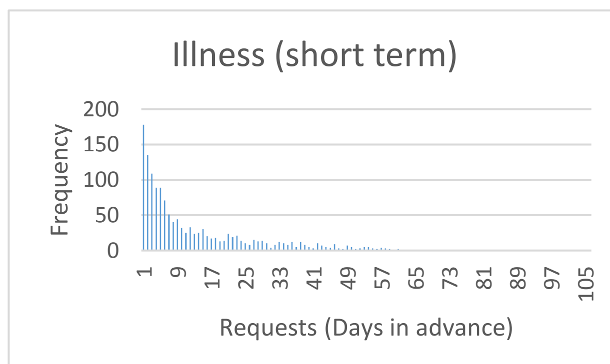

Figure 9: Flex request reason: Illness (short term)

4. Research Design

This Chapter will provide a detailed description of the research design. This includes the current problems the Elkerliek hospital is facing, research objective, the scope, methodology and the scientific and practical relevance.

4.1 Problem statement

Currently the workload of nurses largely fluctuates over time. These fluctuations are caused by the variability in patient arrivals and the fluctuations in nurse availability. Since very few attention is paid to these fluctuations and variability, the nurse capacity very often does not match the patient demand which results in large workload fluctuations. The planning process is also very static, the planning is made at once and is not adjusted once the planning is developed. Besides that, there is no standard planning process in which the strategic planning is translated to tactical nurse planning and operational nurse planning for departments. This results in non-uniform tactical and operational planning systems and different quality of the actual schedules developed as can be reviewed in Chapter 3.3. Lastly, the Flex-department is not able to deliver all the requested nurses from the departments since it is not optimally aligned to the departments.

In the end the fluctuations in nurses' workload causes dissatisfaction of nurses. During busy moments the workload is high and during less busy moments the nurses are recovering from the busy moments. Therefore they hardly perceive the reduced workload during less busy days as relaxing.

4.2 Research objective

The research objective is to develop a planning design that based on patient arrivals and nurse availability, decreases the workload fluctuations of nurses. The second objective is that the planning system is dynamic to create more flexibility for the departments and the flex-department.

At strategic level the amount of annualized nursing hours needed are determined and the flexibility strategies are set. At tactical level, assignment of nurses to shift and the number of shifts is determined and the flexibility strategies are translated in order to be usable for the operational planning level. The planning design developed in this research focuses on the design the strategic and tactical level. This is done since the decision rules regarding nurse planning to enhance flexibility and decrease workload fluctuations are developed at this level. At operational level these are executed.

This results in the following research question:

"How to optimize flexibility and more equally divide workforce within the nurse rostering process of the inpatients clinics within the Elkerliek hospital?"

4.3 Scope

The scope of this thesis will be about the departments that have regular nurses, which are non-specialized nurses. These departments can be reviewed in Table 1**.** The planning design that is developed will contain the strategic and the tactical layers.

4.4 Methodology

In the literature of Chapter 2 it is explained that the flexibility strategies for the allocation of nurses is done both at strategic and tactical level. Therefore, the research will focus on these two layers of the planning design.

Kortbeek et al. (2012) state that the first step of the planning design is to develop a strategic planning in which the annualized nursing hours are set and the flexibility strategies are chosen. Therefore the first part of the research consists of a mathematical model based on Little's Law (Kulkarni, 2011) and the Newsboy equation to estimate the amount of annualized nursing hours necessary per department. The input variables for Little's Law are patients' LOS and the patients' arrivals per department. These variables are based on historic data and result in the amount of patient minutes per department. These can then be translated into nursing hours per department by using the nurse-patient ratios, which are mentioned in Chapter 3. Lastly, with the use of the Newsboy equation different confidence intervals are determined. The confidence intervals determine the amount of annualized nursing hours to make sure that at least X% of all shifts have a sufficient nurse-patient ratio, this is called the nurse occupancy rate. This is done for different confidence interval levels, to get insights in the effects. By using Little's Law and Newsboy equation, both the LOS and the amount of patient arrivals are incorporated, as well as the mean and the variance of both variables. This results in an accurate prediction of the patient minutes and nursing hours. Furthermore, the model is used to test the flexibility strategy of cross-nursing (Inman et al., 2005). This strategy combines departments to see the effects on the variability and amount of annualized nursing hours needed.

Kortbeek et al. (2012) state that the second step of the planning design is to develop a tactical level planning that assigns nurses to shifts as well as including the chosen flexibility strategies at strategic level. Therefore the second part of the research consists of the development of a tactical level simulation model to simulate the patient flow and nurse assignment to shifts in the hospital. This consists of two elements, the first element focuses on the patient arrival process, the second element on the new planning design to assign nurses to departments. To be able to construct a model that represents the stochastic behavior of patient arrivals, department specifications and nurse planning design it is chosen to use simulation. Furthermore, simulation is chosen since it can be easily visualized. The simulation model is developed in Visual Basic for Applications (VBA).

Now the structure of the simulation will be explained. The first element of the simulation, simulates patient arrivals at the different department over a time period of 5 years This is done based on the distribution, standard deviation, mean and seasonality of the different patients per department. As well as the specifications of the different departments, for example, opening weeks/times, reduction weeks, closing weeks/times and hospitalization procedures. Lastly information regarding illness (long and short term) of nurses will be used as input for the simulation model.

The second element of the simulation is the development of a new planning design that assigns nurses to specific shifts at departments. The design of the planning aims to better adjust to the dynamic behavior of the patient arrivals and nurse availability, resulting in a more equally division of workforce to decrease the workload fluctuations. The new planning design incorporates three frequently used flexibility strategies: seasonality, cross-nursing, outside nurses/flex-nurses (Cochran & Roche, 2009), (Inman et al., 2005). The new planning design is split into 6 phases with different planning horizons. This maintains high ability to adjust to the dynamic behavior of patient demand and nurse availability. For example, once the due date to the actual shift decreases, more information becomes available which helps to better match the patient demand with nurse availability. There are specific moments in time when information regarding patient demand and nurse availability becomes available. In Figure 10 the horizon with these moment are depicted. These form the basis for the development of the design.

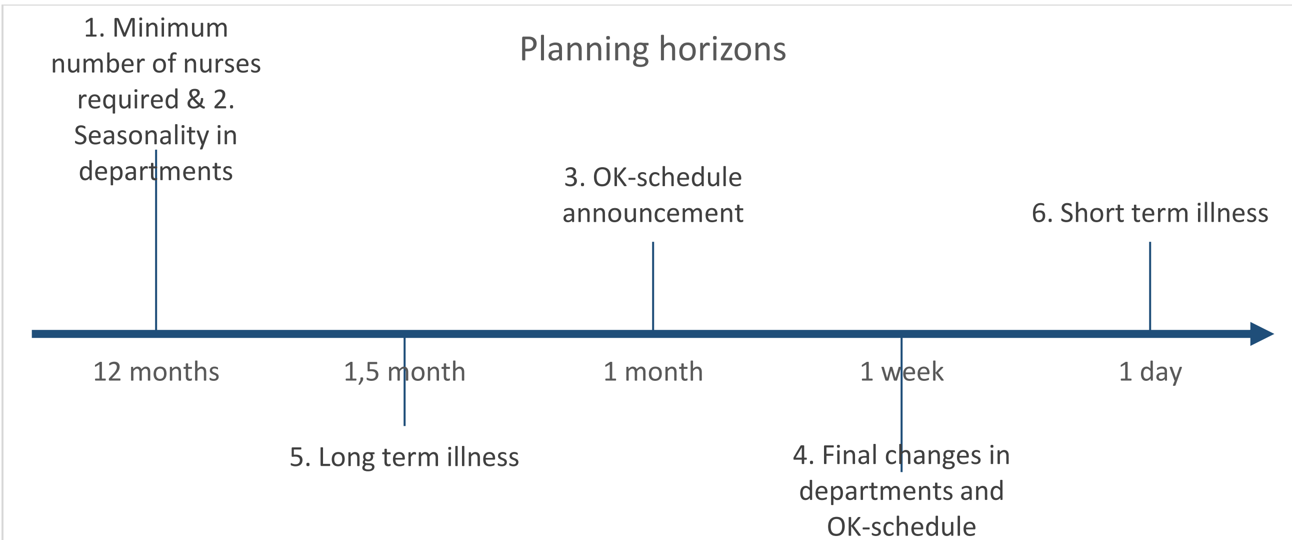

Figure 10: Planning horizon for the 6 planning phases

As stated in previous paragraph, the planning design is split into 6 phases with different horizons. The outcomes of each phase, planned nurses per shift, is the starting point of the next phase. The 6 phases will add up to the planning design. The 6 phases are split into two categories, category 1 (phase 1 to 4) focuses on patient demand and category 2 focuses on nurse availability (phase 5 and 6).

Patient demand:

1. In the first phase the basis schedule will be developed. This phase will only schedule nurses that cover up to 40% of necessary capacity derived from the amount of patient arrivals during the year using the mathematical model of the first part. The 40% is based on a combination of expert knowledge and visual inspection. In Figure 10 it can be seen that these can be planned a year up front. To make it more feasible for the planners, these will be planned three months in advance.
2. The second phase addresses the flexibility strategy of seasonality in the planning design. In Chapter 3.1 seasonality could be observed within several departments. Based on the seasonality of different patient categories, nurses are planned. Nurses planned on seasonality can also be planned more than three months in advance (Figure 10) and will also be planned three months up front. The nurses planned in the first 2 phases are almost certainly necessary at all times in their departments.
3. The nurses in the third phase will be planned once the operating theatre schedule (OT-schedule) is known. The OT-schedule is typically released one month in advance (Figure 10).
4. The fourth phase addresses the flexibility strategy of cross-nursing. In this, the day of work is known, but the department is not announced yet. The nurses in this phase will be planned once the OT-

schedule is known and all possible mutations of the OT-schedule are done, typically one week in prior to the due date (Figure 10).

Nurse availability:

In the flex-department analysis it is seen that the nurse availability mainly varies due to illness (long and short term illness). Based on the peak moments for requests of short and long term illness these two are split, both correspond to one phase of the planning design. With the flexibility strategy of outside nurses/pool nurses, the assignment of nurses to departments is done in these phases.

5. The fifth phase will take care of the long term absence/illness. Long term absence/illness, for example pregnancy, personal circumstances or surgery recovery is known at least 1 months in advance. Therefore this phase will be planned 1 month in advance (Figure 10).
6. The sixth phase, will be planned for short term illness. The short term illness consisting of for example fever, is only known days or hours in advance. Therefore this can only be planned last minute.

Phase 5 and 6 are used as input for the flex-department. With the results, a strategy to better align the flex-bureau to the departments will be developed.

The quality of the scheduling design is measured with four KPI's. The KPI's focus on more equal division of workforce to decrease the workload fluctuations. The first KPI measures the percentage of overcapacity in terms of workforce, the second the percentage of under capacity in terms of workforce. The last 2 KPI's will be regarding the relative under and overcapacity of the workforce.

Furthermore the percentages of nurses that is planned at different phases is calculated and used as input for the ranking-based interview, described later in this methodology.

In order to get relevant feedback for the new planning design a ranking-based-questionnaire which focuses on the trade-off between the fluctuations in workload and the different planning horizons of the phases is conducted. This is based on the results of the 6 phases of the planning design. The questionnaire is filled in by the nurses that develop the nurse schedules at the departments. By conducting a questionnaire the preferences of nurses can be included in the scheduling design.

4.5 Scientific and practical relevance

4.5.1 Practical Relevance

As explained in the previous section the workload of nurses fluctuates largely over time resulting in stress and frustration of nurses. With this master thesis, it is aimed to reduce the large workload fluctuations as well as a reduction in stress and frustration. At the first place, the research makes the workload fluctuations in the Elkerliek quantifiable which helps to create urge towards an accurate nurse planning. Furthermore will a new design process that better matches nurse capacity with patient demand, give insights in the possible reductions of fluctuations in workload within the Elkerliek. Thirdly, will the more uniform design process combined with the insights in the fluctuations in nurse capacity and patient arrivals result in a more sustainable nurse planning process. Lastly helps the new design process to better align the flex-bureau to the department's needs, and reduce the frustration and dissatisfaction among the departments and nurses.

4.5.2 Scientific relevance

In current literature, many articles in nurse planning are written on either patient demand or nurse supply. Despite the fact that nurse planning concerns both elements, only a few focus on finding a proper balance between these elements (S. G. Elkhuizen et al., 2007), (Griffiths, Price-Lloyd, Smithies, & Williams, 2005), (Yankovic & Green, 2011), (Gnanlet & Gilland, 2009). Greater efficiency gains can however be obtained by using both elements instead of one (Ernst, Jiang, Krishnamoorthy, & Sier, 2004).In this thesis, both elements are incorporated. Besides, due to the interrelated character of the nurse planning, an accurate nurse planning needs to have integrated decision levels (Abernathy et al., 1973), (Lowerre, 1979). This thesis therefore focuses on the integration of strategic and tactical level to create a more accurate nurse planning. Lastly, the opinions of nurses is incorporated in the planning design. To the best of our knowledge, there is hardly any research that inserts a feedback element from nurses to evaluate the planning design.

5. Analysis

In this chapter, the mathematical model, simulation model and questionnaire are developed. The first section contains the outline of the mathematical model and the clusters for the cross-nursing analysis. The second section contains the development of the simulation model. The third section will contain the KPI's and the ranking based interview to evaluate the design.

5.1 Mathematical model

This model is developed for two reasons, to get an estimation of the nurses needed per department for certain percentages of occupancy rate and second to see if there are effects on combining departments in their nurse planning. For the model the key variable is total warm bed minutes. This refers to the amount of patient minutes per specialism within a department based on the data of 2016 and 2017. Which in the end, can be converted to the amount of nurses needed.

As a start of the model the expected total patient minutes per department (j) are calculated. This is done with the expected number of patient arrivals and the expected LOS (in minutes) of patients which are assumed to be random independent variables (Silver, Pyke & Peterson, 1998). Since each department hospitalizes multiple patient types (n), first the expected total patient minutes per department (j) per patient type (n), $E(Tot_{nj})$, is calculated with the following formula:

$$E(Tot_{nj}) = E(Pat_{nj}) * E(LOS_{nj})$$

The $E(Pat_{nj})$ is defined as the expected number of patients that will arrive at a j (department) of patient type n. The $E(LOS_{nj})$ is defined as the average length of stay per patient type (n) arriving a department (j). To come to the total expected patient minutes per department (j) the above formula is summed over all patient types (n) hospitalized in a department resulting the following formula:

$$E(Tot_j) = \sum_{n=1}^{N} E(Tot_{nj})$$

The variability of the total patient minutes per patient type (n) for a department (j) is calculated with the following formula:

$$VAR(Tot_{nj}) = E(Pat_{nj}) * VAR(LOS_{nj}) + (E(LOS_{nj})^2 * VAR(Pat_{nj}))$$

To calculate the total variability of Total patient minutes within a department the above formula is summed for the patient types in the department.

$$VAR(Tot_j) = \sum_{n=1}^{N} VAR(Tot_{nj})$$

Assuming that the variable for Total patient minutes is normally distributed a confidence interval to show the estimated range of the total patient minutes can be determined with the use of the following formula's:

$$E(Tot_j)_{Lower} = E(Tot_j) - z_{\frac{\alpha}{2}} \sqrt{Var(Tot_j)}$$

$$E(Tot_j)_{Upper} = E(Tot_j) + z_{\frac{\alpha}{2}}\sqrt{Var(Tot_j)}$$

To analyze the effects of combining the several departments, 4 different confidence interval values are calculated, 80% 90% 95% 99% resulting in a $z_{\frac{\alpha}{2}}$ of respectively 1.29 1.64, 1.96 and 2.58.

To be able to analyze effects of combining several departments based on their expected total patient minutes and variability of total patient minutes the following formulas are used.

$$E(Tot) = \sum_{j=1}^{J} E(Tot_j)$$

$$Var(Tot) = \sum_{j=1}^{J} Var(Tot_j)$$

$$E(Tot)_{Lower} = E(Tot_j) - z_{\frac{\alpha}{2}}\sqrt{Var(Tot_j)}$$

$$E(Tot)_{Upper} = E(Tot_j) + z_{\frac{\alpha}{2}}\sqrt{Var(Tot_j)}$$

Four different scenarios in terms of combinations of departments are tested to see what the effect is based on the confidence interval values, these are depicted in Table 10. The first Scenario contains all the departments, the second scenario consists of the clinical departments. The third scenario will combine short stay and daycare. Lastly the fourth scenario will combine 3A, 3B, 3C and 3D and 4Alg.

Table 9: Different department combinations as input for cross-nursing

Scenario's	Departments
Scenario 1	1B, 1C, 2B, 2C, 2D, 3A,3B,3C,3D ,4Alg
Scenario 2	1B, 1C
Scenario 3	2B, 2C, 2D
Scenario 4	3A, 3B, 3C, 3D, 4Alg

5.2 Simulation Model

This part consists of the development of the simulation model. To do so, first analysis regarding the statistical distributions of the arrivals of different patient types and analysis regarding seasonality factors per patient type are done. This section also contains specification of department. Lastly the actual structure of the simulation model is explained.

5.2.1 Distributions of patient arrivals

In this paragraph analyses regarding the statistical distributions of different patient types are executed. As input for the distribution analysis the average patient arrivals per day, and standard deviation are calculated. This is based on the patient arrivals in 2015 to 2017. First the patient types are defined by splitting based on:

1. Department (short stay, regular stay, daycare)
2. Acute or elective patient
3. Treatment specialism

An example of a patient type is: Elective long patient, regular stay. In total 20 types of specialisms are treated at the short stay, regular stay and daycare department. The patients from a specialism can be either acute or elective. Patient types which have an arrival rate less than 0.05 per day are assumed to be 0 and not taken into account. These low numbers are caused by a combination of treatment type and acute/ Elective or department that does not exist. There are 59 remaining patient types that will be checked for a statistical significant distribution. In Table 26 of the appendix an overview of the average arrivals per day and the standard deviation for these types is calculated. The 59 remaining patient types are tested on their fit to a statistical distribution. To test the statistical significance of the patient types to a distribution a Chi-Square Goodness-of-Fit test is done. The Chi-Square goodness of fit test is a non-parametric test that is used to find out how the observed value is significantly different from the expected value and compares the observed sample distribution with the expected probability distribution. If a Null hypotheses (h=0) is accepted the p-value is smaller than 0.05. A p-value bigger than 0.05 rejects the Null hypotheses. The test is done for 4 different distributions: Lognormal, Normal, Poisson and Uniform. The results of the Chi-square test can be found in Table 27 in the appendix. As explained before, patient types that have an arrival rate which is smaller than 0.05 will not be taken into account. Furthermore if for a patient type no significant match with a statistical distribution is found, an empirical distribution is used for this distribution as input for the simulation model. The average, standard deviation and the statistical distribution are used as input for the simulation of arrivals of patients in the hospital.

5.2.2 Seasonality of patients arrivals

In this section possible patient arrival seasonality per specialism are tested. This is done based on the data of 2015 to 2017. Once significant seasonality is found on a specialism it is used as input for the simulation of patient arrivals in the hospital. The seasonality of specialisms is tested with the use of regression analysis resulting in a factor to represent the seasonality per specialisms in the simulation model. Regression analyses are regularly used to forecast data and analyze trends or seasonality patterns. Based on visual inspection of the data, it can be concluded that there is no clear trend visible in the data. Therefore the trend factor in regression analyses is excluded when determining the seasonality. Resulting in the regression analyses on time series for seasonality without trend.

Table 10: Clusters for Factor analyses

Clusters	Months
Cluster 1	January – February
Cluster 2	March – April
Cluster 3	May – June
Cluster 4	July – August
Cluster 5	September – October
Cluster 6	November - December

Firstly, six clusters are determined, each cluster represents 2 months (Table 9). The second step is to determine the averages and standard deviation of each cluster per specialism. These averages and standard deviations are compared per cluster with the expected values of each specialism to determine significant seasonality. The regression analyses are done with a regression function in Excel, and are considered to be significant for a cluster when the p-value is less than 0.05. Since it is likely that only a few clusters within a specialism are significant to seasonality a stepwise-regression is executed. In this step-wise regression the least significant value is removed from a cluster until only significant clusters remain. Five specialisms are found to be significant for one or multiple clusters. The other 15 specialisms are considered not to be significant which can be caused by either the small number of patient arriving or because there is no seasonality within the specialism. The seasonality factor is determined by dividing the average arrivals per day in the concerning significant cluster by the average arrivals per day calculated over all the clusters:

$$Seasonality\ Factor = \frac{Average\ arrivals\ per\ day\ significant\ cluster}{Average\ arrivals\ per\ day\ all\ clusters}$$

The non-significant clusters within a specialism that have at least one significant cluster have to be compensated for the significant cluster. This is done by subtracting the summed significant cluster factors from the total amount that is divided over the 6 clusters, this is 6 since there are 6 clusters. The resulting number is divided by the remaining amount of non-significant clusters. This results in the following formula in which N is the number of significant clusters and S the number of non-significant clusters:

$$Factor\ nonsignificant\ clusters = \frac{6 - \sum_{n=1}^{N}(Factor\ significant\ cluster)_n}{6 - S}$$

An overview of the results are depicted in Table 22 which is included in the appendix.

5.2.3 Development of model

In this section the patient arrival process and assignment to departments for the simulation is explained. The first phase is to generate daily patient arrivals for all 59 patient types mentioned in the section 5.2.1. The second phase is to give each individual patient a unique LOS and a unique arrival time. The last step is to (re)-assign them to a department.

5.2.3.1 Generation of patient arrivals

The arrivals per patient type are based on the average, standard deviation and statistical distribution calculated in section 5.2.1 as well as three other factors which depend on the arrival date. These three factors are: week/weekend, reduction week/regular week and seasonality. In Figure 11 phase 1 is depicted. The arrival process is simulated for 5 years. For each day in the 5 year simulation the process in Figure 10 is done.

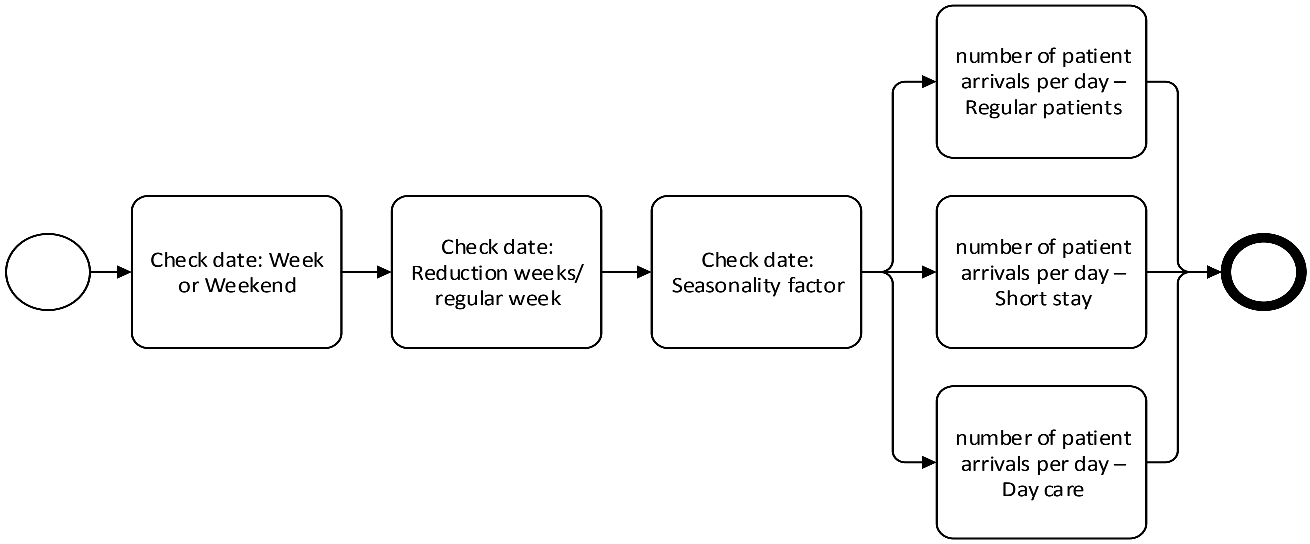

Figure 11: Patient arrivals in simulation model

The first step is to check the weekday, this is to determine if the date is a week or weekend day. For each patient category (regular/daycare/short stay) different restrictions are set.

- Daycare patients only arrive during the weekdays (Monday to Friday).
- Regular patient arrive during week and weekend days. However, the average arrivals during week and weekend days are different since it is assumed that only acute patients arrive during weekend days. Therefore the average arrivals during weekdays and weekend days are separately calculated and used as input.
- Short stay patients only arrive during the weekdays (Monday to Friday)

Second, the week number is checked to determine if the concerning week is a regular or reduction week. Within the Elkerliek hospital week numbers 28 to 33 are the reduction weeks. Meaning that there will be a smaller amount or zero patient admissions. The reduction weeks only concern the short stay department and the daycare department.

- The short stay department is closed during the reduction weeks, therefore zero patient admissions are done.
- The daycare department has a reduced amount of patient admissions. Therefore the average and standard deviation of the patient arrivals is calculated for these weeks separately and used as input.

The third step is to determine if a seasonality factor should be added to increase or decrease the amount of patient arrivals for this patient type. As explained before, the factor is determined per specialism, and the patient types corresponding to the specialism are multiplied by the seasonality factor. After step 3, the amount of patients per patient type arriving per day are known.

5.2.3.2 Assigning attributes to individual patients

The next phase concerns the assignment of attributes: arrival time, LOS to the individual patients within each patient type, depicted in Figure 12.

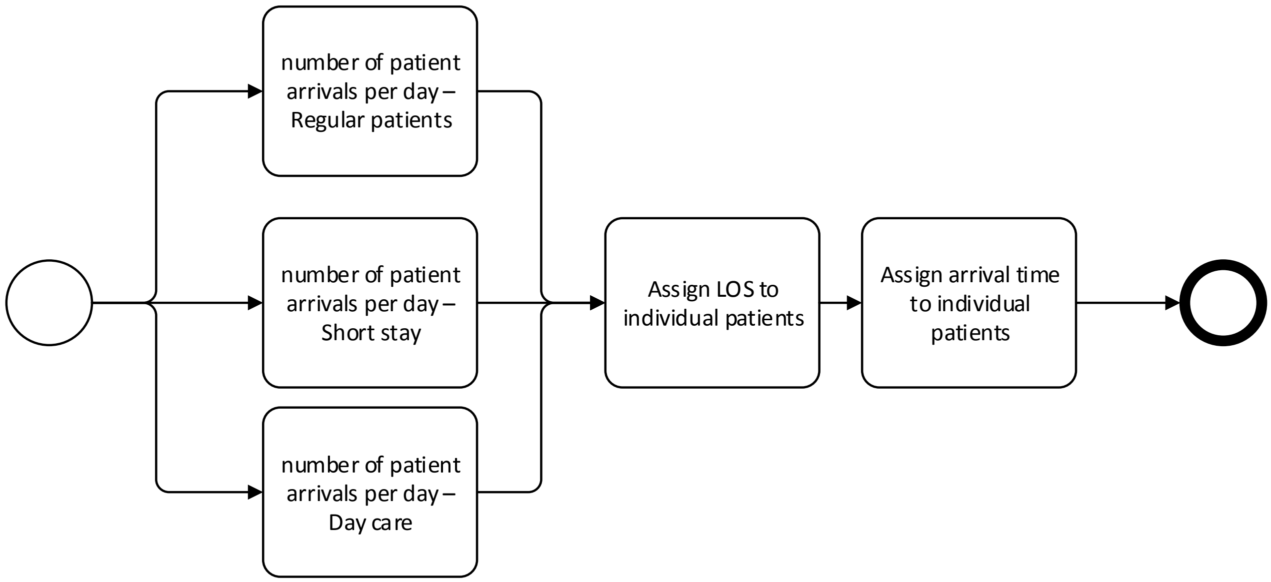

Figure 12: LOS and arrival time in the simulation model

As explained before, the result from the previous part of the simulation is the number of patient arrivals per patient type per day.

- Array arrival times:
  Based on the arrival times of 2016 and 2017 of the patients within a patient type, an array with all possible arrival times is set up.
- Array LOS:
  Based on the LOS of 2016 and 2017 of the patients within a patient type, an array with all possible LOS is set up.

With the use of an empirical distribution, an arrival time is picked from the arrival times array and assigned to each individual patient. Thereafter, also with the empirical distribution a LOS is picked from the LOS array and assigned to each individual patient.

5.2.3.3 Actual assignment and re-assignment to departments

The last step is the actual assignment of assignment of the patients to departments. The assignment process is depicted in Figure 13.

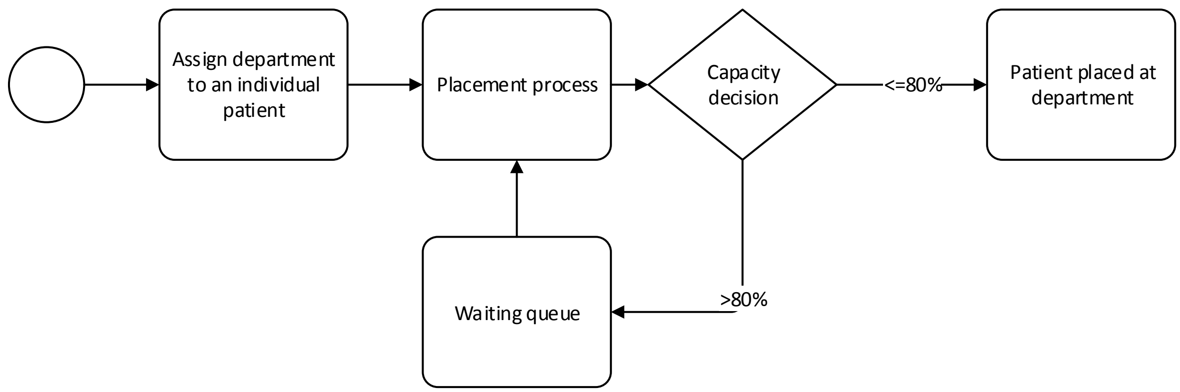

Figure 13: Actual assignment of patients to departments in the simulation model

At first, a department is assigned to an individual patient. This is done based on a Department array that is created.

- Array Department:
  Patients within a patient type can be hospitalized at several departments. Based on the data of 2017 an array is created with all department names for the patient arrivals of this patient type.

With the use of an empirical distribution, the department is assigned to an individual patient. The output is an overview of the amount of patients that are in the hospital at a specific day and part of the day at each department. The day is split into three shifts (Day, evening and night). Dayshift starting at 7:00 and ends at 16:00. The evening shift starts at 16:00 and ends at 23:00. The night shift starts at 23:00 and ends at 7:00. In Figure 14 an example of the output of the simulation is depicted. In Figure 14 one can see the amount of patients per shift in the concerning departments.

Date	*1-1-2019*	*1-1-2019*	*1-1-2019*	*2-1-2019*	*2-1-2019*
Department	Night (23:00 - 7:00)	Day (7:00-16:00)	Evening (16:00-23:00)	Night (23:00 - 7:00)	Day (7:00-16:00)
1B	2	2	1	3	5
1C	3	2	2	3	2
2B	4	1		4	2
2C	4			4	2
2D	4	5		4	2
3A	4	3	1	4	2
3B	2	3	2	4	4
3C				1	
3D	1	2	1	2	4
3E	4	4		4	1
4Alg	6	7	5	3	5

Figure 14: Output table simulation (Patients per shift per department)

In this model also a queuing process is incorporated. This is based on the capacity of each department. Once 80% of the maximum capacity of a department is reached, the patient will be rejected and placed on a waiting list. The week after, the patient will be placed again if the maximum capacity is not reached for that week. If the maximum capacity is reached again, the patient will be placed on the waiting list again. This process is repeated for a maximum of 52 weeks. The maximum capacity is based on the regular beds and included in Table 29 in the appendix.

5.2.4 Nurse assignment

Once the amount of patients per shift are known, the assignment of nurses to shifts is done. As explained before the assignment of nurses to departments is done according to the 6 different phases. A distinction is made between regular nurses (nurses that are under contract at a department) and flex-nurses (nurses that are under contract at the flex department). The regular nurses can only work at the department of which they have a contract. The flex nurses can work at multiple departments. For the assignment of nurses, the regular ratios of the nurses to patients is used: 1:4 (daytime), 1:7 (evening time), 1:10.5 (nighttime). The details on the assignment of nurses based on the 6 design phases is explained in the next chapter.

The simulation model also incorporates two factors that lower the amount of final available nurses per shift. These factors are long- and the short term illness and are based on the annual illness rate within the hospital which is around 5%. In the simulation model the amount of ill nurses per shift based are generated using a Poison distribution for both the long- and the short term illness. The ill nurses are generated using Poison arrivals with $\lambda = 0.02$ and $\lambda = 0.03$ for respectively long and short term illness.

5.3 KPI's

To get a better understanding of the results of the different phases in the new planning design, four KPI's are set up. The KPI's will measure in different ways the mismatch between amount of patient arriving in a department compared to the actual nurses planned (Figure 15). The KPI's are determined per department for each step of the design. The KPI's are measured for the time period of the simulation, 5 years and are measured per shift.

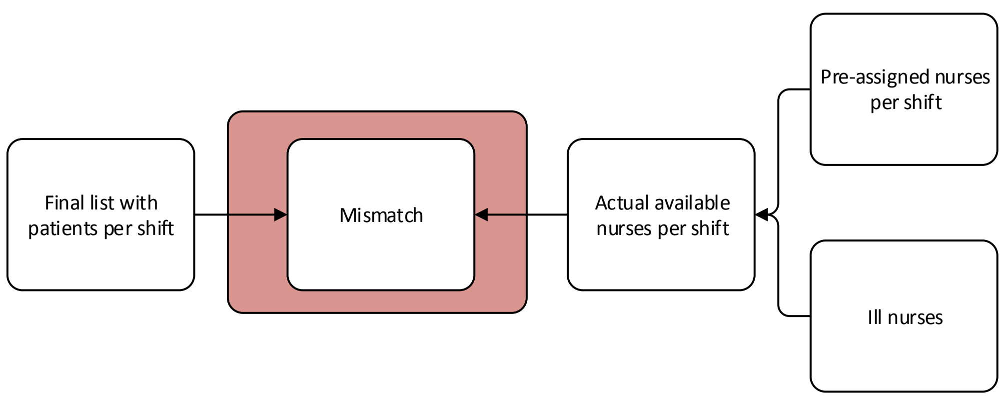

Figure 15: KPI's mismatch visual representation

The first two KPI are regarding the overcapacity of the departments. In the overcapacity situation there are more nurses available for a department during a shift than required based on the patients at the department at that shift. The overcapacity is measured in number of occurrences and the relative difference.

Firstly the overcapacity occurrences within the 5 year simulation are determined. The percentage of overcapacity, is the percentage of shifts (x) within the 5 years simulation a department (n) has overcapacity.

$$Overcapacity_{nx}(\%) = \frac{Total\ shifts\ of\ overcapacity_{nx}}{Total\ shifts\ in\ simulation_{nx}} * 100\%$$

The second KPI calculates the mismatch between the planned nurses and the required nurses per shift once there is overcapacity. The percentage of *relative overcapacity* for department n at shift x (day, evening night) is calculated for the total shifts (i) within 5 years simulation.

The formula that is depicted below measures the overcapacity size, the formula only considers shifts (i) within the simulation with overcapacity.

$$Relative\ overcapacity_{nx}(\%) = \frac{\sum_{i=1}^{I}(Available\ nurses_{nxi} - Required\ nurses_{nxi})}{\sum_{i=1}^{I}(Available\ nurses_{nxi})} * 100\%$$

The 3rd and 4th KPI are regarding under capacity of the departments. In the under capacity situation there are less nurses available for a department during a shift than required based on the patients at the department at that shift. The under capacity is also measured in occurrences and relative under capacity.

Firstly the under capacity occurrences within the 5 year simulation are determined. The percentage of under capacity, is the percentage of shifts (x) within the 5 years simulation a department (n) has under capacity.

$$Undercapacity_{nx}(\%) = \frac{Total\ days\ of\ under\ capacity_{nx}}{Total\ day\ in\ simulation_{nx}} * 100\%$$

The last KPI calculates the mismatch between the planned nurses and the required nurses per shift once there is under capacity. The percentage of *relative under capacity* for department n at shift x (day, evening night) is calculated for the total shifts (i) within 5 years simulation.

The formula that is depicted below measures the under capacity size, the formula only considers shifts (i) within the simulation with under capacity.

$$Undercapacity\ size_{nx}(\%) = \frac{\sum_{i=1}^{I}(Required\ nurses_{nxi} - Available\ nurses_{nxi})}{\sum_{i=1}^{I}(Required\ nurses_{nxi})} * 100\%$$

5.4 Ranking based Interview

In order to evaluate the quality of the design, feedback from nurses is asked on the new planning design. This is done with a ranking-based questionnaire. A ranking based questionnaire is chosen since it provides a lot of information and it is easy to understand for nurses. In Table 11 the outline of the questionnaire is depicted. The questionnaire evaluates the two key elements of the planning design, workforce division and the planning horizons. Each row represent a phase of the planning design. The questionnaire evaluates if a nurse is willing to work harder in order to have a schedule that is set long time in advance. In Column 1 the nurses are asked to fill in the numbers 1 to 6, 1 for most preferred option and 6 to the least preferred. The second column corresponds to the percentage of under capacity (work harder than set nurse-patient ratio) of a phase in the planning design. The third column corresponds to the percentages planned per phase. In the third row, for example, 80% of the planning be fulfilled 3 months in advance, and 20% 1 month in advance. The actual numbers for this questionnaire will be determined in the Results section.

Table 11: Example of ranking-based questionnaire

Rank **(1 = most preferred, 6= least preffered)**	**Under capacity (%)**	**Planning horizon**
	X%	3 months (X%)
	X%	3 months (X%)
	X%	3 months (X%), 1 month (X%)
	X%	3 months (X%), 1 month (X%), 1 week (X%),
	X%	3 months (X%), 1 month (X%), 1 week (X%),
	X%	3 months (X%), 1 month (X%), 1 week (X%), 1 day (X%)

6. Results

6.1 Mathematical model

To illustrate the results of the mathematical model for each cluster, the results are depicted in four Figures. Figure 16 depicts the amount of nurse days needed per month for cluster 1 (combining all departments) and the amount of nurse days needed when planning all the nurses per department separately. On the horizontal axis the percentages described in Chapter 5 are displayed (80%,90%, 95%,99%). By visual inspection one can already see that combining the departments results in smaller amount of nurse days for the upper bound and larger amount of nurse days for the lower bound. Which concludes that shared planning of the nurses based on the patient demand and LOS results a smaller difference between the upper and lower bound, and suggests less fluctuations. The same results are found for the other three clusters. The graphs of these clusters are depicted in Figure 23 to 25 in the appendix.

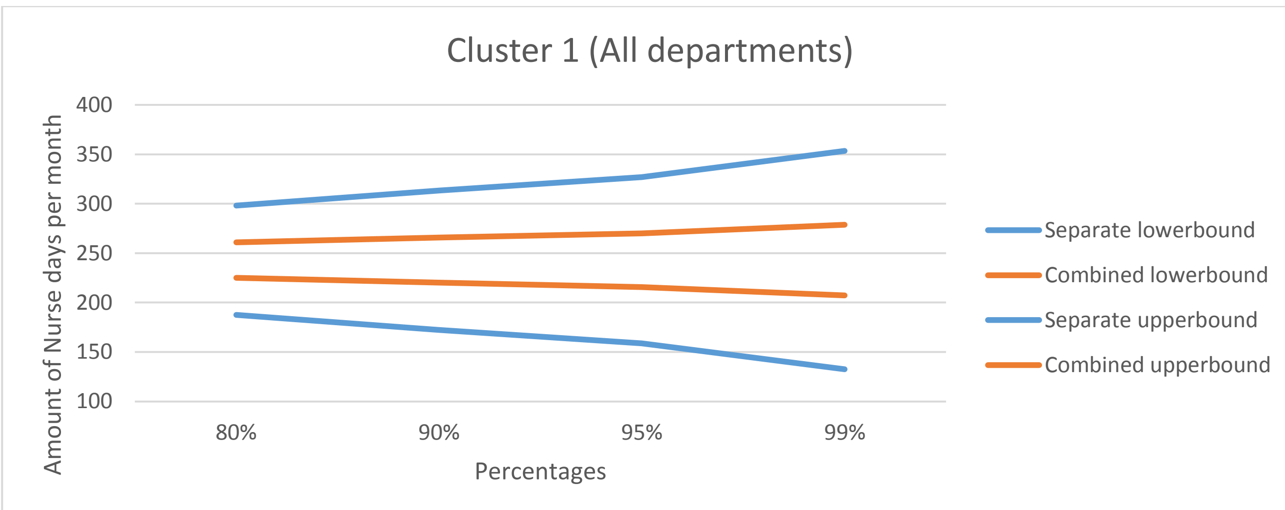

Figure 16: Cluster 1 Mathematical model: sketching confidence intervals for amount of nurse days

6.2 Design of planning process

After the actual assignment of patients to different time slots and the re-assignment of patients with the queuing model the assignment of nurses to patients is done. The starting point of this planning design is the output table of the simulation of patients per shift per department, depicted in Figure 14. In this chapter the 6 phases will be explained more briefly and the results of each phase will be described. The first 4 phases focus on the amount of nurses to plan based on the patient arrivals. Phase 5 and Phase 6 focus on the nurse availability due to the illness rates. Every phase in the model starts with the final amount of assigned nurses in the previous phase.

6.2.1 Phase 1

In the first phase the initial schedule is developed. This phase plans nurses to shifts to have at least sufficient occupancy rate of 40% at all shifts, based on the ratio's set before. This is calculated with the use of the mathematical model developed in Chapter 5.1. After the nurses are assigned to departments, a percentage of nurses is subtracted based on the illness rates to simulate a decrease in nurse availability in some shifts.

The first illness factor corresponds to long term illness and has λ = 0.02, the short term illness has λ = 0.03. The four KPI's: under capacity size (%), relative overcapacity (%), under capacity (%) and relative overcapacity (%) are calculated for each shift (day, evening, night) and each department. The results can be reviewed in Table 11. To explain the results of the KPI's of phase 1, department 1c is used as an example. One can see that in 26% of the shifts more nurses are planned than needed based on the patients in the department. Once overcapacity is reached for a shift, the relative overcapacity, which is defined as the difference between the nurses that have to be planned (based on the amount of patients) in the hospital and the nurses planned is 37%. The under capacity is even bigger, in 56% of the cases the amount of nurses needed is smaller than the amount of nurses needed, while the relative under capacity is 33%.

Table 12: Results Phase 1 planning design

Department	Overcapacity %	Relative Overcapacity (%)	Under capacity (%)	Relative Under capacity (%)
1B	28%	33%	56%	33%
1C	26%	37%	57%	37%
2B	13%	27%	42%	32%
2C	9%	33%	34%	25%
2D	27%	47%	57%	41%
3A	21%	42%	54%	47%
3B	25%	40%	56%	40%
3C	25%	38%	55%	38%
3D	16%	47%	64%	61%
4Alg	27%	33%	58%	34%

By setting a relatively low sufficient capacity percentage of 40%, the amount of overcapacity and relative overcapacity can be decreased. The focus however is on the reduction of the under capacity and under capacity size. Therefore in the next 5 phases, the overcapacity will be almost constant, this will reviewed in the final results.

6.2.2 Phase 2

Phase 2 assigns nurses to shifts based on a seasonality factor. The seasonality factor is already determined in Chapter 5.2 per specialism for 6 clusters. For each cluster, a corresponding amount of nurses is added or subtracted to shifts within that cluster. Phase 2 also contains the 40% sufficient occupancy rate for nurses set in phase 1. After adding nurses to certain shifts on seasonality basis, the model is again corrected for both the short and the long term illness. The results depicted in Table 12 show the under capacity and the under capacity size of nurses planned in phase 1 and 2. Especially at department 1B and 1C as well as 3B, a decrease in under capacity is measured. This is in line with the specialisms that are treated within these departments, these correspond with the 5 specialism that are found to be significant in Chapter 5.2.

Table 13: Results Phase 2 planning design

	1B	1C	2B	2C	2D	3A	3B	3C	3D	4Alg
Under Capacity (%)	53%	52%	41%	34%	57%	53%	49%	55%	64%	57%
Relative under capacity (%)	31%	35%	32%	25%	40%	48%	39%	38%	61%	34%

6.2.3 Phase 3

The third phase adds nurses to the planning of the previous 2 phases based on the OT-schedule of the Elkerliek hospital. The OT-schedule can only schedule elective patients, therefore the percentage of elective patients per department are determined and depicted in Table 28 in the appendixes. Phase 3 only adds nurse to shifts, if the amount of nurses in a shift are lower than the nurses that are needed. The difference between the amount of nurses planned and the amount of nurses that are needed is multiplied by the percentage of elective patients within that department and added to the concerning shift. Finally the two illness rates are again subtracted from the available nurse capacity. The results of adding the nurses based on the OT-schedule to the previous two phases are depicted in Table 13. One can see that phase 3 results in a large decrease of under capacity and relative under capacity, especially on departments 2B, 2C and 2D (short stay and daycare). This is because the short stay and daycare have a large percentage of elective patients. On departments that have a small percentage of elective patients, the effect is very small or zero.

Table 14: Results phase 3 planning design

	1B	1C	2B	2C	2D	3A	3B	3C	3D	4Alg
Under Capacity (%)	53%	39%	20%	20%	22%	53%	49%	55%	55%	57%
Relative under capacity (%)	26%	17%	22%	20%	31%	37%	33%	33%	52%	27%

6.2.4 Phase 4

In Phase 4 the principle of cross-nursing is added to the planning design. In this phase the departments will be divided into three segments based on the specialisms that are treated on each department (Table 14).

Table 15: Segments Phase 4 planning design

Segment	Departments
Segment 1	1B, 1C
Segment 2	2B, 2C and 2D
Segment 3	3A, 3B, 3C, 3D, 4Alg

For each segment a pool of nurses is created, the nurses in this pool are not restricted to work at a single department, but can work at all the departments in their segment. The size of the pool is determined on weekly basis with the use of the previous three phases and the occupancy rate of 85% sufficient nurses (the target occupancy rate of the Elkerliek hospital). For the pools, the summed amount of nurses for a week per segment in order to achieve an 85% occupancy rate (per shift) are determined. Thereafter the nurses per shift that are planned in previous phases for the concerning segment are subtracted. This leaves the capacity of nurses per segment per week that is still available for assignment. The nurses in the pool are only assigned to departments that have less capacity than they should have. The amount of nurses are equally divided over the departments and the assignment process will continue until either there are no nurses left in the pool or the needed capacity for the amount of patients is reached. Finally the two illness rates are subtracted from the available nurse capacity. The results depicted in Table 15 show the under capacity and the under capacity size of nurses planned in phase 1 to 4. A substantial decrease in the under capacity and relative under capacity can be observed in all departments except for the short stay and day care (2B, 2C, 2D). This is caused by large percentage of elective patients that are treated in these departments and which in phase 3 is used as input for the adding of nurses to shifts.

Table 16: Results -Phase 4 planning design

	1B	1C	2B	2C	2D	3A	3B	3C	3D	4Alg
Under Capacity (%)	21%	17%	20%	20%	22%	17%	17%	17%	36%	17%
Relative under capacity (%)	16%	16%	22%	20%	31%	29%	20%	19%	61%	14%

6.2.5 Phase 5

The last two phases (5 and 6) focus on the two illness rates that are used in the simulation model. Phase 5 focuses on the long term illness or absence of the nurses, which is caused by for example the maternity leave. The starting point of this phase are the nurses planned of the first four phases. In this phase one pool is created to deal with the long term illness of nurses for all the departments within the hospital. The size of this pool will be similar to the percentage of long term illness (3%). The nurses in the pool are only assigned to departments that have less capacity than they should have. The amount of nurses are equally divided over the departments and the assignment process will continue until either there are no nurses left in the pool or the required amount of nurses to compensate for the decrease in capacity is reached. The results depicted in Table 16 show the under capacity and the Relative under capacity size of nurses planned in phase 1 to 5 .The decrease in under capacity and relative under capacity is smaller than in the previous phases however more constant among departments. At the end of the 5 year simulation 5, 2% of the nurse amount that is set at the start of the simulation is not assigned to a shift.

Table 17: Results Phase 5 planning design

	1B	1C	2B	2C	2D	3A	3B	3C	3D	4Alg
Under Capacity (%)	19%	16%	18%	19%	21%	16%	15%	15%	35%	15%
Relative under capacity (%)	19%	16%	18%	19%	21%	16%	15%	15%	35%	15%

6.2.6 Phase 6

The last phase focuses on the short-term illness. A pool is set up to deal with short term illness of nurses for all the departments within the hospital. The size of this pool will be similar to the percentage of short term illness (2%). The starting point of this phase are the nurses planned of the first 5 phases. The nurses are equally divided over the departments and the assignment process will continue until either there are no nurses left in the pool or the needed capacity for the amount of patients is reached. The results depicted in Table 17 show the under capacity and the relative under capacity of nurses planned in all 6 phases (final design). The decrease in under capacity and under capacity size is very substantial and found in all departments. The values of department 3D and 2D are relatively big compared to the departments KPI values. Especially the relative under capacity is large, 63% and 37%, for relatively 3D and 2D. This indicates that in periods of under capacity the difference between required nurses and the planned nurses is large, which could be caused by the highly fluctuating number of patients that arrive at this department. For department 2D (short stay) it is likely caused by the hospitalization procedure, 2D is only open during weekdays, however if a patient arrives at Friday and has a LOS longer than one day, the department will stay open on Saturday. This is however a relatively small percentage of patients. Since the patient ratio is at least 4:1, the rounding of nurses (it's not possible to use half nurse shifts in the design) likely causes this big relative under capacity. For department 3D the large amount of relative under capacity is likely caused by the high fluctuation of arrivals at the department. Also 2B has a large percentage of relative under capacity. This however is only caused by a small amount of time periods. At the end of the 5 year simulation 7.7% of the nurse amount that is set at the start of the simulation is not assigned to a shift.

Table 18: Results Phase 6 planning design

	1B	1C	2B	2C	2D	3A	3B	3C	3D	4Alg
Under Capacity (%)	7%	3%	2%	2%	10%	3%	3%	1%	19%	14%
Relative under capacity (%)	15%	7%	48%	2%	37%	3%	3%	3%	63%	14%

6.2.7 Final design

In the previous section the 6 planning phases are described, forming the final design in the end. To make the results more comprehensive, they are visualized in Figure 17. In this Figure the 6 consecutive phases of department 1C for 1 year are depicted. The dark blue area of the two represents the amount of nurses needed according to the amount of patients in the hospital, based on the ratio. The light blue area represents the amount of nurses that are planned based on the different phases. The graphs serve to get a more visual understanding, but differ over the year as well as the department.

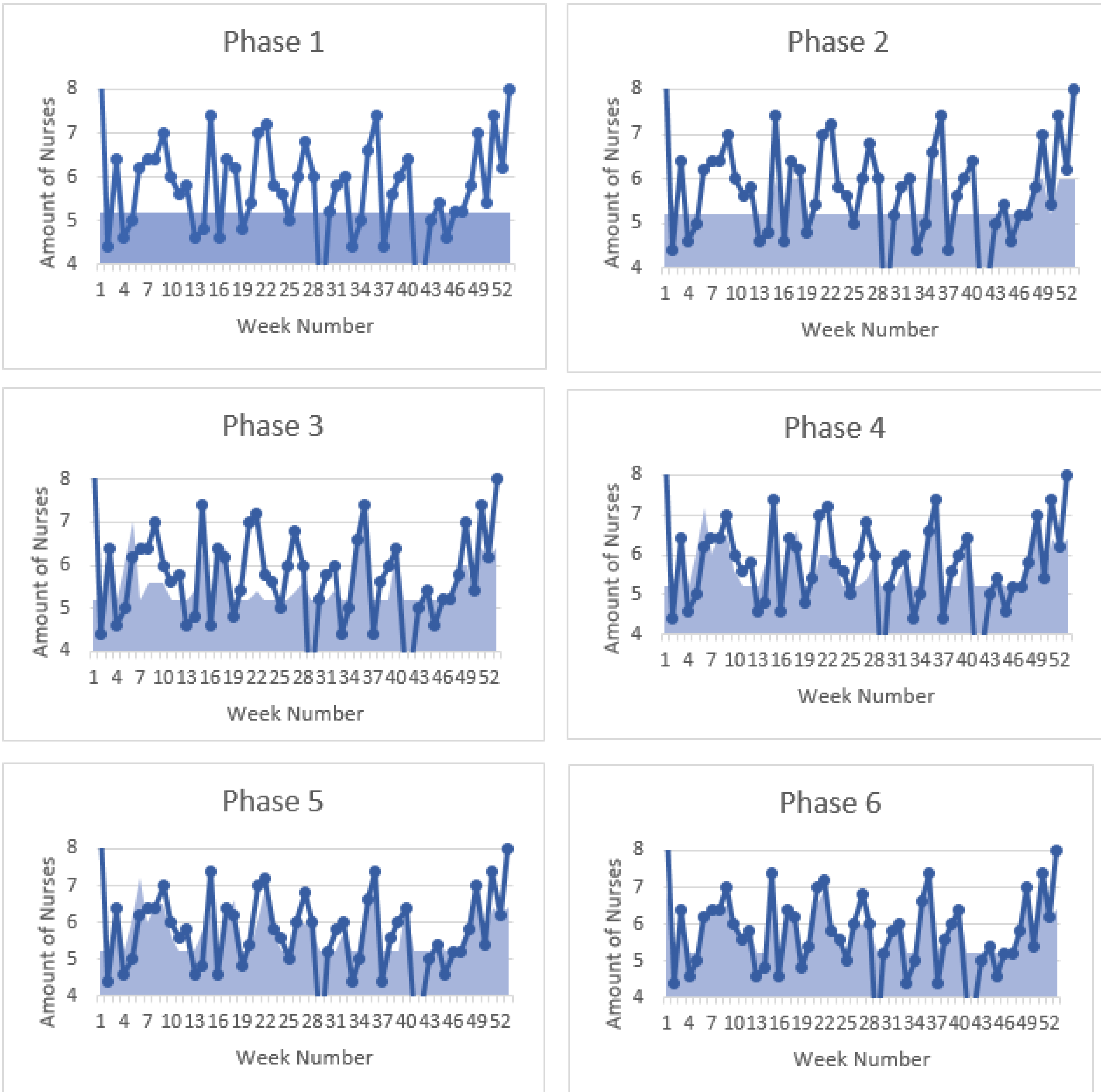

Figure 17: Visualization of Phases department 1c, light blue available nurses, dark blue needed nurses.

Lastly the difference in overcapacity and relative overcapacity is calculated after phase 6, to see if any changes occurred in these two KPI's due to the planning design developed in the six phases. In Table 18 It can be seen that despite the fact no phases in the planning design actively focus on the overcapacity, the percentage of overcapacity increased at almost all department for a small percentage. This is the result of the decrease of personnel planned at phase 2 in which the seasonality factor also can lower the amount of planned nurses at a shift (if nurses are planned during low season).

Table 19: Overcapacity final design

	1B	1C	2B	2C	2D	3A	3B	3C	3D	4Alg
Over Capacity (%)	31%	30%	14%	11%	27%	25%	29%	29%	19%	27%
Relative over capacity (%)	33%	37%	27%	33%	47%	42%	40%	38%	47%	33%

6.2.8 KPI's Current design

In order to compare the new planning design with the current planning design, the KPI's are determined for the current planning design. Currently, the nurse occupancy rate of the hospital is 85%, and means that in 85% of the time sufficient nurses should be available based on the ratios In Table 19 the overview of the results of the overall KPI's are depicted. One can see, that the percentage of overcapacity is very large while the under capacity is relatively small compared to the overcapacity.

Table 20: Current situation results on the 4 KPI's

	Overcapacity (%)	Relative over capacity (%)	Under Capacity (%)	Relative under capacity (%)
1B	74%	37%	14%	18%
1C	75%	41%	13%	19%
2B	36%	33%	18%	19%
2C	26%	39%	21%	16%
2D	61%	41%	21%	32%
3A	69%	45%	14%	27%
3B	72%	42%	14%	21%
3C	73%	41%	14%	21%
3D	55%	47%	31%	58%
4Alg	76%	37%	14%	18%

Comparing these results to the final results (phase 6) of the new planning design, one can see that both the under capacity and the overcapacity KPI's are improved in the new planning design. The overcapacity is lower in the new planning design, since it is based on the 40% occupancy rate of phase 1 and stays constant over the phases. The under capacity in the new planning design is also lower at all departments compared to the current planning design. This is because the new planning design primarily focuses on the decrease in under capacity while keeping the overcapacity constant. Furthermore does the new planning design create flexibility to adopt to the assigned nurses to departments based on the patient arrivals and the nurse availability.

Lastly are the number of nursing hours used for the current planning compared to the number of nursing hours in the final design of the new planning design. This is simply done by summing all the nursing hours needed for the final phase of the new design and compare them with the summed nursing hours needed in the current design. In the end 23% less nursing hours are used in the new design compared to the current design.

6.2.9 Planning moments

As stated in the beginning, the planning of the different phases is done at different due dates. Phase 1 and Phase 2, the basis schedule and the seasonality scheduling can be done longer than 3 months in advance. Phase 3 and phase 5, OT-schedule and long-term illness of nurses can be scheduled 1 month in advance. Phase 4, combining departments, typically 1 week in advance. Lastly phase 6, the short-term illness is done last minute, 1 day in advance. For nurses the time in advance their schedule is announced, is an important factor. An overview of the planning design schedule announcement results are depicted in Table 20 the planning has 4 due dates for different parts of the planning: 3 months, 1 month, 1 week and 1 day in advance in which respectively 80%, 7%, 10% and 3% of the nurses are planned. Translating to schedule announcements; around 43 weeks per year the nurse schedule is announced 3 months in advance, 3 weeks it is announced 1 month in advance, 5 weeks it is 1 week in advance and 2 weeks it is known the day before the actual shift.

Table 21: Planning design schedule announcements

Time planned before shift due date	3 months prior to shift	1 month prior to shift	1 week prior to shift	1 day prior to shift
Total percentage planned of total planning	80%	7%	10%	3%
Total weeks planned of total planning	43 weeks	3 weeks	5 weeks	2 weeks

6.3 Ranking based questionnaire

Based on the results in section 6.2, the ranking based questionnaire attached in Figure 31 in the Appendixes is conducted among the nurses that develop the nurse planning at their departments. The questionnaire evaluates if a nurse is willing to work harder in order to have a schedule that is set long time in advance. As described in the previous Chapter, the planners had to rank their preferences from 1 (most preferable) to 6 (least preferable). The planners were also free to ask questions and were asked to explain the preferences they filled in in the questionnaire. This is done to ensure more information than just the results of the questionnaire. From the 10 departments, 8 planners filled in this questionnaire. Figure 18 depicts the results of the most preferable option filled in by the planners. It can be seen that either option 3 (3 months prior to shift (87%) and 1 month prior to shift (13%)) and option 5 (3 months prior to shift (82%), 1 month prior to shift (7%) and 1 week prior to shift (11 %)) are the most preferred options. The least preferred option by the planners is option 6 (3 months prior to shift (80%), 1 month prior to shift (7%),1 week prior to shift (10% ,1 day prior to shift(3%)).

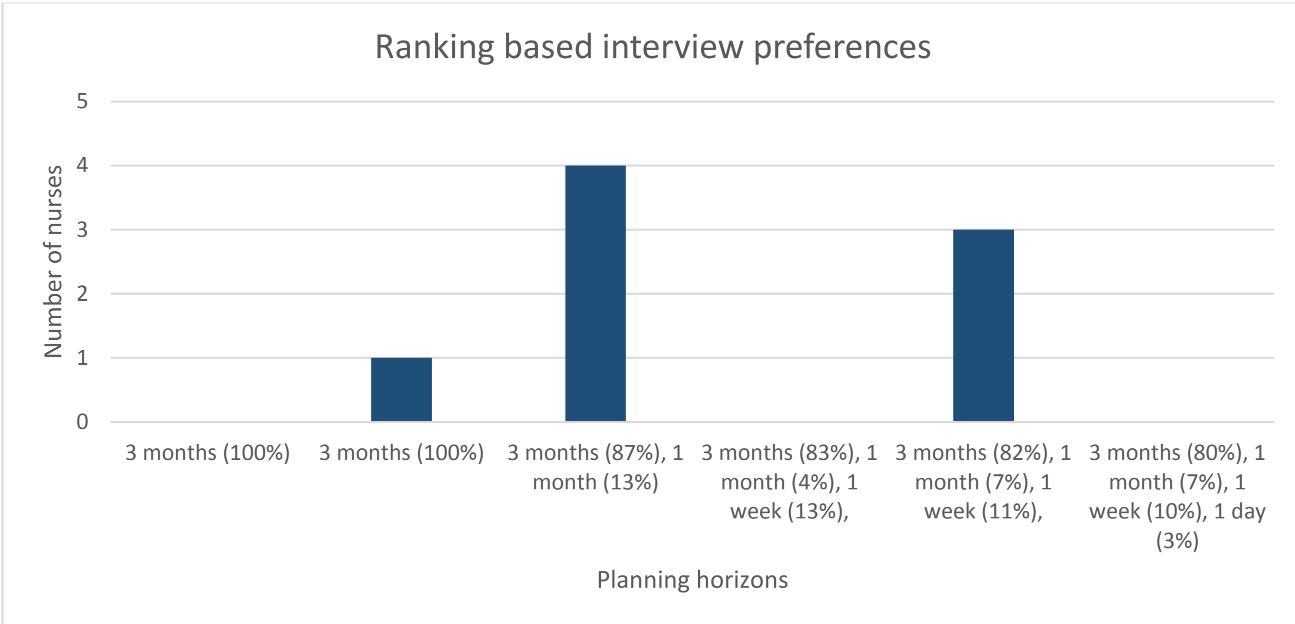

Figure 18: Ranking based interview preferences of nurses

7. Conclusions

This Chapter consists of the conclusions that are drawn on the research conducted. At first a recap is done on the current situation and the research question. Thereafter the conclusions on the mathematical model, simulation model and questionnaire will be stated which will be used to answer the stated research question.

7.1 Current situation and research question formulation

In order to get a better understanding of the current situation, the following three processes are analyzed: current patient arrival process, nurse planning process, and flex-department process. From these, several conclusions are drawn.

First, the patient arrival process shows a stochastic behavior throughout time. This also applies for the nurse availability caused by, for instance, illnesses or holidays. The lack of attention paid to these fluctuations in both patients arrivals and nurse availability often causes a mismatch between patient demand and nurse capacity, resulting in large workload fluctuations. Second, with regards to the nurse planning process, results show that the planning process of departments is very static and non-standardized over the different departments. This makes the nurse planning process not flexible and causes fluctuations in output quality of the schedules produced by the different departments. Finally, the Flex-department (which helps departments that are in need of nurse personnel), is not optimally aligned with the departments. This is mainly caused by the non-matching pattern of nurse requests originating from regular departments and the nurse scheduling process in the flex-department. This can be explained by observing the nurse request pattern over time, which reveals two peak moments: one located 1-6 days prior to a shift and a second peak located around 28-37 days prior to a shift. The actual scheduling of all nurses in the flex-department is done one month in advance.

The problems that arise from each of these three processes will eventually lead to dissatisfaction of the nurses: during peak moments the workload will be too high, thereby increasing the burden experienced by nurses. During decreased workload the nurses are recovering from the periods of increased workload, and therefore hardly perceive the decreased workload as relaxing. Therefore this research started with the following research question:

'How to optimize flexibility and more equally divide workforce within the nurse rostering process of the inpatients clinics within the Elkerliek hospital?'

The research design consists of 3 different elements, which combined will answer the research question. Since the flexibility creation and the workforce division is done at strategic and tactical nurse planning, the elements to answer the research question focus on the strategic and the tactical nurse planning.

7.2 Mathematical model

The mathematical model is developed based on the probability distribution of the patient arrivals, LOS and the Newsboy equation and is used to estimate the amount of annualized nursing hours needed per department. The annualized nursing hours needed per department are used as input for the simulation model, the second element of the research. Furthermore, explores the mathematical model the flexibility strategy of cross-nursing. To do so, four clusters containing several combinations of departments are set up. From the mathematical model it is concluded that shared planning of the nurses based on the patient demand and LOS results in a smaller difference between the upper and lower bound, and suggests less fluctuations. Therefore cross-nursing decreases the amount of nurses needed to cover the occupancy rate and results in smaller fluctuations in nurse planning of the Elkerliek.

7.3 Simulation Model

The simulation model, simulates the patient flow and nurse assignment to shifts in the hospital for 5 years. The simulation consists of two elements, the patient arrival process and the nurse assignment process. The nurses assignment is done based on a new planning design that is developed. Using the results several conclusions can be drawn on the new planning design. To start with the conclusions per phase and thereafter conclusions regarding the planning design.

7.3.1 Phases of design

In phase 1, nurses are planned to cover 40% of sufficient occupancy rate, meaning that in 40% of all shifts sufficient capacity is available. With the use of the mathematical model the 40% nurse occupancy rate is determined. Based on the results in phase 1 it is concluded that the overcapacity as well as the under capacity is still high.

In phase 2 of the design, nurses are planned according to seasonality of patient specialisms per department throughout the year. It is concluded that a decrease in under capacity in several departments is expected. Especially in departments 1B, 1C and 3B a decrease in under capacity is seen of respectively 4%, 5% and 7%. This is in line with the patient specialisms that are significant to seasonality, specialisms that are significant to seasonality are mostly treated at these departments.

In phase 3 of the design, nurses are planned based on the OT-schedule of patients. It is concluded that including the OT-schedule in the planning design of nurses especially has effect on the under capacity in the departments that have a substantial percentages of elective patients. Departments 2B, 2C and 2D (short stay and daycare) contain large percentages in elective patients, which cause a reduction in under capacity for respectively 21%, 13% and 35%. Also a large decrease in relative under capacity is measured in this phase for these departments.

In phase 4, departments are combined based on 3 different clusters. Cluster 1 (1B, 1B) and cluster 3 (3A, 3B, 3C, 3D, 4 Alg) show substantial decrease in the under capacity and relative under capacity. At 4Alg for example a decrease in under capacity can be seen of 41% while in 3A and 3B respectively a decrease of 36% and 32% can be reviewed. At these 2 clusters, the relative under capacity also substantially decreases.

In phase 5 and 6, 2 nurse pools are set up to compensate for the decreased nurse availability caused by long and short term illness of nurses. The results show that both phases cause a decrease in under capacity occurrences and relative under capacity. Especially with the adding of nurses in phase 6 large decrease in the under capacity in the departments is expected.

Lastly it is reviewed if the new planning design changes the overcapacity and relative overcapacity. As expected, it is concluded that the overcapacity and relative overcapacity only changed for a small percentage since the focus is on the under capacity side of the workforce. This small change in overcapacity is caused by the decrease in personnel used during periods which suggest low seasonality demand.

7.3.2 Current situation versus new planning design: KPI's

In order evaluate the new planning design, the KPI outcomes of the new planning design are compared with the KPI outcomes of the current design. In the current situation one can see, that the percentage of overcapacity is very large while the under capacity is relatively small but still substantial. Comparing these results to the final results (phase 6) of the new planning design, it is concluded that both the under capacity and the overcapacity KPI's are improved in the new planning design (lower under capacity and lower overcapacity) for all the departments. Furthermore, the number of nursing hours used for the current planning compared to the number of nursing hours in the final design of the new planning design is decreased with 23%.

7.3.3 Current situation versus new planning design: planning horizon

The new planning design contains multiple planning horizons, while the old design contains 1 planning horizon. Phase 1 and Phase 2, are scheduled 3 months in advance. Phase 3 and phase 5 are scheduled 1 month in advance. Phase 4, is planned 1 week in advance and phase 6, is planned 1 day in advance. During the 4 different planning horizons: 3 months, 1 month, 1 week and 1 day before due date, respectively 80%, 7%, 10% and 3% of the nurses are planned. By planning with multiple horizons, flexibility is created for nurse planning. The results on the nurses planned per planning horizon are used as input for the ranking based questionnaire.

7.3.4 Redesign of flex-department

Based on the 2 peak moments in which departments request nurses at the flex department: 1 to 6 days prior to the shift, and 31 to 36 days prior to a shift, phase 5 and 6 of the new planning design are developed. The results of phase 5 and phase 6 show a substantial decrease in under capacity. Based on the result, the flex-department should be redesigned. After the redesign, the flex department has 2 pools, 1 pool to deal with last minute requests for illness, 1 pool deals with regular requests (long term illness). It is important to make a clear distinction between the two pools, if there won't be a clear distinction between these 2 pools, too much personnel is planned for the long term illness and a shortage in personnel is planned for short term illness.

7.4 Ranking based questionnaire

7.4.1 Motivation of nurses

In order to get relevant feedback for the new planning design a ranking-based-questionnaire is conducted (Table 11) which evaluates the 2 key elements of the planning design, workforce division and the planning horizons related to different phases. The questionnaire is conducted on the nurses that develop the nurse planning at the departments. In Chapter 5.4 it is already stated that the equal division of workforce is measured in terms of under capacity, more equal division of workforce results in smaller under capacity. Based on the results in 6.3 it is concluded that nurses seek to find a proper balance between the amount of under capacity in their work and the due dates of the planning horizons. The most preferred options are either option 3 (87% of the shifts is planned 3 months prior to a shift and 13% 1 month prior to a shift) with corresponding 42% under capacity and option 5 (83% of the shifts is planned 3 months prior to shift, 7% of the shifts is planned 1 month prior to shift and 10% is planned 1 week prior to the shift) with corresponding 19% under capacity.

To get more information, the nurses were asked to motivate their ranking on both elements of the questionnaire. For the under capacity element, nurses had in common that they all remembered the specific periods of under capacity. In these periods the nurses felt in a hurry, the sense of stress, dissatisfaction and felt exhausted. This suggests that under capacity resulting in work pressure is acting as hindrance demand. This is supported by the work of McVicar (2003) who identified work pressure as a major stressor. Also (Lepine et al., 2004) found that work pressure is more a hindrance than a challenge. The planners feelings on being exhausted are in line with the JDR-model which suggests that high workload, an element of job demands, result in increased feelings of exhaustion (Demerouti et al., 2000). Furthermore found Rowe et al. (2006) that increased workload results in increased stress levels, which eventually result in the decreased staff satisfaction, this is in line with the feelings of nurses. The periods of overcapacity, periods of decreased work pressure, were not perceived by nurses as relaxing. The nurses indicated that in these periods they were still recovering from the periods of high work pressure.

The second topic was regarding the different planning horizons of the 6 options in the ranking based interview. The nurses all described that a planning which is developed one day before the actual shift is not desirable since this will interfere in the nurses private life. Once the planning is developed one day in advance, the nurses are not able to, for example, make appointments with their friends or to pick up their children from school. The nurses state that the decrease in due dates of the planning horizon would result in dissatisfaction. Nurses also state that a very short due date would even consider them of quitting their job. This is in line with the work of Luk & Schaffer (2005) who found that many nurses nowadays need to combine work and family demands, which commonly results in work-home conflict and therefore an important antecedent of job and life effectiveness (Kossek, Pichler, Hammer, Bodner, & Hammer, 2011). According to Van Der Heijden et al. (2008), Work-Home Inference (Job demands) contributes to considerations to leave or exit behavior. Furthermore mentioned nurses that they felt a reduced amount of job control once the planning horizons had smaller amount of days to due date. The nurses described that reducing the amount of due days decreased the ability to swap shifts with other nurses. Demerouti et al. (2000) also describe that the lack of control/autonomy of work can provoke stress reactions which can lead to disengagement.

7.4.2 Practical notes for new planning design based on questionnaire

In 7.4.1 it is concluded that it would be best to mostly cover the short due date planning horizons of the new planning design by the flex-pools of the flex-department. In this way the nurses that choose to work at the flex-department also agree on the working conditions with short due dates. The other side of the equation is that the employees at the flex-departments are likely to work during weekdays since during weekend days hardly any shift requests are done. Most nurses that work at the flex-department, are younger and recently graduated. These nurses are more flexible and prefer to work at multiple department with several specialisms to gain experience in them.

Another note that was captured from the opinions of the planners is the urge to help colleague nurses out. The planners often referred to the annoying situation in which often the same nurses take over a colleagues shift when the colleague is not able to work, mostly last minute shifts (e.g. family reasons, illness). This sometimes leads to frustrations of the nurses that feel responsible to take over these shifts. This is in favor of the new system in which all nurses are responsible to take over last minute shifts for a small amount of weeks.

7.5 Research question

Based on the conclusions of the mathematical model, the simulation model and the ranking-based interview, the research question can be answered:

'How to optimize flexibility and more equally divide workforce within the nurse rostering process of the inpatients clinics within the Elkerliek hospital?'

The workload can be more equally divided by developing a new planning design which focuses on the reduction of under capacity and incorporating seasonality, OT-schedules, cross-nursing, long term illness and short term illness of nurses. To optimize the flexibility of the nurse rostering process, the new planning design should consist of multiple planning phases with different due dates, cross-nursing strategy, seasonality strategy and the setup of 2 pools in the flex-department. In the new planning design the trade-off between the decrease in workload and due dates of the planning should be kept in mind to create support from nurses for the design.

8. Discussion

This chapter will focus on the limitations of the research as well as possible future research directions.

8.1 Limitations of Research

There are several limitations regarding this research. The most important limitation/challenge yields that in order to be able to implement this research, the nurses have to be willing to adapt to the new planning design. In the development process of the new planning design, the willingness of nurses to adjust to the design was not taken into consideration. This willingness to change was examined with the use of the ranking-based questionnaire based on the result of the planning design conducted at the nurses. The conclusions already demonstrate that there is no uniform answer to the balance between the due dates of the planning horizons and the under capacity while it varies per nurse. Since there is no uniform opinion from nurses, the implementation process of the research will be more complex.

The second limitation is that the nurses that already work at the flex-department are not asked to fill in the questionnaire. It would be a good addition to question the flex department nurses about their willingness to change since a part of the research design incorporates the restructuring of the flex-department. Based on the fact that nurses at the flex-department already work with a more varying work schedule it is assumed that they are more likely to be willing to work with the new schedule, still it is essential to address the actual willingness of these nurses to change.

The third limitation is the assumption that is made in the new planning design which assumes that nurses are able to work varying number of hours throughout different weeks. In the current situation a substantial number of nurses also work varying number of hours per week, this is however only possible for nurses with a part time contract. Nurses that have a full-time contract are less flexible since an increase in their weekly working hours would suggest a 6 or 7 days working week. In the research conducted, the ratio of fulltime versus part time contracts in the Elkerliek is not incorporated for the development of the planning design. As a result it is assumed that either all the nurses in the planning design are able to work varying number of hours throughout different weeks and therefore have a part time contract, or a part of the nurses is willing to have even more flexible working hours (part-time contract) while others (full-time contract) work with the same flexibility as before the change to the new planning design.

Lastly does the simulation model not incorporate trend developments regarding patient arrivals and patient LOS at the Elkerliek hospital. To make the simulation more robust this could have been incorporated. Incorporating the expected patient arrivals trends is however is a very complex task which combines production appointments set at each department combined with the contracts the Elkerliek hospital has with insurance companies.

8.2 Future Research

There are several interesting future research directions. To start with the balance between due dates of the planning design and the workload of nurses, this is also an important limitation of the research and mentioned in the previous paragraph. As explained there is no uniform answer on balancing the due dates of the planning horizons and the under capacity. This varies depending on each nurse. Interesting future research suggestion would be to focus on the individual preferences of the nurses and divide them in two groups: nurses that are willing to adjust to the new planning design and the nurses that are not willing to adjust to the new planning design. The design could then be recalculated with the capacity constraint of the individual nurse preferences on willingness to change. It would be an interesting future research to see the results on the under capacity with this constraint. Using this approach all nurse preferences are taken into consideration.

In the current research project, the new planning design is focused on reduction of the under capacity side of workload. A possible interesting future direction would be to focus on the overcapacity side of workload. The main focus would be on the regulation of patient arrivals in the hospital. The regulation of patient arrivals is only possible for elective patients. Therefore the restructuring of OT-schedules or the admission procedure of elective patients can be an interesting topic to do further research on.

A third interesting future research direction would be if the planning design could also partly-applicable for specialization departments (departments with specialized nurses). These departments also have to deal with fluctuations in workload. It can already be stated that the planning design is only partly applicable since the exchange of personnel between departments (cross-nursing) is not possible. Furthermore does the flex-department only consists of non-specialization nurses that are not able to work at specialization departments. Therefore the size of the specialization flex pools in order to derive the same results regarding under capacity as in the new planning design would be an interesting future research direction.

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Appendixes

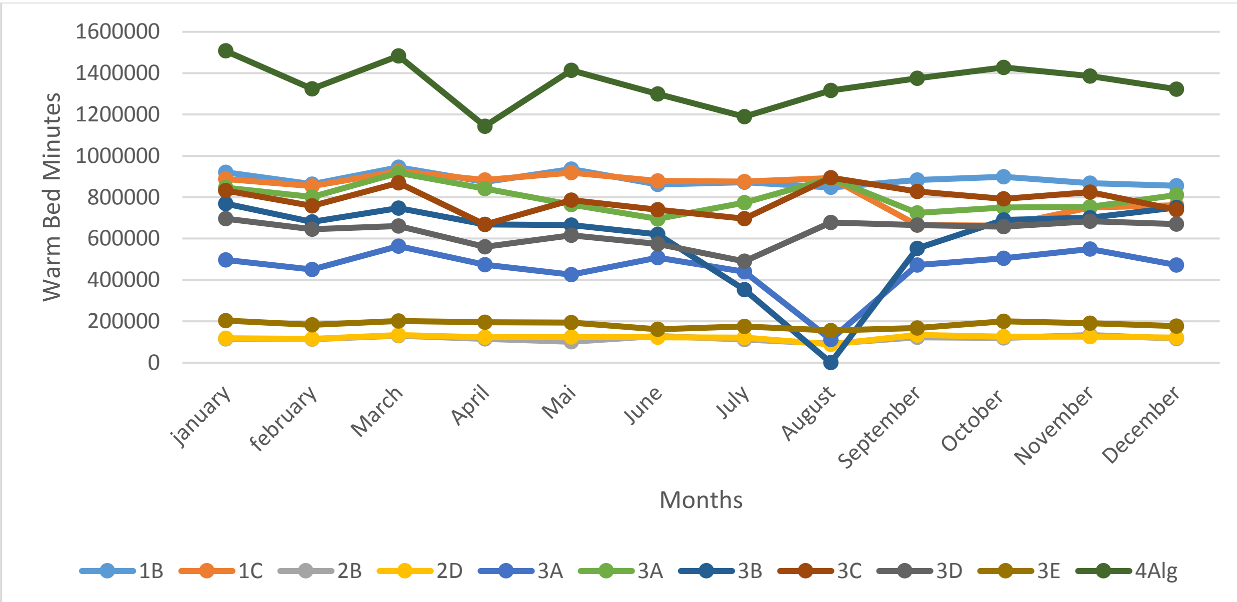


Figure 19: Fluctuations departments in warm bed minutes throughout the year

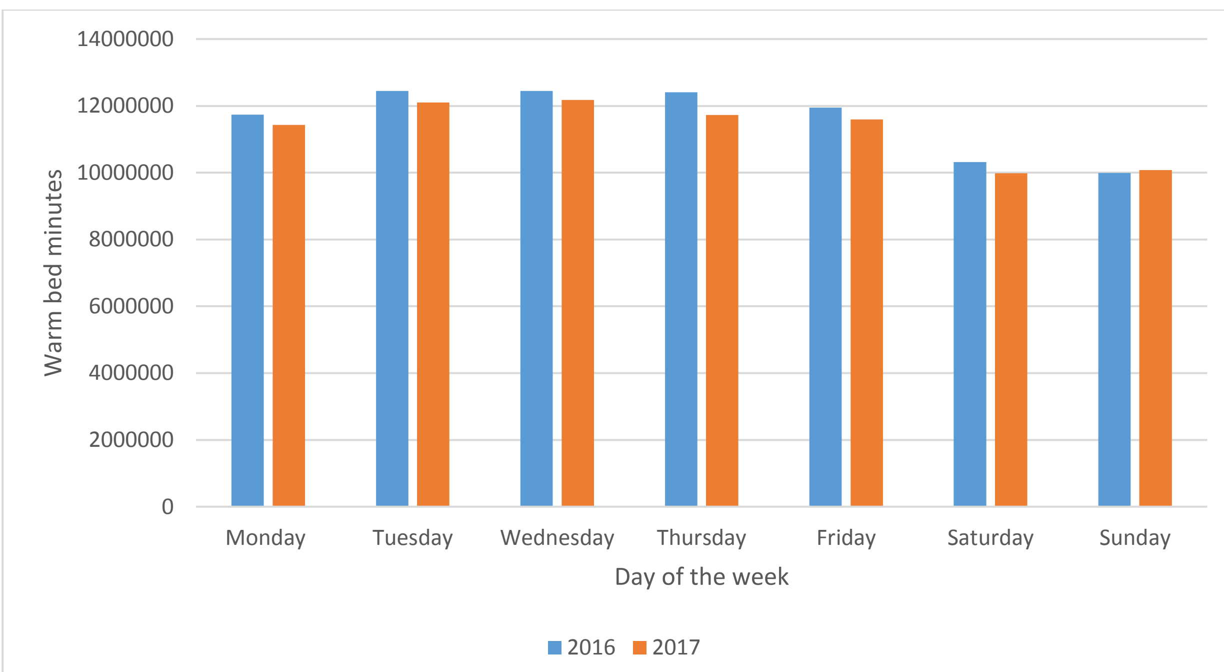


Figure 20: Patient minutes per day of the week

Table 22: Tactical planning decisions in departments

Department	Seasonality	Time in advance	Nurse-Patient ratio	Flex-bureau
1B	No	2 months	Yes	Yes
1C	No	2 months	Yes	Yes
2B	Partly	2 months	No	Yes
2C	Partly	2 months	No	Yes
2D	Partly	2 months	No	Yes partly
3B	Partly	3 months	Yes	No
3C	No	3 months	Yes	Yes partly
3D	No	3 months	Yes	Yes
4Alg	No	2 months	Yes	Yes
Flex	No	1 month	No	-

Table 23: Operational Planning decisions in departments

Department	Nurse preferences	Internal set rules based on CAO norms
1B	No maximum	No
1C	No maximum	No
2B	No maximum	Yes
2C	No maximum	Yes
2D	No maximum	No
3B	No maximum	No
3C	Maximum 6 days	No
3D	No maximum	No
4Alg	Maximum 7 days	No
Flex	-	No

Table 24: Consecutive days worked per department in percentages

Number of consecutive days	1B	1C	2B	2C	2D	3A	3B	3C	3D	4Alg
0	61.8%	60.0 %	50.0 %	57.6 %	56.3 %	60.3 %	59.8 %	58.3 %	55.8 %	60.2 %
1	36.1%	35.3 %	50.0 %	39.8 %	41.9 %	37.2 %	33.8 %	40.6 %	43.1 %	36.4 %
2	1.0%	2.3%	0.0%	1.6%	1.3%	1.0%	3.8%	0.3%	0.7%	1.5%
3	0.7%	0.4%	0.0%	0.8%	0.4%	0.7%	0.7%	0.2%	0.2%	1.0%
4	0.3%	0.2%	0.0%	0.2%	0.1%	0.4%	1.6%	0.1%	0.1%	0.5%
5	0.1%	0.1%	0.0%	0.0%	0.0%	0.3%	0.2%	0.5%	0.1%	0.2%
6	0.1%	1.7%	0.0%	0.0%	0.0%	0.2%	0.1%	0.0%	0.0%	0.1%
7	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.0%	0.0%	0.1%
8	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
9	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

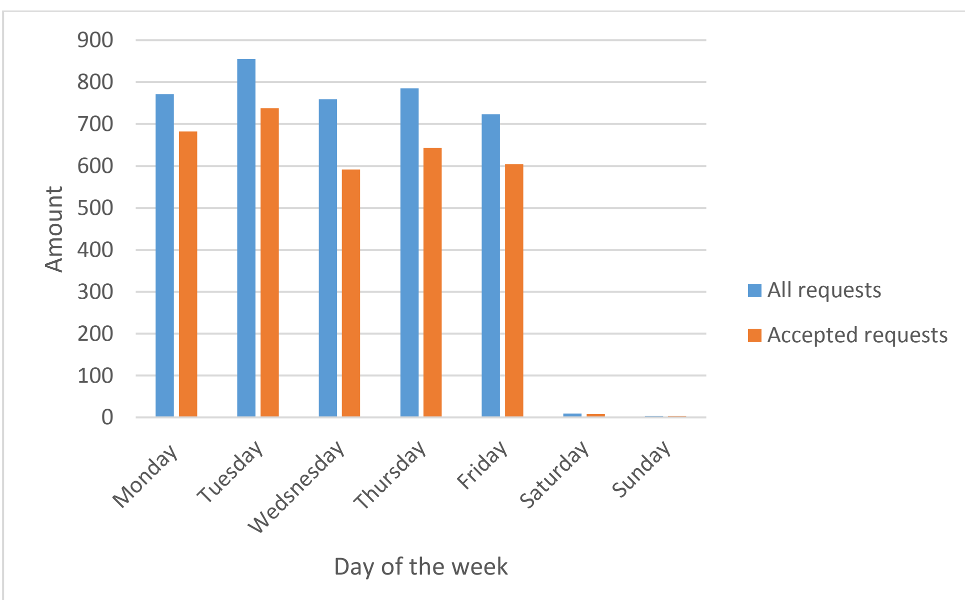
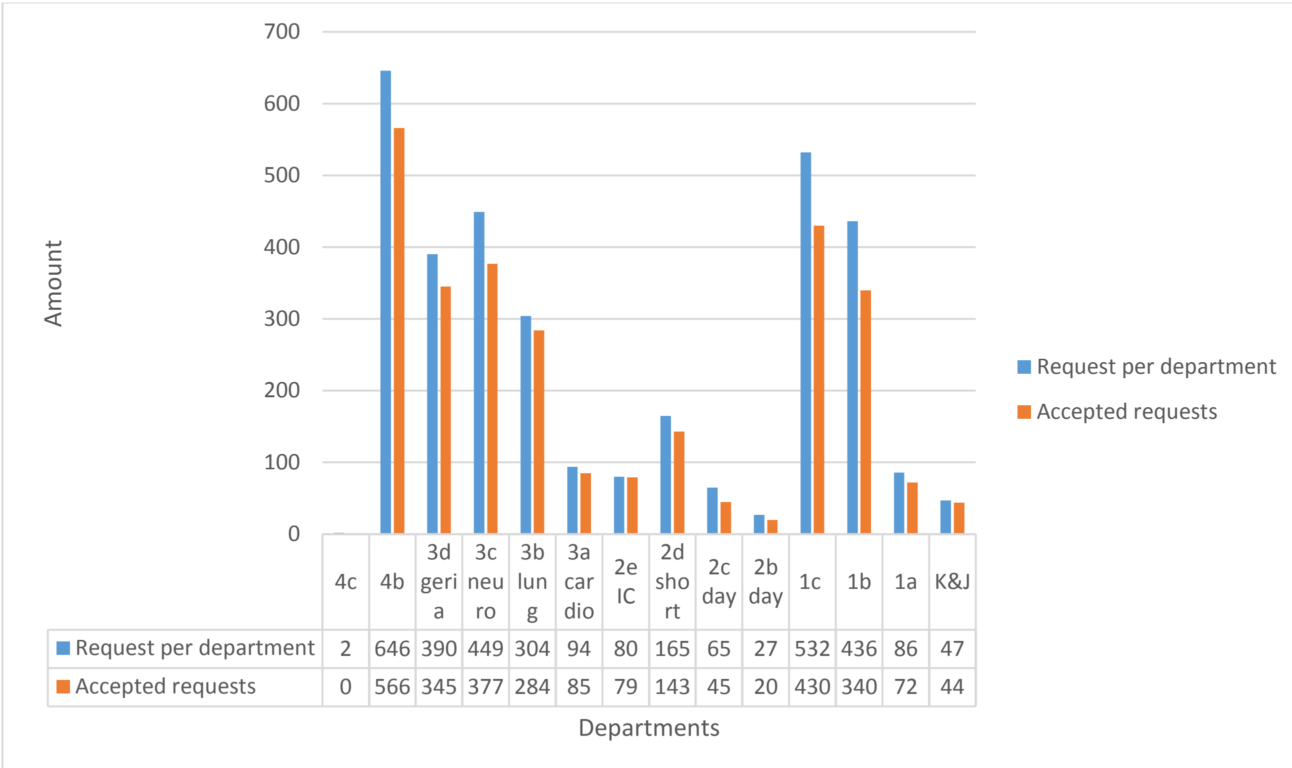


Figure 2: Days of the requests



	4c	4b	3d geria	3c neuro	3b lung	3a cardio	2e IC	2d short	2c day	2b day	1c	1b	1a	K&J
Request per department	2	646	390	449	304	94	80	165	65	27	532	436	86	47
Accepted requests	0	566	345	377	284	85	79	143	45	20	430	340	72	44

Figure 3: Accepted requests versus total requests flex departments

Table 25: Averages and standard deviation per patient type

		Regular Department	Regular Department	Daycare	Daycare	Short stay	Short stay
Specialism	**Acute /elective**	**Average**	**Standard deviation**	**Average**	**Standard deviation**	**Average**	**Standard deviation**
ANE	Elective	<0.05		2.390177	4.922927	<0.05	
ANE	Acute	<0.05		<0.05		<0.05	
CAR	Elective	1.00684	1.054575	1.091405	1.22105	<0.05	
CAR	Acute	12.17921	4.293526	<0.05		<0.05	
CHI	Elective	1.908345	1.695274	3.291951	3.033583	0.994543	1.239404
CHI	Acute	3.432285	2.043775	0.055935	0.252428	0.158254	0.4608
DER	Elective	<0.05		0.327422	0.580984	<0.05	
DER	Acute	<0.05		<0.05		<0.05	
GER	Elective	0.29959	0.537754	<0.05		<0.05	
GER	Acute	0.939808	1.080452	<0.05		<0.05	
GYN	Elective	0.067031	0.295232	1.383356	1.835409	0.357435	0.804449
GYN	Acute	<0.05		NONE		<0.05	
ICA	Elective	<0.05		<0.05		<0.05	
ICA	Acute	<0.05		<0.05		<0.05	
INT	Elective	0.692202	0.938423	2.278308	2.07408	<0.05	
INT	Acute	2.941176	1.828663	<0.05		<0.05	
KAA	Elective	0.057456	0.280675	0.282401	0.804611	0.366985	1.040963
KAA	Acute	<0.05		<0.05		<0.05	0.063844
KNO	Elective	0.094391	0.331821	1.525239	2.012506	0.930423	1.265262
KNO	Acute	<0.05		<0.05		<0.05	
LON	Elective	0.534884	0.838424	1.450205	1.55457	0.159618	0.377261
LON	Acute	2.771546	1.794065	0.053206	0.230442	<0.05	
MDL	Elective	0.300958	0.623074	1.574352	1.887417	<0.05	
MDL	Acute	0.902873	0.982824	<0.05		<0.05	
NCH	Elective	<0.05		<0.05		<0.05	
NCH	Acute	<0.05		<0.05		<0.05	
NEU	Elective	0.377565	0.703511	1.144611	1.358451	0.338336	0.864719
NEU	Acute	2.663475	1.586199	<0.05		<0.05	
OOG	Elective	0.071135	0.301163	7.597544	7.455212	0.171896	0.514909
OOG	Acute	<0.05		<0.05		<0.05	
ORT	Elective	0.329685	0.821684	1.237381	1.43561	2.193724	2.208903
ORT	Acute	0.69357	0.962611	<0.05		<0.05	
PLA	Elective	0.065663	0.258503	0.899045	1.568156	0.257844	0.611695
PLA	Acute	<0.05		<0.05		<0.05	
REU	Elective	<0.05		1.40382	1.777712	<0.05	
REU	Acute	<0.05		<0.05		<0.05	
TND	Elective	<0.05		<0.05		<0.05	

TND	Acute	<0.05		<0.05		<0.05	
URO	Elective	0.30643	0.656817	0.763984	1.236203	0.851296	1.525943
URO	Acute	0.504788	0.729234	<0.05	0.052164	<0.05	

Table 26: Statistical distributions per patient type

		Regular	Day care	Short stay
ANE	Elective		Poisson	Poisson
ANE	Acute			
CAR	Elective	Normal	Empirical	Empirical
CAR	Acute	Normal		
CHI	Elective	Normal	Empirical	Empirical
CHI	Acute	Normal	Normal	Normal
DER	Elective		Poisson	Poisson
DER	Acute			
GER	Elective	Poisson		
GER	Acute	Normal		
GYN	Elective	Normal	Empirical	Empirical
GYN	Acute			
ICA	Elective			
ICA	Acute			
INT	Elective	Empirical	Normal	Empirical
INT	Acute	Empirical		
KAA	Elective	Normal	Normal	Normal
KAA	Acute			
KNO	Elective	Normal	Poisson	Poisson
KNO	Acute			
LON	Elective	Normal	Normal	Normal
LON	Acute	Empirical	Normal	NONE
MDL	Elective	Empirical	Empirical	Empirical
MDL	Acute	Empirical		
NCH	Elective			
NCH	Acute			
NEU	Elective	Normal	Poisson	Poisson
NEU	Acute	Normal		
OOG	Elective	Normal	Normal	Normal
OOG	Acute			
ORT	Elective	Normal	Empirical	Empirical
ORT	Acute	Normal		
PLA	Elective	Normal	Empirical	Empirical
PLA	Acute			
REU	Elective		Normal	Normal
REU	Acute			
TND	Elective			
TND	Acute			

URO	Elective	Empirical	Empirical	Empirical
URO	Acute	Empirical		

Table 27: Seasonality factors per specialism per cluster

Specialism	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
CAR	1.03	1.03	1.03	0.83	1.03	1.03
CHI	1.07	1.34	0.95	0.95	0.95	0.95
DER	1.00	1.00	1.00	1.00	1.00	1.00
GER	1.03	1.03	1.03	0.85	1.03	1.03
GYN	1.00	1.00	1.00	1.00	1.00	1.00
ICA	1.00	1.00	1.00	1.00	1.00	1.00
INT	1.00	1.00	1.00	1.00	1.00	1.00
KAA	1.00	1.00	1.00	1.00	1.00	1.00
KNO	1.00	1.00	1.00	1.00	1.00	1.00
LON	1.38	1.18	0.91	0.71	0.91	0.91
MDL	1.13	0.93	0.93	0.93	0.93	1.15
NEU	1.00	1.00	1.00	1.00	1.00	1.00
OOG	1.00	1.00	1.00	1.00	1.00	1.00
ORT	1.00	1.00	1.00	1.00	1.00	1.00
PLA	1.00	1.00	1.00	1.00	1.00	1.00
REU	1.00	1.00	1.00	1.00	1.00	1.00
URO	1.00	1.00	1.00	1.00	1.00	1.00
ANE	1.00	1.00	1.00	1.00	1.00	1.00
RCR	1.00	1.00	1.00	1.00	1.00	1.00
RIR	1.00	1.00	1.00	1.00	1.00	1.00

Table 28: Percentage of Elective patients per department

Department	Elective (%)
1B	35%
1C	38%
2B	99%
2C	99%
2D	97%
3A	22%
3B	15%
3C	15%
3D	29%
3E	5%
4Alg	16%

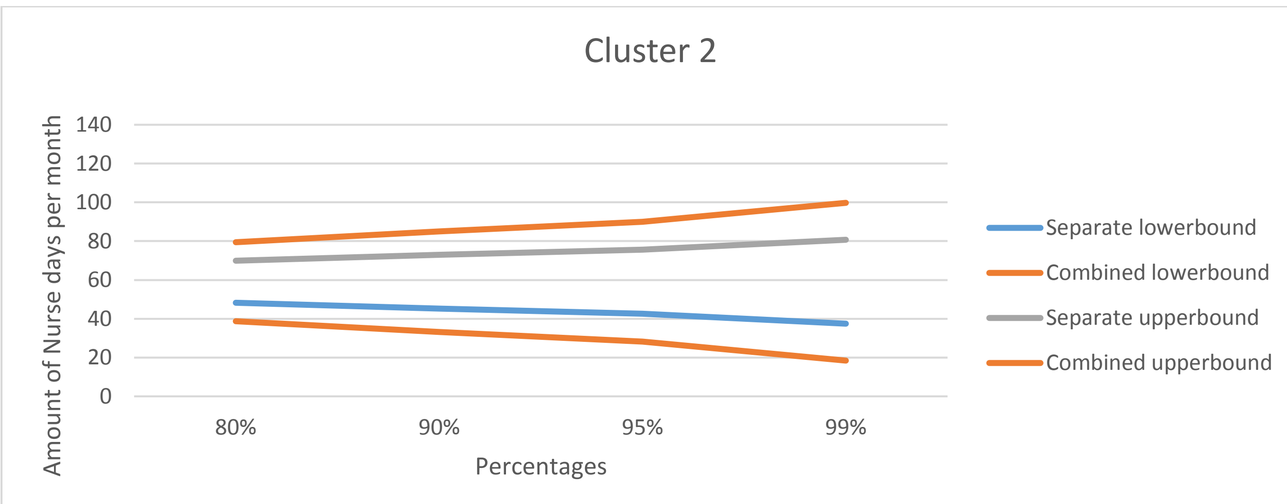


Figure 4: Cluster 2 mathematical model: sketching confidence intervals for amount of nurse days

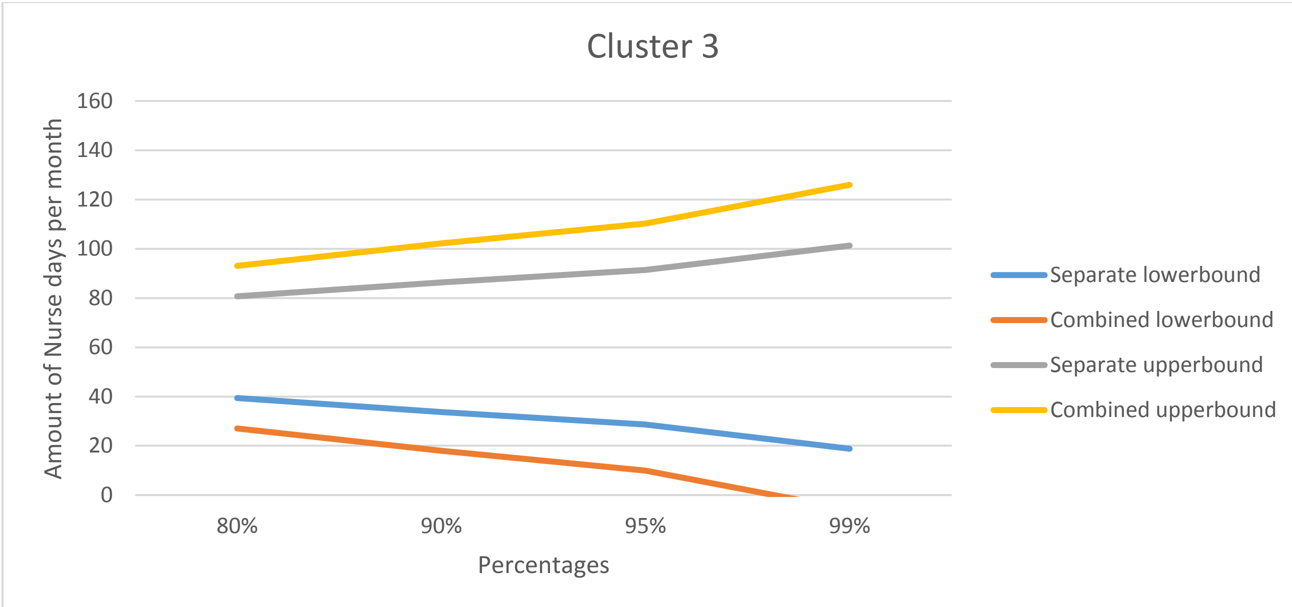


Figure 5: Cluster 3 mathematical model: sketching confidence intervals for amount of nurse days

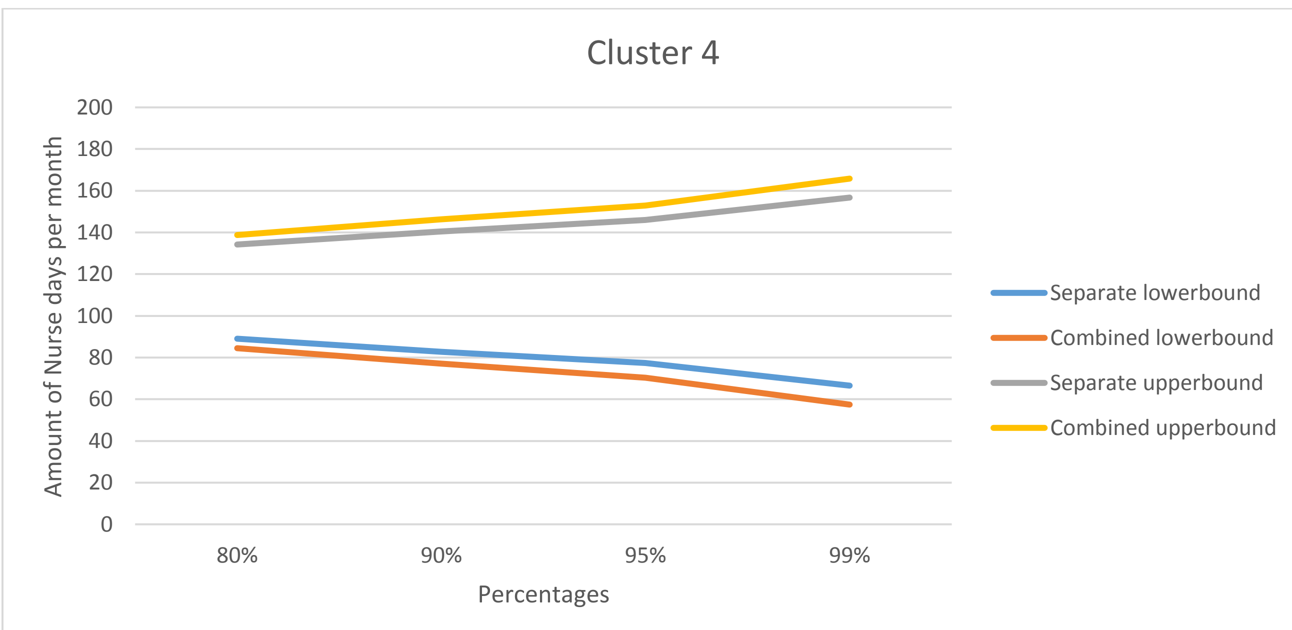


Figure 6: Cluster 4 mathematical model: sketching confidence intervals for amount of nurse days

Table 29: Maximum bed capacity departments

Department	Maximum capacity
1B	20
1C	20
2B	20
2C	20
2D	23
3A	23
3B	19
3C	14
3D	16
3E	12
4Alg	32

Table 30: Ranking based questionnaire example

Ranking	Under capacity (%)	Percentages planned
	53%	3 months (100%)
	51%	3 months (100%)
	42%	3 months (87%), 1 month (13%)
	20%	3 months (83%), 1 month (4%), 1 week (13%),
	19%	3 months (82%), 1 month (7%), 1 week (11%),
	6%	3 months (80%), 1 month (7%), 1 week (10%), 1 day (3%)