MASTER

Integrated fixed scheduling strategy to allocate users to resources and timeslots application on outpatient clinics within a hospital

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Award date:
2015

Link to publication
Integrated Fixed Scheduling Strategy to Allocate Users to Resources and Timeslots: Application on Outpatient Clinics within a Hospital

by

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in partial fulfilment of the requirements for the degree of

Master of Science
in Operations Management and Logistics

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Subject headings: scheduling strategy, capacity management, hospital planning, allocation problems
Preface

This report is written for the fulfilment of my graduation project of the master Operations Management & Logistics at University of Technology Eindhoven (TU/e). I greatly appreciate that Servicebedrijf Pantein and Maasziekenhuis Pantein gave me the opportunity to conduct a research within their organization. Since February 2014, I have been working on this research project. I enjoyed working with the experts who have helped me with bringing this project to a success. I would like to thank several people for their help and support during the project.

In the first place I would like to thank Henny van Ooijen for being my mentor and first supervisor of the TU/e. You provided me insights which helped me greatly during the project. Moreover, I really appreciate the frequent meetings we had which provided me structure. In addition I would like to thank Nico Dellaert for being my second supervisor of the TU/e. You provided me valuable ideas which opened up new directions.

In the second place I would like to thank Astrid Wolters and Henk Willems from Servicebedrijf Pantein. Both of you provided help and support anytime I needed it. Astrid Wolters, you gave me an interesting look behind the scenes within Pantein and provided me with useful tips for conducting a research within Pantein. Henk Willems, your endless suggestions and insights inspired me many times. I really enjoyed my time at Servicebedrijf Pantein. Furthermore from Maasziekenhuis Pantein I would like to thank Margot van Haren, Marco van Reenen, Hetty Lentjes-Wolters, Jacqueline Filippini and Marianne van de Burght. The pleasant cooperation helped me enormously with creating this result.

Finally, I want to thank my family for their support. Besides during the project, the entire time when I was a student you believed in me and were confident in a successful ending. This motivated me a lot. Furthermore I want to thank my friends for the good times we had at the university working on our projects. And last but not least I want to thank my girlfriend Marloes for being there for me and always were willing to listen if necessary.
II Abstract

Limited literature is available about planning and scheduling of consult rooms in the outpatient clinics. Hospital management of MZH indicates that relatively a large share of rooms in the outpatient clinics are often unoccupied, while signals from departments of outpatient clinics indicate that there is shortage of rooms. In other words there are strong signs that rooms in the outpatient clinics can be better utilized by a more efficient and effective planning. This study proposes a general model to allocate users to timeslots and resources which can be used for deriving an integrated baseline schedule considering multiple departments and multiple locations. The objectives of the model are to satisfy timeslot preferences of users, to satisfy resource preferences of users by allocating users from similar departments to resources of similar clusters and defragment remaining available resources as much as possible. The designed performance indicators are timeslot preference violations, resource preference violations and defragmentation. In the case study the model was applied on the outpatient clinics of Maasziekenhuis Pantein in Boxmeer. Three scenarios were considered. The first scenario considers current demand of sessions, the second scenario considers forecasted demand of sessions and the third scenario considers forecasted demand of sessions if 4-hour sessions would be used. The results of the three scenarios show that rescheduling provides solutions where more sessions will be performed in rooms of the location where the reception of the department is positioned, while current timeslots of sessions can be maintained and where less rooms will be required. However, a trade-off has to be made between resource preference violations, timeslot preference violations and defragmentation, since these three cannot be optimized simultaneously.
III Management Summary
In 2006 the Dutch government introduced the free market into healthcare. The increasing amount of elderly people in the Netherlands contributes to expanding costs of the healthcare system (van der Horst, van Erp, & de Jong, 2011). These two developments result in, that since the introduction of the free market increasing pressure is put on the health care system by health insurances companies and the government. Consequently health care providers have to optimize work processes in their organization in order to survive financially.

Problems overview
Efficient use of space in the area dedicated to the outpatient clinics of hospitals is a common topic of hospital management. Some departments of the outpatient clinics (e.g. neurology, geriatrics, internal medicine and pulmonary diseases) use only standardized rooms with fixed dimensions. The rooms of those departments in the outpatient clinics are flexible and can be used by specialists of different departments. Therefore, a change in the allocation of rooms to departments can be made without having high conversion costs to the physical layout of the outpatient clinics. The rooms are facilitating the consult process and therefore it is of concern that enough rooms are available to support an effective and efficient consult process. Demand for consults and thereby demand for rooms of departments within the outpatient clinics is dynamic because of hospital business strategy, demographic changes and government requirements. The growth and decline of departments resulted in an unbalanced distribution of room capacity over the departments in MZH. An unbalanced distribution of rooms effects the efficiency of work processes. Lack of available facilitating rooms, movement inefficiencies of medical staff and ineffective communication between reception and medical staff are caused by inefficient planning of rooms in the outpatient clinics.

Literature shows that very little is known about planning of rooms in the outpatient clinics which include multiple departments and multiple locations. The closest topic to the planning of rooms in the outpatient clinics is probably represented by the college timetabling problem. In the college timetabling problem, the allocation of teachers to college rooms and timeslots with respect to certain constraints is considered in order to minimize the number of college rooms required. However, in solving the college timetabling problem no distinction between departments and locations is considered. For this reason research is needed for developing a scheduling strategy to efficiently distribute room capacity over the departments within the outpatient clinics in order to reduce work inefficiencies, reduce the amount of rooms required, while having a minimum impact on the current way of working. The research question is formulated as followed.

*How can a decision tool be developed to assist managers to allocate users to rooms and timeslots in order to make efficient use of room capacity and stimulate efficient work processes while having a minimum change in the current way of working?*

In addition to the research question a research assignment is stated. The research question and research assignment are strongly related. The research assignment is generalized and formulated in a way that it
can be applied for more alternative problem formulations. The research assignment is formulated as followed.

*Develop a tool to allocate users to resources and timeslots in order to utilize resources efficiently and maximize resource preferences and timeslot preferences of users*

**Detailed analysis**

The detailed analysis was focused on the departments neurology, geriatrics, internal medicine and pulmonary diseases of the outpatient clinics of MZH. First a data analysis was performed on the room utilization of the current scheduling strategy. Secondly the requirements for scheduling rooms in the outpatient clinics were identified to explore how a model can be developed to allocate users to rooms and timeslots. In the current scheduling strategy a fixed number of rooms are allocated to every department. For every department a fixed baseline schedule is developed based on the number of rooms allocated to the department. This baseline schedule is repeated every week. In the operational planning many of the scheduled sessions in the baseline schedule are cancelled due to holidays, congress, absence by illness or because of other dominant tasks in the agenda of the specialist. Hence, many rooms are unoccupied in the operational planning compared to the baseline schedule. Due to unexpected emergency consults, a variable number of rooms is required for performing emergency consults. Emergency consults often have short durations and therefore it would be interesting to use one similar room for handling emergency consults of multiple departments.

The data analysis focused on room demand distribution, long term trends (between years), seasonal trends (between weeks) and timeslot trends (within the week). The maximum number of available rooms was 16. In none of the analysed timeslots the maximum room capacity was reached or exceeded, only in 0.4% of the timeslots 15 rooms were simultaneously used and in 1.2% of the timeslots 14 rooms were simultaneously used. In 66% of the timeslots, between 8 and 12 rooms were used simultaneously. This means that room capacity should have been sufficient to satisfy all demand in the analysed period. Since 2008 room demand of the department of geriatrics was growing, while room demand of the department of internal medicine was declining. Furthermore the data analysis showed that school holidays have a small impact on the average number of rooms used simultaneously. During the school holidays specialists often take some days off and rooms stay unutilized during this period. There were no large differences of rooms used simultaneously between timeslots within the week. On average the lowest utilization of rooms was reached on Friday afternoon.

**Conceptual and mathematical model**

A generalized conceptual and mathematical model was developed to allocate users to resources and timeslots in order to maximize timeslot preferences, resource preferences and defragmentation of remaining available resources. The specific timeslot preferences per user are predefined. The resource preferences are defined by the allocation of departments to clusters. When a department is allocated to a cluster, all the users of the department will have resource preferences for all the resources of the cluster. In this way the allocation of departments to clusters determines the specific resource preferences of users.
Three performance indicators were designed on which the solution is evaluated. These three performance indicators are timeslot preference violations, resource preference violations and defragmentation. Users are allocated as much as possible to specific preferred timeslots. However, if this is not possible and the user has to be allocated to another timeslot than the preferred timeslot of the user, this will be count as a timeslot preference violation. Resource preferences of users are satisfied when users from similar departments are assigned to resources of similar cluster. In case the user is not allocated to a resource of the right cluster, this will be count as a resource preference violation.

Defragmentation is defined by the percentage of resources which are available on all timeslots and allocated to one similar cluster.

Case study
An integrated baseline schedule considering multiple departments and multiple locations can be derived from the allocation method of the general conceptual and mathematical model. In the model resources are referred to rooms, users are referred to specialists and timeslots are referred to day parts (Monday morning, Monday afternoon, Tuesday morning, etc.). Sessions performed by specialists are returning every week in the integrated baseline schedule on fixed timeslots and in fixed rooms. Users from similar departments are assigned to rooms of similar locations as much as possible. Clear distinctions in locations with each having a reception and multiple rooms were identified. Specialists have sessions as much as possible in rooms on the location where the reception of the department is positioned. This was due to two reasons. First, performing sessions in rooms close to the reception of the department stimulates effective and efficient communication between specialists and the reception. Secondly, a distinction between “work area” and “patient area” is desired. Timeslot preferences of specialists are based on the original timeslots of sessions. Sessions are currently planned for more than a year ahead. When you change the timeslot of a session, all the consults in the planned sessions have to be rescheduled. Therefore a minimal change in current timeslots of sessions is desired. The specialist can rely on that every week a similar room is available for the planned session. Specialists have various other tasks in their portfolio. Thus for specialists it is very difficult to move sessions to another timeslot and thus fixed timeslots of sessions is desired. Remaining available rooms are defragmented as much as possible. When not all room capacity is required, the remaining available rooms are assigned to one single location and are available on all timeslots. The rooms, available on all timeslots and located on one similar location, can be used for other purposes. A model was built in Excel 2010 for solving the problem defined in the case study. An attempt was made to solve the problem by the integrated solver tool of Excel. It appeared that the problem was too complex for solving it with the solver tool. Subsequently an add-in of CPLEX was used. The CPLEX add-in was successful in finding a feasible solution.

Results
In the current situation 163 sessions were scheduled for 29 users of the 4 departments geriatrics, neurology, internal medicine and pulmonary diseases in 21 rooms of 3 locations A, B and C. For 46 of 163 planned sessions the current baseline schedules did not provide an appropriate room. This means that the session was not performed in a room on the location where the reception of the department of the user was positioned. In other words 28,2% of the resource preferences were violated. In addition, at
least one timeslot of all rooms was used for performing sessions and thus all rooms were needed what means that 0,0 % defragmentation occurred. However, because the original baseline schedules were used, all the existing preferences for timeslots of sessions were maintained and thus 0,0% timeslot preferences were violated.

After rescheduling all the users are allocated to a room of the location where the reception of the department is positioned (0,0% resource preference violations). In this way all the sessions of users from a similar department are performed in rooms near to each other and near to the reception of the department. This stimulates the communication between the medical staff and between the medical staff and the reception. Movement outside the corridor is also minimized, because most movement of medical staff occur between the rooms where the sessions are performed and the reception of the department. In addition 4 adjacent rooms on one location are completely available after rescheduling and thus the 4 rooms can be used for a different purpose (19,0% defragmentation). For example the 4 rooms can be rent out to an external party or used by another department of the outpatient clinics. However, in the solution 7 sessions have to be scheduled on different timeslots than the original timeslots of the sessions (4,3% timeslot preference violations).

**Conclusion and recommendations**

In this study a supportive decision tool is developed which assists managers to allocate users to rooms and timeslots in order make efficient use of room capacity and stimulate work processes while having a minimum impact on the current way of working. Work processes are stimulated by scheduling sessions in rooms near to associating receptions. This reduces movement of specialists and encourages communication between specialists and receptions. Only small changes have to be made in the current way of working because the current timeslots of sessions are maintained as much as possible.

The results show that integrated scheduling provides remarkably better results. The timeslots of sessions can be maintained fully and the number of resource preference violations can be reduced from 28,2% to 0%. The demand of sessions in the outpatient clinics is dynamic and the model only considers the demand of sessions which are known. The model itself cannot anticipate on the future. Therefore structurally reconsidering the integrated baseline schedule will be necessary in order to prevent shortage of facilitating rooms when demand of sessions changes.

In addition this study fulfilled the research assignment. The tool elaborated in Excel can be used to maximize timeslot and resource preferences of users and maximize defragmentation of remaining available resources. In order to use the tool Excel and IBM CPLEX optimization studio is required.

From literature little is known about scheduling rooms in outpatient clinics considering multiple departments and multiple locations. This study opens up an entire new area of research. Further research could be conducted on allocating users to similar rooms as much as possible. If users have their sessions consistently in the same room, this will increase the transparency of the integrated baseline schedule.
IV List of abbreviations
DBC Diagnose Behandeling Combinatie
ICT Information and Communication Technology
MZH Maasziekenhuis Pantein
SB Servicebedrijf Pantein
TU/e University of Technology Eindhoven

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1. Introduction
Efficient and effective management in healthcare is increasingly becoming more interesting for research. In 2006 the Dutch government introduced the free market into healthcare. The free market forced hospitals and other healthcare organizations to be financially responsible. Consequently, the processes and flows in healthcare facilities have to be made more efficient for healthcare facilities to survive. The Dutch government is focusing on centralization of hospitals (Wester, 2013). Hospitals will become larger in production capacity and the number of hospitals is decreasing. Multiple small hospitals are merging into large hospitals and thereby they are combining knowledge of medical specialism’s which will contribute to higher quality of healthcare. In 2008 the economic crisis started and is still continuing. The economic crisis has direct and indirect influence on almost every sector including healthcare. The Dutch government is still cutting costs on healthcare. For example admission of patients into care centers is extended as long as possible and patients are offered care at home instead to save costs. New regulations are introduced to increase the free market and encourage efficiency in healthcare. In response to these developments, we will study the room planning and scheduling of the outpatient clinics of Maasziekenhuis Pantein in this thesis.

In section 1.1 the company guiding the project, the commissioner and the relationship between the two are discussed. In section 1.2 an overview of problems is provided. And finally in section 1.3 the structure of the overall report will be shortly discussed.

1.1. Pantein
A distinction has to be made between the company guiding the project and the company commissioning the project. The structure of the organization of Pantein will be elaborated prior to the explanation of the distinction between the commissioner and the company guiding the project.

Pantein is a foundation and delivers diverse healthcare services, ranging from medical treatments in a hospital to helping patient at home. The goal of Pantein is to deliver effective and efficient patient-centered healthcare. The number 1928 is the number visualizing the goals of Pantein. The 1 represents the limitless healthcare Pantein provides. The clients experience complete and cohesive care provided by Pantein. Pantein pursues a 9+ for customer satisfaction. Currently customer satisfaction is an 8+. The 2 stands for the minimum 2% return on turnover, which needs to be achieved to perform a healthy financial management. And the 8 represents the objective to accomplish an 8 for employee satisfaction. Pantein is continuously pursuing improvement for a more efficient and effective management of processes and flows.
Figure 1 presents the organization chart of Pantein.

Pantein is a foundation and consists of Maasziekenhuis Pantein (MZH), Zorgcentra Pantein, Thuiszorg Pantein and Servicebedrijf Pantein (SB). Servicebedrijf Pantein emerged when Pantein decided to centralize and combine services of Maasziekenhuis Pantein, Zorgcentra Pantein and Thuiszorg Pantein.

Servicebedrijf Pantein (SB)
Servicebedrijf Pantein (SB) provides five categories of services to the internal customers (Maasziekenhuis Pantein, Zorgcentra Pantein and Thuiszorg Pantein) and the external customers (Huishoudelijke Hulp Pantein-Vivent, Kraamzorg Pantein – Vivent and Syntein). Syntein is a corporation of general practitioners and MZH. The five categories of services SB provides are:
• ICT
• Technical maintenance and logistics
• Business administration
• Facilitating service
• Meals and catering

Appendix 1 shows a more elaborated view of the services SB provides. The service categories are associated with units and each of the units have an own responsible manager. The unit managers are under supervision of the managing director. In addition the secretary and staff are under the supervision of the managing director. The staff includes consultants, strategic purchasers and project managers. The structure of the employees in relation to the organization is visualized in appendix 2.

Maasziekenhuis Pantein (MZH)
Maasziekenhuis Pantein (MZH) is a new-build hospital in Beugen. The construction of the new hospital started in 2009 and was opened officially on April 22 in 2011. The hospital is built on the health campus Sterckwijk. The health campus is created to combine and centralize healthcare, education and industry focused organizations. MZH has 220 beds and is thereby a relatively small hospital (Referentieproject Maasziekenhuis Pantein, 2012). The hospital is offering 22 specialisms (Maatschappelijk Verslag Stichting Pantein, 2012). Appendix 3 displays the list of specialisms provided by MZH.

Relationship between Maasziekenhuis and Servicebedrijf
The project will be executed under the guidance of SB. However, the subject of the project considers the optimization of the outpatient clinics of MZH, by improving scheduling of rooms in the outpatient clinics in MZH. This is when the relationship between SB and MZH has to be defined more clearly. SB offers services for a certain predetermined price to MZH. Besides that SB and MZH are officially different companies and market forces are certainly present between the companies, both of the companies are also colleagues and cannot operate without each other. SB is also responsible for certain services within MZH (e.g. front office management, technical maintenance, catering etc.). Real estate management is also covered by the services SB provides for MZH. Thus MZH and SB have shared responsibility about certain management within the hospital. Therefore, in this case SB is guiding the research project.

1.2. Problem overview
There are strong indications that a large amount of rooms of the outpatient clinics are not efficiently used in MZH (low utilization rates of rooms), while opportunities for departments willing to expand are blocked. In addition, the possibilities for potential new departments are limited, because the availability of rooms is scarce. Management of MZH is interested in a more efficient planning and scheduling of rooms in the outpatient clinics. This interest can be split into two main points. First, management wants more insight into what extent the capacity of rooms is used. It often appears that when rooms are randomly checked, rooms are not occupied. And secondly, management wants to know how to arrange and schedule those rooms in order to optimize the utilization rate of rooms.
Due to the aging of the population an increasing focus for attention on care for elderly people is developing. The consequence of this development for MZH is the introduction of the department of geriatrics into MZH. On the moment MZH was build, no space was reserved for positioning the department of geriatrics into the layout of the hospital. The department of geriatrics requires consult rooms for providing consults for patients. The solution was to use consult rooms of three already positioned departments in the outpatient clinics (neurology, internal medicine and pulmonary diseases). The three departments were positioned at three different corridors. In case of customer satisfaction, this solution was not desirable. The layout of the area dedicated to the outpatient clinics is built in a way that a clear distinction between departments is present. One reception for each department and a clear geographical distinction between departments is desirable for patients and medical staff to avoid confusion. By adding the department of geriatrics to three already existing departments, this desire is affected. Hospital management would like to take into account this aspect in addition to the efficiency of scheduling and planning of the consulting rooms in the outpatient clinics.

Currently different parties such as management, doctors and medical staff have conflicting interests. For example in the current situation, medical specialists have no benefit for using room capacity efficiently. However, this subject becomes more interesting due to an upcoming development in 2015. The government decided to introduce integrated financing in 2015. This implies that Dutch insurance companies only have to pay one sum for the combinations of diagnosis and treatment (DBC). Room capacity efficiency will not be solely a matter for hospital management anymore. Self-employed specialists and hospital management will have common goals to efficiently use resource capacity in hospitals to save costs. The new regulations will cause active participations of more stakeholders to facilitate collaboration of more efficient use of resources, such as space in the outpatient clinics. In other words, the new regulations will make it easier to make better use of capacity, because more stakeholders have interest in doing so.

1.3. Report outline

In this section the structure of the report will be briefly discussed. This first section provided information about the commissioner of the project, the company guiding the project and the observed problems of hospital management which led to the execution of this study. In section 2 the research project will be discussed. The summarized literature review will provide the gaps in literature, the research question will be given which defines the exact topic of the research and the scope will provide the demarcation of the project. In section 3 the detailed analysis will be described to identify the core of the problems and to explore opportunities for improvement. In section 4 a general conceptual and a mathematical model will be provided. In section 5 the model will be applied on the outpatient clinics of MZH in order to perform the case study. The conceptual and mathematical model will be used to derive an integrated fixed baseline schedule for the case study. Furthermore in this section the results of the performed case study will be discussed. In section 6 the steps for implementation will be described. And lastly, in section 7 the conclusion will be discussed with reflection to the research question and research assignment formulated in section 2. Furthermore recommendations for MZH and further research will be provided in this section.
2. Research project

In this section the research project is discussed. The research project will function as a framework to the study. First a summary will be provided of the literature review in section 2.1. In section 2.2 the scope is applied to demarcate the project and more accurately define the question asked by hospital management. Subsequently in section 2.3 the research question will be formulated. In section 2.4 the research assignment is derived from the research question and the scope. And finally in section 2.5 the research approach will be discussed. The research approach describes the steps which need to be taken to successfully provide an answer to the research question.

2.1. Literature review

The literature review has the objective to find gaps in literature considering the problem hospital management faces. What makes the problem the hospital faces unique that new research is needed to solve the problem? For a more extensive elaborated literature review, we refer to Lunenburg (2014).

Efficient use of space

Hospital management is interested in more efficient use of space in the outpatient clinics. Because consult rooms covers a large area of the outpatient clinics, more efficient use of space is therefore in this study defined as more efficient use of consult rooms. Efficient use of consult rooms can be defined by a higher utilization rate of consult rooms and a lower amount of consult rooms required. For that reason the literature review was focused on research regarding optimizing efficient use of space and the planning and scheduling of consult rooms in outpatient clinics of hospitals. The literature review starts with a wide focus on different hospital related problem formulations with the goal finding similar problem formulations regarding efficient planning and scheduling to achieve a higher utilization of rooms in the outpatient clinics. The focus on different hospital related research is due to the fact that specific search into planning and scheduling of consult rooms in outpatient clinics provided very limited results.

Operation room planning is a widely studied subject in healthcare facilities because operation rooms are an expensive asset in hospitals and has to be utilized as much as possible (Ronald & Shipperd, 2005). Efficient planning and scheduling of the operation room will lead to a higher rate of resource utilization. The operation room planning is a complex problem and requires to take into account various parameters. For that reason mathematical programming is the most common method for solving the problem. The operation rooms are shared by many different parties and the amount of rooms to be considered is limited. Those aspects make the operation room problem unique. The planning and scheduling of outpatient clinics considers multiple rooms and departments too. However, the planning and scheduling of the outpatient clinics have to consider other relations between rooms and departments. For example there is a preference for scheduling consults of medical staff from one specific department in rooms near to the reception of the department. The operation room planning problem is widely studied and the challenges appear to be located primarily in the implementation of the recommendations (Cardoen et al., 2008).
There are various studies to the effects of treatments to the hospital length stay, hospital re-admission and mortality. All those studies are related to hospital length of stay and discharge planning. The studies of discharge planning face sometimes comparable problems related to the planning and scheduling of consult rooms in hospitals. However the comparison is very limited and not usable for the planning and scheduling of consult rooms in outpatient clinics.

Considering facility layout planning, a wide variety of research is already existing and is still diverging (Singh & Sharma, 2006). The purpose of facility layout planning is to support effective and efficient processes and achieve efficient occupancy of space. Facility layout planning can be categorized in three different problem formulations: QAP, graph theoretic approach and MIP. If all locations have an equal rectangular shape and size, can be physically interchanged and have a limited number of n locations, the layout problem can be defined as a quadratic assignment problem (QAP) (Smith & Tate, A genetic approach to the quadratic assignment problem, 1995). The objective of the QAP is to minimize time, flows, cost or travelling distance in discrete layout formulation. Graph theoretic approach can be used despite of unequal areas. The approach optimizes the distribution of departments over a particular given area given the size and relation of the departments. The objective is to realize a set of relationships of departments which have a maximum desired adjacencies and a minimum undesired adjacencies. The MIP (Mixed Integer Problem) is an extension of the discrete QAP, where a distance based objective was used in a continuous layout formulation. The factory layout planning problem formulations are different from the layout planning problems service facilities face (Shrikrishna Padgaonkar, 2005). In service facilities the service is the product and the product cannot be stocked unlike in factories. Other additional aspects make the layout of service facilities completely different from factory layouts. Various studies already exist to solve initial layouts for service facilities and specifically hospitals by allocating functions to rooms or users to rooms. However, a study to find a solution for assigning users to rooms and timeslots is still missing, which can be applied to the planning and scheduling of consult rooms in outpatient clinics.

The problem formulation of the planning of college rooms and timetabling has many similar aspects to the problem formulation of scheduling and planning of consulting rooms in outpatient clinics. In both cases it involves assigning events to rooms with respect to capacity restrictions. The most important performance indicator in the planning and scheduling of college rooms is minimizing the amount of rooms used (Fizzano & Swanson, 1998). Schools and hospitals are both service providing facilities where two actors have to be present on the event; the service provider (e.g. teacher, specialist) and the service taker (e.g. student, patient). However, there are large differences which makes it impossible to use the same solutions to the problem formulation of the planning and scheduling of consult rooms in outpatient clinics. For instance a very important recurring factor in the scheduling and planning of consult rooms in outpatient clinics is a dominant work planning of specialists and the utilization of the specialist’s time, which is bringing many new constraints. In addition the existence of departments and receptions brings whole new challenges.

**Gaps & research opportunities**

The identified gaps in literature with respect to the questions asked by hospital management can be summarized as followed.
Planning and scheduling of the operation room and thereby the effects on various resources in hospitals is widely studied. The constraints of planning and scheduling operation rooms compared to consult rooms of outpatient clinics are different. For example for scheduling the rooms in outpatient clinics, the allocation of a specialist to rooms near to the reception is desirable. Moreover the challenges of operation room planning are located in the implementation of the schedules.

In the area of facility layout planning, research into the specific section of healthcare facility layout is still very scarce. In determining an optimal layout, only rooms and space are considered. In some cases the availability of workforce is considered as well. However, the availability of timeslots in addition to the workforce and rooms are not considered in literature.

Research into timetabling and college room planning can be extended by searching solutions for more complex problem instances. The problem formulation does not consider specific constraints of users (specialists) such as the existence of departments and therefore it cannot be adopted to optimize the scheduling and planning of rooms in the outpatient clinics.

The planning and scheduling of outpatient clinics can be translated into the allocation of users to resources and timeslots. The planning and scheduling of outpatient clinics is considering rooms as resources, users and timeslots with specific constraints. This is making the problem formulation new and unique.

2.2. Scope

In this section the demarcation of the project will be provided since MZH hospital management question can be split into multiple areas of interest all concerning the allocation of users to resources and timeslots. We consider the department of ophthalmology and the combination of the departments of neurology, geriatrics, internal medicine and pulmonary diseases of the outpatient clinics.

Ophthalmology
On the department ophthalmology are in addition to specialists, also multiple categories of paramedics’ part of the medical staff which can perform consults. Paramedics are specialists, but only provide consults in a certain domain. Paramedics cannot do all consults in contrast to specialists. However, the paramedic can perform certain specific consults fully autonomously. For performing consults, specialists and paramedics require equipment. The equipment is fixed and allocated to specific rooms. In other words the equipment cannot be easily transferred to another room. The consequence is that a large part of the consults can only be held in those rooms where the required equipment is available. These restrictions and constraints make the planning and scheduling of rooms of the department of ophthalmology complex. The most important challenge here is to develop a model which automatically generates a feasible schedule.

Neurology, geriatrics, internal medicine and pulmonary diseases

The combination of the departments of neurology, geriatrics, internal medicine and pulmonary diseases is selected for the inclusion of multiple adjacent departments with limited constraints to users and rooms. There are no paramedics working at these departments. The consult rooms of all departments are flexible to use. The consult rooms are standardized rooms with a desk, bed and a small kitchen. The
consult rooms have no special built-in equipment. Thus the consult rooms can be used by all the departments. The layout of the outpatient clinics is in such a way that there is a clear distinction of locations with each having an own reception. The challenge in this problem is in the allocation of sessions in a way that transparency is created for both patients and the medical staff and enough rooms are available for departments to satisfy the demand for sessions. A session is a time period reserved in the specialist’s agenda to perform consults for patients. In most cases the session covers a morning or an afternoon.

Hospital management is interested in solutions for both situations and both of the situations are related to the allocation of users to rooms and timeslots. In situation 1, unique constraints and restrictions occur for both rooms and users for scheduling the outpatient clinic ophthalmology. In situation 2, the existence of different locations and the existence of multiple departments makes the problem and thereby model completely different from situation 1. In the research proposal the appearance of multiple locations and multiple departments are considered as well. Therefore situation 2 is more in line with the research proposal and for that reason the further project will focus on situation 2. In addition the team managers of MZH are currently proactively searching for a solution for the problem described in situation 2 and therefore situation 2 is a more topical problem by hospital management currently.

2.3. Research question
In this section the research question is formulated. The research question should cover the question of hospital management, where existing literature is not sufficient to provide an answer. In the literature review a clear gap is identified in the allocation of users to resources and timeslots. This can be applied to planning and scheduling rooms of outpatient clinics within hospitals.

In the new-build hospital a certain area is dedicated to the outpatient clinics. The area consists of standardized consult rooms with fixed dimensions. The standardization makes the rooms flexible to use between different specialists and departments, which makes the problem of planning and scheduling of consult rooms dynamic. Implementation of a potential solution can be executed at low cost, because almost no psychical changes to the layout of the hospital have to be made. Changing the function of the area dedicated to the outpatient clinics will be very expensive and is assumed not going to happen for the upcoming years. Thus the field site is expected to be consistent, making it appropriate for research. The research question which articulates the essence of the project is formulated as followed:

Research question
How can a decision tool be developed to assist managers to allocate users to rooms and timeslots in order to make efficient use of room capacity and stimulate efficient work processes while having a minimum change in the current way of working?

Efficient use of room capacity is defined as maximization of the utilization rate of used rooms. Currently there are indications that many rooms are utilized for only a small fraction of time. For hospital management it is interesting to know if the rooms can be utilized for a larger fraction of time. In that case fewer rooms would be required. The remaining available rooms could be used for other purposes.
In addition efficient work processes of medical staff should be stimulated as much as possible. Currently specialists of the department of geriatrics provide consults in rooms of three different corridors. This situation leads to unnecessary movement of specialists between corridors. Moreover a minimum change in the current way of working is desired. Many schedules and agendas within hospitals are aligned. Changing the agendas of specialists can cause interference with other schedules (e.g. operation room scheduling) of the hospital. Therefore it is preferred that the current way of working is maintained as much as possible.

The demand and supply of consults have to be aligned to obtain an efficient planning and scheduling. The demand of consult can be considered as patients requiring a consult, which can fluctuate daily. The supply of consults is represented by specialists of the hospital performing consults. When demand is higher than supply, waiting lists for patients will develop or consults needs to be cancelled. When supply is higher than demand, expensive work hours of specialists are lost. The demand should be aligned to the supply of consults and rooms should facilitate the consults. For that reason it is of essence that the planning and scheduling of facilitating consult rooms is effective and efficient.

2.4. Research assignment

The research question can be translated into a research assignment. The research assignment is generalized and formulated in a way that it can be used for more alternative problem formulations. The research assignment is formulated as followed:

**Research assignment**

*Develop a tool to allocate users to resources and timeslots in order to utilize resources efficiently and maximize resource preferences and timeslot preferences of users*

A practical example will be provided to clarify the generalized research assignment. In the example rooms are used as resources. Suppose there are 4 outpatient clinics positioned on 4 different locations with each having a reception. The reception is associated with the outpatient clinic which is on the same location. Three of the locations are sufficiently large in size to meet the demand of room capacity. However, outpatient clinic 3 wants to expand and in the current situation there are no extra rooms available to meet this expansion. Besides, the hospital wants to introduce a new outpatient clinic. Also for the new outpatient clinic are currently no rooms available. The problem is visualized in Figure 2.
The blocks represent rooms. Every block is divided in to two parts. The left top part is the room occupation is the morning and the right bottom part in the room occupation in the afternoon. If the color of the capacity occupation is red, the room is occupied (in use). When it is green, the room is not occupied (free).

By visualizing the problem it is clear that in the current situation rooms are not efficiently utilized. It could be that effectively rescheduling rooms can provide a solution which serves not only the current demand, however also provides a solution for the requested expansion and the potential new outpatient clinic 5.

By rescheduling the rooms, a solution is provided which satisfies the current demand as well as the requested expansion and availability for a new potential outpatient clinic 5. In this solution outpatient clinic 2 and 4 are combined on the 2nd location. Location 4 becomes available for a potential new outpatient clinic 5. Outpatient clinic 1 and 3 switched from locations, which opens up new rooms for the expansion of outpatient clinic 3. All the departments are positioned at only one location with a reception. The example given is simplified. However, it provides a clear indication of the purpose of the research assignment.
Subsequently associated with the research assignment the following deliverables are expected at the end of the project.

1. Theoretical model
2. Case study
3. Supportive decision tool

A generalized theoretical model will be developed to assign of users to resources and timeslots. The theoretical model will be applied to perform a case study. The case study will be MZH in Boxmeer, the commissioner of the assignment. For implementation purposes and to get insight about how to use the information of the case study, subsequently a supportive decision tool will be developed. The supportive decision tool will help MZH to make more careful considered decisions in the future.

2.5. Research approach

In the research approach four steps will be described in order to determine what deliverables are expected in which phase of the project.

1. The detailed analysis
The main purpose of this step is to give clear insight in the problem formulation and to find the specifications of the problem formulated by the detailed situation of MZH. The complete process of planning the consult and the actual consult will be mapped, which will provide an overview of all the bottlenecks and constraints. In addition the current scheduling strategies and the trends of room demand will be discussed. In other words in this step the objective and constraints will be identified, which will be taken directly into account in the phase where the conceptual model and the mathematical model will be developed. The information required for the detailed analysis will be acquired by desk research, field research and interviews. All the relevant steps will be visualized and where possible quantified.

2. Development of the conceptual and mathematical model
In this step the conceptual model and mathematical model will be developed. First the conceptual model will provide qualitative solutions to the problem formulation. Subsequently the qualitative constraints and objectives will be translated into formulas. The model should map the available resource capacity and distribute a set of users over a set of resources and a set of timeslots in order to reduce the amount of resources used and in order to optimize satisfaction of timeslot and resource preferences of users. The model should provide for all users, one or more certain resources in combination with one or more certain timeslots.

3. The case study
In this step the application of the model on the hospital will be executed and discussed. All information to quantify the required parameters of the mathematical model will be accumulated in MZH. The values of the quality-based parameters will be discussed and determined in accordance with management of
MZH. Mixed integer linear programming software will be required for calculating the mathematical model. The exact method for solving the problem will be determined and discussed in this step.

4. Development of a decision support tool
In this step the implementation of the solution of the case study will be discussed. How can the hospital use this information for decision making? A mathematical model is developed, subsequently the model is applied on the hospital and results are presented. In this section the framework will be discussed about how management of MZH needs to use the results of the case study to help them in making well-considered decisions. In addition, recommendations and suggestions for implementations will be discussed. How can the solution be implemented and what are the consequences?
3. Detailed analysis Maasziekenhuis Pantein

The detailed analysis is focused on the departments geriatrics, neurology, internal medicine and pulmonary diseases of the outpatient clinics. From now on the departments geriatrics, neurology, internal medicine and pulmonary diseases will be simply referred to as the departments. The detailed analysis will be split into four sections. In section 3.1 the current scheduling strategy will be described. In section 3.2 the data analysis on the room demand will be discussed. In section 3.3 the complete consultation process and requirements for planning sessions will be discussed to show what is needed for scheduling sessions in the outpatient clinics. In section 3.4 a summary will be provided.

3.1. Current scheduling strategy

A distinction can be made between long-term, medium term and short term planning of rooms in outpatient clinics of MZH.

- **Long term strategy (1 – 25 years)**
  - allocation of rooms to departments

- **Medium term strategy (1 year)**
  - fixed week baseline schedule per department

- **Short term strategy (1 – 52 weeks)**
  - operational planning

**Long term strategy**

Each department of the outpatient clinics has a fixed number of rooms assigned to the department. The allocation of a room to a department implies that the specific department has the right for scheduling the room for sessions. In some cases two departments have a number of rooms assigned to the departments combined, because the receptions of the two departments are positioned in a similar corridor. A change of allocation of rooms to departments occurs only when the area dedicated to the outpatient clinics is revised (for example this happened when the new hospital was built) or when structural shortage of rooms by a department exists. In the last case only the allocation of one or a few rooms are switched between departments. The allocation of rooms to departments is not structurally reconsidered.

In 2014 the allocation of consult rooms to departments was:

- 9 rooms were allocated to the departments of geriatrics and neurology combined
- 8 rooms were allocated to the department of internal medicine (diabetics and dietetics included)
- 4 rooms were allocated to the department of pulmonary diseases

The rooms were distributed over three corridors A, B and C. Each corridor has a reception at the beginning of the corridor with a front office and a back office. The department of geriatrics and the department of neurology share a reception on corridor A. The department of internal medicine has a reception on corridor B and the department of pulmonary diseases has a reception on corridor C.

**Medium term strategy**

The departments of the outpatient clinics in the hospital are under supervision of different team managers. One team manager has the responsibility over 1 – 3 departments of the outpatient clinics.
Consequently, team managers have an own personal interpretation of a schedule. Thus differences are present between the schedules of the different departments. However, all team managers make use of a fixed weekly scheduling strategy. Every year a fixed baseline schedule for each department is developed with respect to the amount of rooms allocated to the department. That means that fluctuations in patient arrivals, which result in a variable demand of consults does not have direct influence on the fixed baseline schedule. The schedules are similar in the way that all of them are working with 2 timeslots per day and 5 days a week; one timeslot in the morning and one timeslot in the afternoon from Monday until Friday. Thus in total, the schedule works with 10 timeslots a week. Table 1 shows the baseline schedules of the departments geriatrics (G), neurology (N), internal medicine (IM) and pulmonary diseases (P).

**Baseline schedule geriatrics and neurology**

| Corridor | Room | Monday | | Tuesday | | Wednesday | | Thursday | | Friday |
| --- | --- | --- | | | | | | | | |
| A | 1 | N1 | N1 | | N1 | N1 | | N1 | N1 | |
| A | 2 | N2 | N3 | | N4 | N5 | | N7 | N3 | |
| A | 3 | N7 | N6 | | N5 | N4 | | N4 | N6 | |
| A | 4 | G1 | G4 | | N7 | N6 | | N6 | N7 | |
| A | 5 | G2 | G1 | | G5 | G4 | | G4 | G2 | |
| A | 6 | G3 | G3 | | G3 | G3 | | G3 | G3 | |
| B | 7 | G4 | G2 | | G2 | G1 | | G1 | G4 | |
| B | 8 | G5 | G5 | | G4 | G4 | | G4 | G5 | |
| C | 9 | | | | | | G5 | | |

**Baseline schedule internal medicine**

| Corridor | Room | Monday | | Tuesday | | Wednesday | | Thursday | | Friday |
| --- | --- | --- | | | | | | | | |
| B | 1 | IM1 | IM1 | | IM1 | IM1 | | IM1 | IM1 | |
| B | 2 | IM2 | IM3 | | IM2 | IM4 | | IM2 | IM5 | |
| B | 3 | IM8 | IM7 | | IM3 | IM4 | | IM8 | IM4 | |
| B | 4 | IM6 | IM7 | | IM9 | IM8 | | IM8 | IM6 | |
| B | 5 | IM9 | IM8 | | IM8 | IM9 | | IM9 | IM8 | |
| C | 6 | IM10 | IM10 | | IM10 | IM10 | | IM10 | IM10 | |
| C | 7 | IM11 | IM12 | | IM13 | IM11 | | IM12 | IM13 | |
| C | 8 | IM11 | IM13 | | IM12 | IM11 | | IM13 | IM12 | |

**Baseline schedule pulmonary diseases**

| Corridor | Room | Monday | | Tuesday | | Wednesday | | Thursday | | Friday |
| --- | --- | --- | | | | | | | | |
| C | 1 | P1 | | P1 | | P1 | | P1 | | |
| C | 2 | P2 | | P2 | | | | | |
| C | 3 | | | | | | | | |
| C | 4 | P4 | | P4 | | P4 | | P4 | | |

Table 1. Baseline schedules of departments

The character-number combinations represent employees from the medical staff occupying a room. For example the character “N1” represents a specialist from the department of neurology performing sessions and the letter “G3” represents a specialist from the department of geriatrics performing sessions. The baseline schedules of the departments of geriatrics and neurology are combined because the two departments share a reception and a room. The baseline schedules are based on the amount of rooms allocated to the departments (see allocations in “long term strategies”). Note that medical staff
from the department of internal medicine is allocated to rooms of two corridors B and C and the medical staff from the department of geriatrics is allocated to rooms of three corridors A, B and C. We can extract from the baseline schedules that 46 of 163 sessions (28.2%) are scheduled in rooms of a corridor where not the reception of the department is positioned.

Short term strategy
The baseline schedule is repeated every week and therefore the operational planning should be similar between weeks. However, because of irregularities the baseline schedule actually often differs between weeks. The fixed baseline schedule will be adjusted to an operational planning to deal with irregularities. The operational planning is the actual feasible planning. The operational planning has to deal with the following irregularities:

- holiday
- congress
- functional department weeks
- absence by illness
- emergency consults
- extra planned sessions

Due to irregularities some of the sessions are cancelled in the operational planning (e.g. holidays, congress, functional department weeks and absence by illness) and some extra sessions are required in the operational planning (e.g. emergency consults and extra planned sessions). Emergency consults are consults which must be scheduled on short notice (often on the same or the next day) and therefore they are scheduled outside the “normal” sessions. Rooms become available when sessions are cancelled and a variable amount of rooms is required for unexpected emergency consults. Hence the demand of rooms is variable in the operational planning. In the following section a data analysis on the variable room demand is provided.

3.2. Data analysis room demand
In this section a data-analysis is provided on the effects of current scheduling strategy (e.g. the operational planning). MZH makes use of the software package CS-EZIS for the planning and scheduling of consults for patients. Data was extracted from CS-EZIS in the period between 1 Jan 2014 - 30 June 2014. The data before 2014 could not be used from CS-EZIS because it was incomplete (some of the personnel in 2013 was not working anymore in 2014 and due to that reason they were removed). Diabetics and dietetetics were excluded in the data-analysis because there was no data available about the planning and scheduling of consults for patients at the moment of the analysis. Per specialist and nurse it was checked if they occupied a room for performing consults in the morning or afternoon of the day and if it the consult was a regular consult or an emergency consult. Regular consults are scheduled in sessions (sessions consists of multiple consults). Emergency consults are consults which have to be scheduled on short notice and therefore they are often scheduled outside the normal sessions. If one or more patients were scheduled between 8:00 and 13:00 the room was marked as occupied in the morning and when one or more patients were scheduled between 13:00 and 18:00 the
room was marked as occupied in the afternoon. In the period were 129 working days (national holidays included) and 258 available timeslots (one in the morning and one in the afternoon each day).

The data analysis will focus on three different topics; room demand distribution, room demand trends, and emergency consults. A specific section is dedicated to the emergency consults, because the current baseline schedules do not take the emergency consults into account and thereby no information is available about the effect of emergency consults on room occupations. In the first section the room demand distribution will be discussed. In the second section the trends of room demand will be described and the third section the effects of emergency consults will be discussed.

3.2.1. Room demand distribution

In this section the distribution of room demand will be described. Room demand distribution was analyzed by determining the frequency rates of room occupations. The frequencies rates are expressed in percentage for all the departments combined. For example the departments combined occupied 8 rooms in 10,1% of the 258 timeslots. Figure 3 displays the rooms used simultaneously in percentage for the departments combined.

![Room demand distribution](chart)

**Figure 3. Room demand distribution**

In 4,3% of the timeslots 0 rooms were used. This can be explained by the national holidays. On these timeslots the specialists and nurses were free from work and thus no rooms were used. The total available capacity of rooms for the departments combined was 16. From Figure 3 it can be extracted that in the period never an occupation of 16 rooms on one timeslot occurred and only in 0,4% of the timeslots an occupation of 15 rooms occurred. From figure 3 can also be obtained that the highest frequency rates were on the occupations of 9, 10 and 11 rooms. One can conclude that a shortage of rooms should not be necessary in the operational planning during this period. Even on the busiest timeslot one room should be still available.
3.2.2. Trends

In this section the trends for the departments will be discussed. A distinction can be made between:

- long-term trends (between years)
- seasonal trends (between weeks)
- timeslot trends (between timeslots)

**Long-term trends**

Data from CS-EZIS for the planning and scheduling of patients is stored in an external database. The data of durations of first visits and revisits of consults per year per service provider per department is stored in the external database. The service providers are specialists, paramedics and nurses. This data is used for the analysis of the long-term trends of growth or decline of the departments.

The data only shows the sum of durations of scheduled consults for every service provider. Specialists do use multiple rooms for performing consults. To calculate the total planned minutes for rooms per department, we first had to separate the time planned for consults of nurses and the time planned for consults of specialists. Subsequently the specialists planned consult minutes were multiplied by the room factor the department uses. For example the department of geriatrics has a room factor of 2 because the specialists use two rooms when performing a consult. The second room is used by a nurse to assist the specialist in the pre-consultation and post-consultation. From interviews with hospital management the room factors were obtained. From the planned minutes per service provider per year and the room factors, the total planned time for rooms per department was determined. The planned minutes for rooms cannot be directly translated into the amount of rooms required per department. The differences in the consult process have a large influence on the amount of rooms required. For example the department of geriatrics has relatively high consult durations and high duration deviations, which makes it hard to plan and schedule the patients efficiently. Besides, the department of geriatrics needs room capacity for multi-disciplinary meetings where no data is available about.

To get more insight in the long-term trends the percentage of planned time for rooms per department of the total planned time for rooms was calculated between 2008 and 2013. This value can be directly translated into the total percentage required of the total available room capacity. Figure 4 displays the percent required of the total available room capacity.
Internal medicine was declining since 2008 and since the introduction of the department of geriatrics in 2008, the department of geriatrics is growing. This trend can be confirmed by the change of allocation of 2 rooms of internal medicine to geriatrics between 2010 and 2014.

Figure 5 shows the expected 65+ and 80+ inhabitants in the Netherlands.
The amount of 65+ and 80+ inhabitants in the Netherlands is expected to increase. Consequently we will assume that the department of geriatrics (note that the department of geriatrics focuses on elderly patients) is expected to remain growing in the future.

Seasonal trends
For seasonal trends the average numbers of rooms used simultaneously per week in the period from 1 Jan 2014 until 30 Jun 2014 were analysed. Figure 6 shows the average room occupations per week of the departments combined.

![Average room occupation per week](image)

**Figure 6. Average room occupation per week**

The first week of the analysed period did not contain 5 working days and therefore the average of the first week was not included. The maximum of the average room occupation was reached in week 16 with an average room occupation of 10.3, while in total 16 rooms were available in that week. From these figures can be calculated that every average room occupation was below 65% of available capacity. The peaks in the graph can be explained by the school holidays. In week 10 was the “carnavalsvakantie” and in week 18 was the “meivakantie”. Both school holidays were showing downward peaks. This indicates that room occupation was influenced by the school holidays. Specialists and nurses are going on holiday during the school holidays and thus rooms are unoccupied during the school holidays.

Timeslot trends
The timeslot trends were defined as recurring differences in room occupations on timeslots within the week. For example Friday afternoon many rooms were unoccupied. Figure 7 displays the average room occupation per timeslot in the week.
From figure 7 it can be concluded that on Friday afternoon on average many rooms were unoccupied. The maximum of average room occupation was achieved on Wednesday morning. However, a simple change from transferring Wednesday morning sessions to Fridays afternoon sessions will still have a minimum impact on the required amount of rooms, because the values of average occupations were far below the maximum capacity of 16 rooms. It seems that peaks in room demand distribution determines the number of rooms required. Hence rooms should be facilitating the consults and it should be prevented that there are not enough available rooms for the medical staff to perform consults.

### 3.2.3. Emergency consults

In this section the data-analysis on the emergency consults will be discussed. Regular sessions are filled up with consults as much as possible and rooms are required during a large part of the timeslot. Emergency consults only take a very small part of a timeslot and thus more emergency consults (of more departments) could be handled in one timeslot. As described before, emergency consults are consults which have to be scheduled on short notice. In most cases this means at the same day or the next day. If the emergency consult can be scheduled during a regular session, no extra room is required for handling the emergency consult. The emergency consult is in that case added to a regular session. However, if the emergency consult is scheduled outside the regular sessions, extra rooms are required for processing the emergency consult. A more accurate analysis is performed on the emergency consults to explore the opportunities to use a similar room for handling emergency consults of different departments.

The same data from 1 Jan 2014 until 30 June 2014 is used for the analysis. In this period per timeslot the amount of emergency sessions are counted and the durations of the emergency sessions are noted. The morning timeslot is from 8:00 to 13:00 and the afternoon timeslot is from 13:00 to 18:00. An emergency session can be defined as a period where one or multiple subsequent emergency consults were provided by one person. For example specialist X performs 3 subsequent emergency consults between 10:00 and 11:30, this was listed as 1 emergency session from 10:00 until 11:30. The durations of emergency sessions are important for determining if it is possible to handle the emergency sessions in one single
timeslot of one room. The number of emergency consults in an emergency session is not important as long as they do not have overlap and are subsequent, because only the overlap and durations determine how many rooms are required for handling the emergency sessions. Table 2 provides the frequencies of number of emergency sessions within a timeslot.

<table>
<thead>
<tr>
<th>Number of emergency sessions within a timeslot</th>
<th>Frequencies (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>54.3%</td>
</tr>
<tr>
<td>1</td>
<td>37.2%</td>
</tr>
<tr>
<td>2</td>
<td>7.0%</td>
</tr>
<tr>
<td>3</td>
<td>1.5%</td>
</tr>
<tr>
<td>4</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Table 2. Frequencies of number of emergency sessions within a timeslot

In 54.3% of the 258 timeslots there were no emergency sessions within the timeslot. We can conclude that in those timeslots no rooms were required for the emergency consults. In 37.2% of the timeslots there was only 1 emergency session in the timeslot. If only 1 emergency session occurred in a timeslot, one room should be sufficient to handle the emergency session. For the cases where 2 or more emergency sessions were present within a timeslot, it was more difficult to determine the number of rooms needed to support the emergency sessions. To determine the number of rooms required when one or more emergency sessions exists within a timeslot, we first need to know the durations of the emergency sessions and if overlap exists. If all the emergency sessions within the timeslot do not overlap, you will only need 1 room to support the emergency sessions. If emergency sessions do overlap, the amount of overlapping emergency sessions determines the number of rooms required for emergency consults. Table 3 provides the specific cases where overlap of emergency sessions was present.

<table>
<thead>
<tr>
<th>Cases with overlap</th>
</tr>
</thead>
<tbody>
<tr>
<td>date</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>10-Jan</td>
</tr>
<tr>
<td>16-Jan</td>
</tr>
<tr>
<td>31-Jan</td>
</tr>
<tr>
<td>4-Feb</td>
</tr>
<tr>
<td>11-Mar</td>
</tr>
<tr>
<td>23-Apr</td>
</tr>
<tr>
<td>7-May</td>
</tr>
<tr>
<td>9-May</td>
</tr>
<tr>
<td>16-May</td>
</tr>
<tr>
<td>13-Jun</td>
</tr>
<tr>
<td>18-Jun</td>
</tr>
<tr>
<td>15-Jun</td>
</tr>
</tbody>
</table>

Table 3. Cases with overlap of emergency sessions
The number of rooms required for emergency consults is determined by the highest amount of overlapping emergency sessions on a particular moment in a timeslot. The amount of rooms required to support the emergency sessions can be extracted from table 3. In 2 cases an overlap of 3 emergency sessions occurred. This is the maximum overlap which occurred in the period. Therefore at least 3 rooms were required in this period to support all the emergency consults, if specialists should not have to wait in any case for available rooms to perform the emergency consult. If the schedule was more transparent, the emergency consults could be scheduled in a subsequent way and fewer rooms would be required.

One could decide to implement an aggregate planning system to create transparency in scheduling rooms for emergency sessions. One single planning system would be used by all departments. With aggregate planning the emergency sessions can be scheduled in a subsequent order and in a way that minimum overlap of emergency sessions exists and thus a minimum amount of rooms are required for handling the emergency consults. The last column of table 3 provides the cumulative durations in minutes of the emergency sessions within specific timeslots. These values determine the amount of rooms required if an aggregate planning system for emergency sessions would be implemented. For example on 10-Jan in the afternoon the summed durations of the emergency sessions were in total 90 min. The afternoon timeslot consists of 300 min (13:00 – 18:00). Thus it is possible to schedule all the emergency consults in one timeslot in one room without having overlap. We assume that timeslots can be scheduled fully with emergency consults if an aggregate planning system would be used. In the analyzed time period the maximum cumulative durations of emergency sessions occurred on 31-Jan with 190 min. Even in this case one timeslot of 300 min would be enough (190 < 300) and thus one room would have been sufficient to handle the emergency consults.

Emergency consults are very difficult to predict. However, the scheduling and planning of rooms in the outpatient clinics has to take into account that rooms are required for scheduling the emergency consults. A fixed number of rooms could be used by all departments for specifically handling the emergency consults. With use of an aggregate planning system less rooms would be required for handling the emergency consults.

3.3. Consult process and session scheduling requirements
The framework of the consult planning analysis is visualized in figure 8. The framework shows what is required for scheduling and planning consults in outpatient clinics.

![Figure 8. Framework of the consult planning analysis](image-url)
First the complete consult process for patients in the outpatient clinics in MZH will be elaborated and described. Subsequently each of the requirements for scheduling and planning of consults in the outpatient clinics of MZH will be identified and discussed.

3.3.1. Complete consult process

In this section the complete process of the patient from making an appointment for a consult until the patient is discharged from the outpatient clinics will be discussed to give more insight in what is required from the scheduling and planning of consults.

Overview

In figure 9 an overview of the processes is provided from the moment a patient makes an appointment (start) until the moment he is discharged from the outpatient clinics (finish).

![Diagram of the complete consult process of patients in the outpatient clinics](image)

**Figure 9. The complete consult process of patients in the outpatient clinics**

From the moment the patient makes an appointment with the specialist, the process analysis starts. On the moment the patient is discharged from the outpatient clinic the process analysis ends. The 7 most important sub processes are:

a. Make appointment
b. Pre-examination
c. Visit specialist
d. Make appointment examination-treatment
e. Examination-treatment
f. Clinical admission
g. Discharge

*Make appointment*

In principle a patient first visits the general practitioner. If the general practitioner cannot help the patient sufficiently, the general practitioner will refer the patient to a specialist. The patient is referred to a department in the outpatient clinics with respect to the particular complaint the patient experiences. The patient makes an appointment with a specialist of the department he is referred to by the general practitioner. The patient will in that case call with the back office or front office assistant to make an appointment. Subsequently the back office or front office assistant will schedule the patient in one of the predefined sessions for a consult with respect to the specialist preference of the patient.

*Pre-examination*
When needed, a pre-examination takes place prior to the consultation by the specialist. The pre-examination will be done by a nurse or a back office assistant. This saves time for the specialist and therefore the specialist can work more efficient (Hulshof, Vanberkel, Boucherie, Hans, van Houdenhoven, & van Ommeren, 2012). For example at the department of internal medicine, prior to the consultation of the specialist an RR (Riva-Rocci) measurement is performed to measure the blood pressure of the patient. The RR measurement is performed by a back office assistant and therefore the specialist can use his time for consultations more efficient (because the specialist does not need to perform the RR measurement himself).

Visit specialist
The specialist will meet the patient in the waiting area and walks the patient to the consult room. The consult already starts from the moment the specialist meets the patient in the waiting area. Subsequently the specialist examines the patient and provides the consultation. The specialist will make a diagnosis and based on the diagnosis the next steps will be determined.

Making appointment examination-treatment
When the specialist does not have enough information yet to make the diagnosis or the patient needs to come back for a treatment, he can refer the patient to an examination-treatment. In most cases the patient will have to make an extra appointment for this examination-treatment. In general the appointment for the examination-treatment is made right after the visit to the specialist at the front office with the front office assistant.

Examination-treatment
The examination-treatment can be performed at the outpatient clinic or at the function department. At the function department examinations are carried out which examines the functions of organs. The examination-treatment is performed by a specialist, nurse or a paramedic, depending on the examination or treatment the patient requires.

Clinical admission
The patient receives clinical admission when the diagnosis requires intensive treatment and cannot be cured by a simple treatment. This means that the patient stays 24 hours a day at the hospital for a short or long period. Clinical admission is out of scope in this study.

Discharge
Before a patient is discharged from the hospital, always a conversation takes place. In the conversation a specialist or nurse provides the patient with information about the further process, the health condition of the patient and overall what the patient can expect.

3.3.2. Identification of scheduling requirements
Hospitals are service providing facilities (Schmenner, 1986). One of the services hospitals provide are consults. Consults are performed in the outpatient clinics. The consults are scheduled in sessions. A session is a time period which is reserved for scheduling consults. The sessions must be planned first in order to schedule consults into the preplanned sessions. Medical staff and consult rooms are required on
certain timeslots in order to plan sessions in the outpatient clinics. For each of the requirements, the restrictions and characteristics will be discussed in the next sections.

Medical staff
The medical staff consists of specialists, nurses, front office assistants and back office assistants. Specialists are the most important asset for performing consults in sessions. Specialists have different tasks within the hospital and specialists work in half day shifts. Categories of tasks could be: research, sessions, patient visiting hours and administration. In some cases specialists also work in other hospitals on certain days of the week. Specialists often have a fixed schedule already for a long time. Switching the timeslot of tasks is very difficult because many parties are involved in the agenda of the specialist. This implies that tasks cannot be easily interchanged within the schedule of a specialist. Therefore sessions of the specialist are preferred to be on a fixed timeslot and do not change between weeks.

Consult rooms
The consult rooms of the departments are all standardized rooms. The consult rooms of the departments contain similar equipment. In all the rooms there are a bed, a small kitchen and a desk. Because the rooms are standardized by size and equipment, the rooms are flexible to use by different departments. From interviews with specialists and hospital management the following preferences for location of room for performing sessions was retrieved:

- Specialists and nurses prefer performing sessions in consult rooms which are near to the reception of the associated department. This stimulates the communication between back office assistants, front office assistants, specialists and nurses.
- Specialists and nurses prefer performing sessions in consult rooms near to each other. This stimulates the communication between specialists and nurses within the department.
- Movement of medical staff outside the corridors should be minimalized. It is desired that the area for medical staff and the area for patients is separated as much as possible for patient transparency purposes.

Timeslots
A session is a period of time where a specialist or nurse provides consults to patients. The exact start and end times of the sessions are different between the departments. In rare cases the start and end times of sessions between specialists or nurses within a department could differ. However we can assume that in most cases the start and end times of sessions within a department are similar. Table 4 provides the start/end times and durations of morning and afternoon sessions of the departments.

<table>
<thead>
<tr>
<th>Department</th>
<th>Morning session</th>
<th>Duration (hours)</th>
<th>Afternoon session</th>
<th>Duration (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal medicine</td>
<td>8:30 – 12:00</td>
<td>3,5</td>
<td>13:00 – 16:30</td>
<td>2,5</td>
</tr>
<tr>
<td>Geriatrics</td>
<td>8:15 – 12:40</td>
<td>4,4</td>
<td>13:45 – 16:15</td>
<td>2,5</td>
</tr>
<tr>
<td>Neurology</td>
<td>8:30 – 11:30</td>
<td>3</td>
<td>13:30 – 16:30</td>
<td>3</td>
</tr>
<tr>
<td>Pulmonary diseases</td>
<td>9:00 – 11:50</td>
<td>2,8</td>
<td>13:30 – 16:20</td>
<td>2,8</td>
</tr>
</tbody>
</table>

Table 4. Start/end times and durations of sessions
The start time of the session implies that the first appointment with a patient can be scheduled at the moment the session starts. The end time of the session implies that the last consult with a patient can be scheduled on or before the end time of the session. Note that the combination of morning and afternoon sessions of the different departments never has an overlap. Thus it is always possible to combine a morning and afternoon session of two different departments without having an overlap. For example if the department of geriatrics would use a specific room in the morning from 8:15 until 12:40, than it is still possible for the department of internal medicine to use the same specific room in the afternoon from 13:00 until 16:30. Furthermore you can extract from the durations of sessions that often only a small part of a timeslot is used for doing sessions. At average 3,3 hours of a timeslot is used for performing sessions, while the durations of timeslots consists of 5 hours. Thus during large parts of timeslots the rooms remain unused when a session is performed.

3.4. Summary

Most departments in the outpatient clinics have fixed equipment placed in the rooms. Therefore the rooms planning of most departments within the outpatient clinics are bounded by inflexibility and high conversion costs in case of change. However the adjacent departments geriatrics, neurology, internal medicine and pulmonary diseases in MZH do not have fixed equipment in the rooms and thus rooms are flexible to use by all departments. Therefore the room planning of those departments can be changed without having high conversion costs to the layout of the building.

In 2008 the department of geriatrics was introduced and located in the corridor combined with the department of neurology. Due to the expansion of the department of geriatrics in the next years, two rooms in the adjacent corridor were allocated to the department of geriatrics at the expense of the department of internal medicine. In addition one room in the corridor where the department of pulmonary diseases is positioned switched from allocation to the department of geriatrics. Therefore the distribution of rooms of the department of geriatrics is currently over three locations. This situation is not desirable, because the specialists and patients frequently have to communicate with the front and back office assistants. The specialists have to discuss with the office assistants about planning, scheduling and patient related questions and the front office is the point of contact for the patients (e.g. making appointments, for questions, etc.).

With the current amount of room capacity allocated to the department of geriatrics, it occasionally occurred that not enough rooms were available to support the scheduled sessions of the department of geriatrics. Subsequently, last-minute a room had to be found outside the rooms allocated to the department of geriatrics to support the planned session. The detailed analysis showed that the total room capacity should have been sufficient in all cases to satisfy the total demand for rooms. This implies that reconsidering the allocation of room capacity could provide solutions for the shortage of available rooms. The problems and characteristics of MZH identified in the detailed analysis can be summarized as followed:

- The department of geriatrics is growing since 2008 and is expecting to remain growing in the future
- There is no structural reconsideration of distribution of room capacity resulting in an unbalanced distribution of room capacity
- The department of geriatrics did occasionally not have enough room capacity for supporting the planned sessions and emergency consults
- Only relatively small parts of timeslots are used for sessions
- Room planning and scheduling is based on a fixed room capacity per department, which is restricting the room capacity distribution unnecessarily
- During school holidays specialists go on vacation, which causes unbalanced demand for room capacity
- On Friday afternoon many specialists take time off, causing many unutilized rooms on this timeslot
- The room planning should facilitate the planning of the medical staff (e.g. medical staff planning is prioritized)
- Transparency of room planning and scheduling is very limited
- Exact demand for room capacity is difficult to predict due to irregularities
- Moving planned sessions of specialists to another timeslot is difficult due to scheduled patients in the already planned sessions
- The rooms of the department of geriatrics are located on three different locations which has a negative effect on the communication between the back office assistants, front office assistants, specialists and nurses, and the transparency for patients.
- The back office has a maximum capacity of back office assistants which can work in the back office (e.g. not all back offices can handle the amount of back office assistants of more departments combined on one reception).

With the goal to resolve the summarized problems, the room capacity allocation has to be reconsidered. In addition it is important to structurally reconsider the room capacity allocation due to the dynamics of the departments. The room capacity allocation has to be aligned to the growth and decline of departments to prevent shortage of available suitable rooms for sessions and excessive work inefficiencies.
4. Conceptual and mathematical model

In this section we will propose a general conceptual and mathematical model to allocate users to resources and timeslots in order to maximize timeslot preferences, resource preferences and defragmentation of remaining available resources. Subsequently in section 5 the case study will be performed.

4.1. Conceptual model

A session is a time period reserved for performing consults. Variable supply of sessions would be interesting if high waiting lists were identified. Extra sessions could be planned when demand for consults is high and sessions could be cancelled when demand for consults is low. However, from interviews with hospital management it was retrieved that demand and supply of consults are closely aligned and waiting lists for patients are minimal. It is actually preferred that the number of sessions per time period is fixed and the sessions are performed on fixed timeslots and in fixed rooms. Fixed timeslots and rooms for specialists and nurses provide reliability and transparency to the schedule. Specialists and nurses can rely on the fact that every week the same rooms are available on the same timeslot for scheduled sessions. For example specialist X performs sessions every Tuesday morning in room 5. Hence, the conceptual model will consider fixed demand of users and fixed allocations of users to resources and timeslots.

Changing the timeslots of sessions of specialists and nurses will be very difficult because of scheduled patients in preplanned sessions. Patients are scheduled up to more than a year ahead. Suppose that the preplanned sessions of the specialist or nurse change to a different timeslot, all the scheduled patients in those sessions have to be rescheduled as well. In addition many parties are involved in the personal agenda of specialists. The specialists have different tasks within their portfolio and switching from timeslot is very difficult because of the other tasks the specialists have to fulfil. Minimizing the amount of change to the current timeslots of sessions of specialists and nurses is desired. Therefore the conceptual model will consider satisfying specific timeslot preferences of users as much as possible.

From interviews it was retrieved that intensive communication between specialists, nurses and the reception of a department was essential. Close collaboration between the workforces within a department is essential for working effectively and efficiently. The back office assistants and front office assistants have to communicate frequently with specialists and nurses on the planning and scheduling of patients and about patients health related subjects. Thus clustering the reception and the rooms used for sessions of similar departments is important. Specialists and nurses of a similar department have preferences for performing sessions in rooms of a similar location where the reception of department is positioned. Hence, the conceptual model will create preferences of users of a similar department for resources of a similar cluster. The conceptual model will allocate departments to clusters in order to create specific resource preferences of users.

Currently receptions of departments in the outpatient clinics are fixed and do not switch from location between timeslots. One could decide to create flexible receptions which can be switched from location
between timeslots. Flexible receptions allow for flexible room capacity, because the corridors where the receptions are positioned have different associating room capacities. Therefore it could be interesting to use flexible receptions. However, flexible receptions will cause a large change in the way of working. Front and back office assistants of the receptions will have to change from location between timeslots. In the hospital, signs are provided to geographically guide the patient in the hospital. For example if the patient follows sign 111, it will lead to the reception of the outpatient clinic of neurology. In case flexible receptions would be used, flexible signs and flexible department tags of receptions would be required too. In this study flexible receptions are out of scope and we solely consider fixed receptions. Thus in the conceptual model if a department is allocated to a cluster of resources, it will apply for all timeslots.

There are various possibilities for defragmentation of remaining available timeslots of rooms. One could conclude that it is interesting to defragment availability on a specific timeslot in order to open up a large area on a specific timeslot. However hospital management is interested in defragmentation of fully available rooms concentrated on one location. This is interesting because if rooms, concentrated on one location, are free from sessions on all timeslots, the rooms can be used for a completely other purpose. Thus the conceptual model will consider defragmentation of fully available resources concentrated on a single cluster.

**Allocation method**

The objective of the conceptual model is to allocate users to resources and timeslots in order to maximize:

1) Satisfaction of preferred timeslots of users
2) Satisfaction of preferred resources of users
3) Defragmentation of fully available resources

For every user $i$ a fixed demand of sessions $S_i$ is scheduled. Every user $i$ has timeslot preferences $TP_{i,t}$ and resource preferences $RP_{i,j}$. The timeslot and resource preferences of users are maximized by the model. Specific timeslot preferences of users are predefined. Every user $i$ is allocated to exactly one department $d$ and every resource $j$ is allocated to exactly one cluster $k$. Thus every user is part of a department and every resource is part of a cluster. Resource preferences of users are determined by department-to-cluster allocations $Y_{d,k}$. If department $d$ is assigned to cluster $k$, all users of department $d$ will receive preferences for all resources of cluster $k$. In this way, users from a similar department will be allocated as much as possible to resources of a similar cluster. For defragmentation of remaining available resources, virtual users and a binary dummy variable $V_i$ are added to the model. Every defragmented available resource ($V_i = 1$) is scheduled as a virtual user assigned to all timeslots and allocated to one similar cluster. This implies that fully available resources are concentrated on a single cluster of resources. Enabling virtual users ($V_i = 1$) is maximized by the model. Note that every enabled virtual user represents a defragmented resource. Resource preferences, timeslot preferences and defragmentation cannot always be optimized simultaneously. Therefore weights are added. The weights will decide on the relative importance of resource preferences, timeslot preferences and defragmentation. The relative importance of resource preferences, timeslot preferences and defragmentation needs to be assessed by management and is defined by a number between 1 – 100. For
example if the relative importance of timeslot preferences is 5 times lower than the relative importance of defragmentation, than at most 5 timeslot preferences will be violated if a resource will be defragmented fully available.

**Performance indicators**

*Timeslot preference violations*

Timeslot preference violations are defined the number of preferred timeslots which are not met. The timeslot preference violations will be minimized. A timeslot preference is violated when the allocation of an user to a timeslot is not to one of the preferred timeslots of the user.

*Resource preference violations*

Resource preference violations are defined the number of preferred resources which are not met. The resource preference violations will be minimized. Users from similar departments are allocated as much as possible on similar clusters. A resource preference is violated when an user of a department is not allocated to one of the resources of the cluster where the department is assigned to.

*Defragmentation*

Remaining available resources will be defragmented on all timeslots on a single cluster as much as possible. A resource is only defined defragmented when it is available on all timeslots and when it is allocated to a single cluster (the cluster assigned for defragmentation). Defragmentation is defined by the number of resources fully available on a single cluster.

**Restrictions**

The allocation is restricted to some limitations. The amount of resources is fixed for every timeslot $t$. Consequently the maximum amount of timeslots is fixed for every resource $j$. The demand for sessions in the entire time period of $T$ timeslots for every user $i$ is fixed and known. The amount of sessions scheduled for user $i$ is always exactly the amount of sessions user $i$ demands. The timeslot preferences for every user $i$ are known. Every user $i$ is assigned to exactly one department and every resource $j$ is assigned to exactly one cluster. Every user $i$ from a similar department has resource preferences for a similar cluster. Every defragmented resource is available on all $T$ timeslots and is allocated to exactly one single cluster $k$.

4.2. Mathematical model

In this section we formulate the allocation method as a mathematical programming model derived from the conceptual model discussed in section 4.1.

**Input parameters**

- $I$: Set of users
- $i$: User index
- $E \subseteq I$: Subset of virtual users
\( R \subset I \) Subset of real users
\( J \) Set of resources
\( j \) resource index
\( T \) Set of timeslots
\( t \) Timeslot index
\( K \) Set of clusters
\( k \) Cluster index
\( D \) Set of departments
\( d \) Department index

\( S_i \) Demand of sessions of real user \( i \) \( (i \in R) \)
\( \alpha_i \) Relative importance of real user \( i \) assigned to preferred resource \( (i \in R) \)
\( \beta_i \) Relative importance of real user \( i \) assigned to preferred timeslot \( (i \in R) \)
\( \gamma \) Relative importance of defragmentation

\( V_i \) For every real user \( i \) it equals 0 \( (i \in R) \)

\( L_{k,j} \) \( \begin{cases} 1 & \text{if resource } j \text{ is assigned to cluster } k \\ 0 & \text{otherwise} \end{cases} \) \( (k \in K, j \in J) \)

\( M_{d,i} \) \( \begin{cases} 1 & \text{if user } i \text{ is assigned to department } d \\ 0 & \text{otherwise} \end{cases} \) \( (d \in D, i \in I) \)

\( TP_{i,t} \) \( \begin{cases} 1 & \text{if real user } i \text{ has a preference for timeslot } t \\ 0 & \text{otherwise} \end{cases} \) \( (i \in R, t \in T) \)

Decision variables

\( X_{i,j,t} \) \( \begin{cases} 1 & \text{if user } i \text{ is assigned to resource } j \text{ on timeslot } t \\ 0 & \text{otherwise} \end{cases} \) \( (i \in I, j \in J, t \in T) \)

\( Y_{d,k} \) \( \begin{cases} 1 & \text{if department } d \text{ is assigned to cluster } k \\ 0 & \text{otherwise} \end{cases} \) \( (d \in D, k \in K) \)

\( V_{i} \) \( \begin{cases} 1 & \text{if virtual user } i \text{ is enabled for defragmentation} \\ 0 & \text{otherwise} \end{cases} \) \( (i \in E) \)

Objective function

The objective is to determine \( X_{i,j,t} \) and \( Y_{d,k} \) and \( V_{i} \) in order to satisfy timeslot and resource preferences and to defragment remaining available timeslots of resources as much as possible.

\[
\text{Maximize } \gamma \sum_{i=1}^{I} V_i + \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=1}^{T} X_{i,j,t} \cdot (\alpha_i \cdot RP_{i,j} + \beta_i \cdot TP_{i,t})
\] (1)

In the objective function \( RP_{i,j} \) are the resource preferences and \( TP_{i,t} \) are the timeslot preferences. The values of \( \alpha_i \), \( \beta_i \) and \( \gamma \) determine the relative importance of resource preferences, timeslot preferences and defragmentation.
Subject to
\[ \sum_{d=1}^{D} M_{d,i} = 1 \quad i \in I \quad (2) \]
\[ \sum_{k=1}^{K} L_{k,j} = 1 \quad j \in J \quad (3) \]
\[ \sum_{k=1}^{K} Y_{d,k} = 1 \quad d \in D \quad (4) \]
\[ R_{i,j} = Y_{d,k} \times M_{d,i} \times L_{k,j} \quad i \in R, j \in J \quad (5) \]
\[ \sum_{i=1}^{I} X_{i,j,t} \leq 1 \quad j \in J, t \in T \quad (6) \]
\[ \sum_{j=1}^{J} X_{i,j,t} \leq 1 \quad i \in I, t \in T \quad (7) \]
\[ \sum_{j=1}^{J} \sum_{t=1}^{T} X_{i,j,t} = S_i \quad i \in I \quad (8) \]
\[ \frac{J \times T - \sum_{i=1}^{I} S_i}{T} \geq 0 \quad (9) \]
\[ X_{i,j,t} \leq Y_{d,k} \times M_{d,i} \times L_{k,j} \quad i \in E, j \in J, t \in T \quad (10) \]
\[ S_i = T \times V_i \quad i \in E \quad (11) \]

Integrality constraints
\[ X_{i,j,t} \in \{0,1\} \quad i \in I, j \in J, t \in T \]
\[ Y_{d,k} \in \{0,1\} \quad d \in D, k \in K \]
\[ V_i \in \{0,1\} \quad i \in I \]

The objective function (1) reflects a preference function combined with defragmentation that requires to be maximized subject to equations (2) until (11). Equation 2 and 3 ensure that users are assigned to exactly one department and that resources are assigned to exactly one cluster. Equation 4 states that every department will be allocated to exactly one cluster. Equation 5 determines the specific resource preferences of users. Equation 6 states that resources can only be utilized by one user at a time. Equation 7 ensures that users can only utilize one resource at a time. Equation 8 imposes that the amount of sessions scheduled for user \( i \) is always exactly the demand of session \( S_i \) of user \( i \). Equation 9
states that the maximum defragmentation is restricted by room capacity and session demand. Equation 10 ensures that every virtual user assigned for defragmentation can only be assigned to one similar cluster. Equation 11 imposes that every virtual user assigned for defragmentation is scheduled with demand of $T$ timeslots.

4.3. Solution

In literature different methods are discussed for developing feasible schedules. Jha (2014) studied the exam timetabling problem. For this problem the allocation of resources over time to perform a set of tasks was considered. The solution provided a timetable for exams, which can be compared to the allocation of users to resources and timeslots. A genetic algorithm was provided for solving the problem. The genetic algorithm can be used for many problems and can also be used for the scheduling problem introduced in this study. However the genetic algorithm does not always provide the most optimum solution and stops when the found solution satisfies a certain minimum criteria or after a predetermined number of generations. In addition the genetic algorithm does not scale well with complexity. Since the problem instance of the case study will consist of a high level of complexity the genetic algorithm will not be appropriate in this study.

Hulshof, Boucherie, Hans & Hurink (2011) studied tactical resource allocation and elective patient admission planning in care pathways. The main objectives were to achieve equitable access for patients, to serve the strategically agreed number of patients and to use resources efficiently. The tactical plan allocates resources to care pathways and determines which patients to be served at a particular phase of their care pathway. The method used in the study considers multiple resources, multiple time periods, multiple patient groups and uncertainties. Hulshof et al. (2011) used a mixed integer linear programming framework in combination with an iterative method in which weights are determined in every step. The disadvantage of this method is that there is no guarantee for an optimal solution.

Mixed integer linear programming is usable for optimization problem formulations where an objective must be maximized or minimized by changing decision variables, subject to some constraints. In a relatively high number of cases in literature (mixed) integer linear programming was used for deriving a feasible schedule. Wasfy & Aloul (2007) defined the university class scheduling problem (UCSP) as an ILP problem and thereby they successfully provided optimal solutions for reasonably sized problems. The UCSP is a problem formulation concerning the allocation of courses to a number of classrooms with respect to certain constraints, such as classrooms capacities and university regulations. Adan, Bekkers, Dellaert, Jeunet, & Vissers (2011) used a similar method for obtaining a tactical planning for elective and emergency patients at the operation room. They also used mixed integer linear programming (MILP) for finding a solution. The objective was to minimize the deviation between target resource usage and resource consumption. With simulation the effects of the schedule was tested on the set performance indicators.

This study considers the allocation of departments to clusters and the allocation of users to timeslots and resources. In addition users are a subset of departments and resources are a subset of clusters, which is making this problem formulation unique. Integer linear programming (ILP) can be used for
solving the mathematical problem. Software using the SIMPLEX algorithm would be appropriate. The advantage of the SIMPLEX algorithm is that it always provides an optimal solution. However, the disadvantage is that it may take an unreasonable amount of time (C. Mendez, 2006). Excel has an add-in “solver” which uses the SIMPLEX algorithm for finding optimal solutions for integer linear programming problems. Excel is user-friendly and easy interpretable. However, the size of the problem and the amount of decision variables will determine if solver can handle the complexity of the problem instance of the case study.
5. Case study Maasziekenhuis Pantein

Now the conceptual model and mathematical model is developed to allocate users to resources and timeslots, the model can be applied on the outpatient clinics of MZH to determine the effects of the allocation method on the scheduling strategy. In section 5.1 the settings of the case study will be discussed. In section 5.2 will be explained how the allocation method can be used to derive a fixed scheduling strategy. In section 5.3 relevant scenario’s with different session demand will be provided. In section 5.4 the mathematical formulation will be given. In section 5.5 the software will be provided to calculate the described mathematical formulation of the case study. In section 5.6 the verification will be shortly discussed and finally in section 5.7 the results will be provided.

5.1. Settings

In this section the settings of the model will be discussed. The input parameters are quantified in accordance with the situation of the departments geriatrics, neurology, internal medicine and pulmonary diseases of the outpatient clinics in MZH.

Timeslots
Currently every week the baseline schedule is repeated and thus the total time period of the schedule will be one week. Sessions are held in the morning and in the afternoon from Monday until Friday. Departments have different start and end times for sessions. From the detailed analysis it can be extracted that in the morning the earliest start time of a session is at 8:15 and the latest end time is at 12:40. In addition from the detailed analysis it can be extracted that in the afternoon the earliest start time of a session is at 13:00 and the latest end time is at 16:30. The start and end times of the timeslots are chosen such that every current session is possible in the timeslots without having overlap. The morning timeslot is from 08:00 until 13:00 and the afternoon timeslot is from 13:00 until 18:00. Thus every session can be scheduled within the timeslot, without having to change the current start or end times of sessions. The total available timeslots for rooms are 2 per day and 5 days a week, makes in total 10 timeslots per week. Timeslot 1 will stand for Monday Morning from 08:00 until 13:00, timeslot 2 for Monday afternoon from 13:00 until 18:00, timeslot 3 for Tuesday morning from 08:00 until 13:00, etc. If a session is planned in the morning or afternoon, the timeslot will be marked as occupied, no matter if the session does not utilize the entire timeslot.

Resources
The resources are represented by standardized consult rooms. The resource capacity includes rooms the departments currently use in the outpatient clinics and which are allocated to the departments. Figure 10 displays the rooms the departments use clustered into locations with receptions A, B and C.
Rooms 1 until 6 are clustered with reception A, rooms 7 until 13 are clustered with reception B and rooms 14 until 21 are clustered with reception C. The clustering rooms process is based on the distance between rooms and the reception and on stimulating minimum movement of medical staff outside the corridors. Clustering the rooms into locations is done in accordance with hospital management. Every location requires one reception. Table 5 can be derived from Figure 10 and quantifies the room capacity of the locations.

<table>
<thead>
<tr>
<th>Location</th>
<th>Amount of rooms</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
</tr>
<tr>
<td>B</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
</tr>
</tbody>
</table>

Table 5. Locations with room capacity
Users
Users are represented by specialists and nurses of the departments. Every user is assigned to exactly one department and for every user the timeslot preferences are defined. If a specialist uses three rooms in one timeslot (for pre-consultation and post-consultation), the specialist is represented by three users in the model with same timeslot preferences and same department allocations.

Emergency consults
From the data analysis it was retrieved that emergency consults often occupy only a relative small part of a timeslot. Thus it is possible to process more emergency consults in one timeslot of a room. For that reason it is interesting to allocate a single room for handling the emergency consults of all departments. The room should be fixed and available on all timeslots to retain transparency and reliability. In this way it will be clear for all departments which room can be used for scheduling emergency consults.

An aggregate planning of emergency consults can help to make more efficient use of rooms assigned for emergency consults of all departments. Aggregate scheduling of emergency consults will prevent departments from scheduling emergency consults on exactly the same moment within a timeslot. Consequently fewer rooms will be required for handling the emergency consults with use of an aggregate planning.

In the current way of working the department of neurology already assigned one room on all timeslots for emergency consults. In the sequence of the case study we assume that this one room already used for emergency consults by the department of neurology would be sufficient for handling all the emergency consults of all departments. The room for handling the emergency consults is added to the department of neurology because from the data analysis on the emergency consults was retrieved that the department processes the highest share of emergency consults.

5.2. Integrated fixed scheduling strategy
With an integrated fixed scheduling strategy, users are performing a fixed number of sessions on fixed timeslots in fixed rooms every time period. For example specialist A performs every week on Tuesday morning a session in room 3. The output consists of an integrated baseline schedule with users performing a fixed number of sessions, which are returning every week. The integrated baseline schedule will include all demand, users, rooms and timeslots of all departments and locations. Figure 11 shows an example of an integrated baseline schedule with 10 timeslots, 21 rooms, 3 locations (A, B and C) and 4 departments (P, IM, G and N)
### Figure 11. Example of an integrated baseline schedule

Every number-character combination represents an user of the medical staff. Every department in the example is clustered on one single location. Thus all room preferences are met, assuming no departments have specific preferences for a location and every department desires to be allocated to only one location. In addition 4 rooms are defragmented and fully available on one location.

#### 5.3. Scenarios

The following scenarios will be evaluated on the performance indicators timeslot preference violations, resource preference violations and defragmentation.

1. Current demand of sessions (existing session durations)
2. Forecasted demand of sessions (existing session durations)
3. Forecasted demand of sessions (4 - hour sessions)

In the first scenario the sessions from the baseline schedules displayed in the detailed analysis will be used as input for the model. In addition, the current timeslots of sessions of the medical staff are used as timeslot preferences. In this scenario start times, end times and durations of sessions are maintained. Different weight priorities will be given to evaluate the impact of the weights on the three performance indicators.

In the second scenario the forecasted demand of sessions will be inserted as input. From hospital management the forecasted demand of sessions is retrieved. The expectancies of growth of the department of geriatrics will be taken into account which is causing increasing demand for room capacity (detailed analysis). New medical staff is included and demand of sessions of current medical staff is in

<table>
<thead>
<tr>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>P4</td>
</tr>
<tr>
<td>A</td>
<td>P1</td>
</tr>
<tr>
<td>A</td>
<td>P2</td>
</tr>
<tr>
<td>A</td>
<td>P3</td>
</tr>
<tr>
<td>A</td>
<td>P1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>IM4</td>
</tr>
<tr>
<td>B</td>
<td>IM8</td>
</tr>
<tr>
<td>B</td>
<td>IM10</td>
</tr>
<tr>
<td>B</td>
<td>IM1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>N1</td>
</tr>
<tr>
<td>C</td>
<td>G2</td>
</tr>
<tr>
<td>C</td>
<td>N2</td>
</tr>
<tr>
<td>C</td>
<td>G3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>IM12</td>
</tr>
<tr>
<td>D</td>
<td>IM9</td>
</tr>
<tr>
<td>D</td>
<td>IM13</td>
</tr>
<tr>
<td>D</td>
<td>IM3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>IM10</td>
</tr>
<tr>
<td>E</td>
<td>IM7</td>
</tr>
<tr>
<td>E</td>
<td>IM1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>IM2</td>
</tr>
<tr>
<td>F</td>
<td>IM10</td>
</tr>
<tr>
<td>F</td>
<td>IM11</td>
</tr>
<tr>
<td>F</td>
<td>IM10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>IM12</td>
</tr>
<tr>
<td>G</td>
<td>IM1</td>
</tr>
<tr>
<td>G</td>
<td>IM8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>IM11</td>
</tr>
<tr>
<td>H</td>
<td>IM11</td>
</tr>
<tr>
<td>H</td>
<td>IM12</td>
</tr>
<tr>
<td>H</td>
<td>IM12</td>
</tr>
</tbody>
</table>
some cases adjusted in agreement with hospital management. Note that knowledge and experience of hospital management is crucial for determining forecasted demand of sessions.

In the third scenario the forecasted demand of 4-hour sessions will be inserted as input for the model. Currently the durations of sessions are at average 3,3 hours. The timeslots are from 8:00 until 13:00 and from 13:00 until 18:00, consisting of 5 hours per timeslot. One could decide to extend the durations of sessions and make more efficient use of timeslots, which will reduce the amount of sessions required. When fewer sessions are required, more timeslots of rooms will become available which can be defragmented. The available defragmented rooms could be used for other purposes. Therefore calculations are made to determine the required amount of 4-hour sessions.

Table 6 provides the current demand (scenario 1), forecasted demand (scenario 2) and forecasted demand if 4-hour session would be used (scenario 3), based on an one week baseline schedule and equal cumulative session durations.

<table>
<thead>
<tr>
<th></th>
<th>Geriatrics</th>
<th>Pulmonary diseases</th>
<th>Neurology</th>
<th>Internal medicine</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scenario 1</strong></td>
<td>40</td>
<td>16</td>
<td>38</td>
<td>69</td>
<td>163</td>
</tr>
<tr>
<td><strong>Scenario 2</strong></td>
<td>60</td>
<td>16</td>
<td>41</td>
<td>75</td>
<td>192</td>
</tr>
<tr>
<td><strong>Scenario 3</strong></td>
<td>51</td>
<td>12</td>
<td>34</td>
<td>66</td>
<td>163</td>
</tr>
</tbody>
</table>

Table 6. Demand of sessions for a one week baseline schedule

In total 210 timeslots are available for scheduling sessions (21 rooms multiplied by 10 timeslots). The current demand of 163 sessions can be extracted from the baseline schedules provided in the detailed analysis. The identified forecasted demand of sessions is 192 sessions. If a 4 - hour session system would be used, 163 sessions would be required. However, implementing a 4 - hour session system would require a large change in the current way of working for specialists. This applies especially for the cases where specialists have a complex agenda with many other dominant tasks. To determine the values for $S_i$ (sessions planned per user $i$), a fixed percentage is extracted from the original values of $S_i$ per user $i$ until the required amount of 4-hour sessions of the department was reached. This implies that the total supply of sessions in hours of all specialists combined of one department is still the same. However, the exact supply of sessions in hours per specialist within a department can slightly differ.

5.4. Mathematical formulation

**Decision variables**

\[ X_{i,j,t} = \begin{cases} 
1 & \text{if user } i \text{ is assigned to resource } j \text{ on timeslot } t \\
0 & \text{otherwise} 
\end{cases} \quad (i \in I, j \in J, t \in T) \\
Y_{d,k} = \begin{cases} 
1 & \text{if department } d \text{ is assigned to cluster } k \\
0 & \text{otherwise} 
\end{cases} \quad (d \in D, k \in K) \\
V_i = \begin{cases} 
1 & \text{if virtual user } i \text{ is enabled for defragmentation} \\
0 & \text{otherwise} 
\end{cases} \quad (i \in E) \]
Scheduling restrictions

\[ \sum_{k=1}^{3} Y_{d,k} = 1 \quad d = 1 \text{ to } 5 \]

\[ \sum_{d=1}^{5} M_{d,i} = 1 \quad i = 1 \text{ to } 40 \]

\[ \sum_{k=1}^{3} L_{k,j} = 1 \quad j = 1 \text{ to } 21 \]

\[ R_{P,i,j} = Y_{d,k} * M_{d,i} * L_{k,j} \quad i = 1 \text{ to } 30; j = 1 \text{ to } 21 \]

\[ X_{i,j,t} \leq Y_{d,k} * M_{d,i} * L_{k,j} \quad i = 31 \text{ to } 40; j = 1 \text{ to } 21; t = 1 \text{ to } 10 \]

\[ \sum_{i=1}^{40} X_{i,j,t} \leq 1 \quad j = 1 \text{ to } 21; t = 1 \text{ to } 10 \]

\[ \sum_{j=1}^{21} X_{i,j,t} \leq 1 \quad i = 1 \text{ to } 40; t = 1 \text{ to } 10 \]

\[ \sum_{j=1}^{21} \sum_{t=1}^{10} X_{i,j,t} = S_i \quad i = 1 \text{ to } 40 \]

\[ S_i = 10 * V_i \quad i = 31 \text{ to } 40 \]

Demand of sessions per user \( i \) per scenario

<table>
<thead>
<tr>
<th>User</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_i )</td>
<td>7</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>10</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

| User  | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| \( S_i \) | 5 | 10 | 4 | 4 | 2 | 1 | 3 | 6 | 6 | 5 | 10 | 5 | 5 | 8 |

Table 7. The number of planned sessions \( S_i \) per user \( i \) for scenario 1

<table>
<thead>
<tr>
<th>User</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_i )</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>5</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

| User  | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| \( S_i \) | 10 | 1 | 3 | 4 | 3 | 5 | 4 | 5 | 4 | 6 | 10 | 10 | 10 | 10 | 10 |

Table 8. The number of planned sessions \( S_i \) per user \( i \) for scenario 2
The number of planned sessions $S_i$ per user $i$ for scenario 3

5.5. Software

Different software packages can be used for finding a solution for the described mathematical problem in the case study of MZH. Optimization with the SIMPLEX algorithm would be preferred in order to find an optimal solution. First a small comparable problem instance was tested in Excel with solver using the SIMPLEX algorithm. Excel found an optimal solution for the simple test. However, when applying the problem instance of the case study, solver of Excel was not sufficient to find a feasible solution. Solver of Excel is limited to 200 decision variables (Frontline Solvers). Unfortunately, the problem instance of the case study has more than 200 decision variables.

To overcome this obstacle, subsequently the problem instance of the case study was modelled with help of CPLEX optimization studio of IBM. Excel supports a plugin of CPLEX. CPLEX is an optimization studio which makes use of the SIMPLEX algorithm, but also supports other types of mathematical optimization. The advantage of CPLEX is that it can handle more complex problem instances. With help of IBM CPLEX, we succeeded to find feasible solutions for the problem instance of the case study.

5.6. Verification

The verification of the conceptual model determines if the model is executed properly and if the derived integrated baseline schedule will be feasible. Furthermore in this section the current situation with respect to the performance indicators will be briefly discussed.

All the timeslot preferences are verified in the integrated baseline schedule. In addition the scheduled sessions per user, the preferred timeslots of users and the resource and timeslot preference violations in the derived integrated baseline schedule are identified. This is important in order to verify the model. Besides, it also helps hospital management to determine which alternatives were present for users on whom the resource preference violation or timeslot preference violation can occur.

As can be extracted from the baseline schedules provided in detailed analysis, currently 163 sessions were scheduled for 29 users of 4 departments (geriatrics, neurology, internal medicine and pulmonary diseases) in 21 rooms of 3 locations A, B and C. For 46 of 163 sessions the current baseline schedules did not provide an appropriate room. This means that the session was not performed in a room on the location where the reception of the department was positioned. In other words 28,2% of the resource preferences were violated. In addition at least one timeslot of all rooms was used for performing sessions and thus all rooms were required. This means that 0,0 % defragmentation was achieved. From interviews with hospital management was retrieved that the current timeslots of sessions correspond with the preferred timeslots of sessions of the medical staff. Thus 0,0% timeslot preferences were violated.
5.7. Results
In section 5.1 the settings of the case study were described. In section 5.2 was described how the allocation method of the conceptual and mathematical model can be used for scheduling rooms in the outpatient clinics. In section 5.3 three scenarios with different sessions demand were provided. Subsequently in section 5.4 the mathematical formulation was given, in section 5.5 the software was provided which was used to calculate the described mathematical problem formulation and in section 5.6 the verification was briefly discussed. In this section the results will be discussed. First for scenario 1, scenario 2 and scenario 3 we will propose a possible solution. Secondly, a summary of all possible solutions will be provided.

5.7.1. Solution scenario 1
Scenario 1 represents the situation where current demand of sessions is inserted, retrieved from the baseline schedules provided in the detailed analysis. Hospital management is interested in efficient use of space and efficient work processes. To answer this request we propose a possible solution in which all users perform sessions on the location where the reception is positioned in order to stimulate efficient work processes (0,0% resource preference violations). In addition 4 fewer rooms are required in order to achieve an efficient use of space (19,0% defragmentation). However, in the solution 7 sessions have to be scheduled on different timeslots than the original and preferred timeslots of sessions (4,3% timeslot preference violations). Figure 12 visualizes the solution.

![Current situation vs. After rescheduling](image)

**Figure 12. Visualization possible solution scenario 1**
The blocks represent rooms and the numbers in the blocks represent the timeslots of the rooms. Number 1 implies Monday morning, number 2 implies Monday afternoon, number 3 implies Tuesday morning, etc. If the timeslot is red, a session is scheduled in the timeslot. If the timeslot is green, it is available and free of sessions.

After rescheduling, all the users are allocated to a room of the location where the reception of the department is positioned. In this way all the sessions of users from a similar department are performed in rooms near to each other and near to the reception of the department. This stimulates the communication between the medical staff and between the medical staff and the reception. Movement outside the corridor is also minimized, because most movement of medical staff occur between the rooms where the sessions are performed and the reception of the department. In addition 4 adjacent rooms on one location are completely available after rescheduling and thus the 4 rooms can be used for a different purpose. For example the 4 rooms can be rent out to an external party or used by another department of the outpatient clinics.

5.7.2. Solution scenario 2
In scenario 2 forecasted demand of sessions is inserted as input, which is identified by hospital management. We propose a possible solution where the forecasted extra demand is included. The solution cannot be compared to the current situation in sense of rescheduling, because in the current situation fewer sessions are scheduled. In total 163 sessions are scheduled in the current baseline schedules of the detailed analysis, while in total 192 sessions are required to be scheduled if we consider forecasted demand. Figure 13 displays the solution.

![Figure 13. Visualization possible solution scenario 2](image-url)
In the proposed solution sufficient session time will be available for all departments in the integrated baseline schedule for planning consults. All users perform sessions on the location where the reception is positioned, which stimulates efficient work processes (0,0% resource preference violations). Furthermore 1 room is defragmented on the location where the reception of internal medicine is positioned (4,8% defragmentation). However, 3 sessions have to be scheduled on a timeslot other than a preferred timeslot (1,6% timeslot preference violations).

### 5.7.3. Solution scenario 3

In scenario 3 forecasted demand of sessions is considered. However, in scenario 3 session durations are standardized to exactly 4 hours per session. Currently the durations of sessions are between 2,5 and 4,4 hours with an average of 3,3 hours. By using 4-hour sessions, fewer sessions are required to fulfill consult demand. In scenario 3 only 163 sessions have to be scheduled compared to 192 sessions in scenario 2, while the cumulative session durations per department remains equal. We propose a possible solution which considers forecasted demand of sessions and 4-hours sessions. Figure 14 visualizes the solution.

![Figure 14. Visualization possible solution scenario 3](image-url)

In the solution 4 rooms are defragmented and fully available for other purposes (19,0% defragmentation). In addition all the sessions are performed on preferred timeslots (0,0% timeslot preference violations). However, in this solution 3 sessions have to be scheduled on a different location than where the reception of the department is positioned (1,6% resource preference violations).
5.7.4. Summary of results
In this section the impact of the described scenarios on the performance indicators timeslot preference violations, resource preference violations and defragmentation will be summarized and discussed. For every scenario all possible orders of priorities for timeslot preferences, resource preferences and defragmentation will be given. The most important priority is valued with a relative importance of 100, the second priority is valued with a relative importance of 10 and the least important priority is valued with a relative importance of 1. The relative importance values are based on a minimum multiplier of 10 between two performance indicators to ensure precedence. The results of the scenarios in combination with the orders of priorities are displayed in Table 10.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Performance indicators</th>
<th>current situation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>timeslot preference violations</td>
<td>0 (0,0%)</td>
</tr>
<tr>
<td></td>
<td>resource preference violations</td>
<td>46 (28,2%)</td>
</tr>
<tr>
<td></td>
<td>defragmentation</td>
<td>0 (0,0%)</td>
</tr>
<tr>
<td>1</td>
<td>timeslot preference violations</td>
<td>0 (0,0%)</td>
</tr>
<tr>
<td></td>
<td>resource preference violations</td>
<td>1 (0,6%)</td>
</tr>
<tr>
<td></td>
<td>defragmentation</td>
<td>1 (4,8%)</td>
</tr>
<tr>
<td>2</td>
<td>timeslot preference violations</td>
<td>0 (0,0%)</td>
</tr>
<tr>
<td></td>
<td>resource preference violations</td>
<td>2 (1,0%)</td>
</tr>
<tr>
<td></td>
<td>defragmentation</td>
<td>2 (9,5%)</td>
</tr>
<tr>
<td>3</td>
<td>timeslot preference violations</td>
<td>0 (0,0%)</td>
</tr>
<tr>
<td></td>
<td>resource preference violations</td>
<td>3 (14,3%)</td>
</tr>
<tr>
<td></td>
<td>defragmentation</td>
<td>4 (19,0%)</td>
</tr>
</tbody>
</table>

Table 10. The impact of scenarios and prioritizing on the performance indicators

In the order of priorities, timeslot preferences, resource preferences and defragmentation are represented respectively by the numbers 1, 2 and 3. Thus for example the order of priority 1 - 3 - 2 means that timeslot preferences are prioritized with a relative importance of 100, resource preferences are prioritized with a relative importance of 1 and defragmentation is prioritized with a relative importance of 10. Scenario 0 represents the original situation as discussed in the verification.

In scenario 1 current demand of sessions is used as input for the model. In scenario 1 at most 4 rooms can be defragmented. This means that 19% of all rooms are completely available on all timeslots on one single location. We can conclude from scenario 1 that it is possible to achieve 0 timeslot preference violations or 0 resource preference violations. However, this would be always at the expense of other performance indicators. It seems that the three performance indicators cannot be optimized simultaneously.

In scenario 2 the forecasted demand of sessions with respect to the current durations of sessions is used as input for the model. Similar to scenario 1, it is possible to optimize all performance indicators separately. However, again it appears that timeslot preference violations, resource preference violations and defragmentation cannot be optimized simultaneously.
In scenario 3 the forecasted demand of 4-hour sessions is used as input for the model. For all orders of priorities the timeslot preferences violations are 0,0%. This can be explained by the adjusted durations of sessions. Some of the sessions are cancelled because 4-hour sessions are used. However, the timeslot preferences of users still are maintained. Therefore the amount of preferences for timeslots outnumbers the demand of sessions and consequently less timeslot preferences are violated. From the results of scenario 3 it can be concluded that the timeslot preferences can be optimized simultaneously with resource preferences or defragmentation. However, resource preferences and defragmentation cannot be optimized simultaneously. For achieving 1 extra defragmented room, 3 sessions need to be scheduled in rooms where the reception of the department is not positioned.

Advantages and disadvantages
The advantages and disadvantages of the scenarios will be briefly summarized. Maintaining durations of sessions, using forecasted demand instead of current demand and the performance indicators will be taken into account. Table 11 summarizes the advantages and disadvantages of the three scenarios.

<table>
<thead>
<tr>
<th></th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecasted demand</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Maintaining durations of sessions</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Timeslot preference violations</td>
<td>0 - 7</td>
<td>0 - 3</td>
<td>0</td>
</tr>
<tr>
<td>Resource preference violations</td>
<td>0 - 2</td>
<td>0 - 2</td>
<td>0 - 3</td>
</tr>
<tr>
<td>Defragmentation</td>
<td>1 - 4</td>
<td>0 - 1</td>
<td>3 - 4</td>
</tr>
</tbody>
</table>

Table 11. Advantages and disadvantages of the three scenarios

In scenario 1 presumably not sufficient enough sessions will be scheduled in order to satisfy the expected consult demand. Hospital management indicated that they have received clear signs that some departments (e.g. department of geriatrics) have not enough session time for processing current consult demand. If the current number of scheduled sessions will be maintained, presumably not sufficient enough session time will be available for planning the consults. This will subsequently lead to long waiting lists for patients or in overflow of planned consults in the scheduled sessions (possibly at the expense of quality of care). However, with scenario 1 no change in the start and end times of sessions is required, leading in a minimum change in the current way of working. In addition it is possible to defragment up to 4 rooms, which is equal to 19,0% of the total room capacity.

In scenario 2 the total session time is expected to be sufficient for planning the consults. The forecasted demand of sessions identified by hospital management is assumed to be an accurate predictor. Waiting lists for patient will be minimum. In addition sufficient session time results in less stress for specialists, because specialists will experience less time pressure on performing consults. Furthermore in scenario 2 current durations of sessions are maintained, which consequently results in a minimum change in the current way of working. However, in this scenario only up to 1 room can be defragmented.
In scenario 3 the total session time is expected to be sufficient for planning the consults, because the forecasted demand of sessions is considered. In scenario 3 a 4-hour session system is taken into consideration. Implementing a 4-hour sessions system will have a large influence on the current way of working. The start/end times and durations of sessions will have to be adjusted and aligned to the current agendas of specialists. However, by implementing a 4-hour session system it would be possible to defragment up to 4 rooms, while still satisfying forecasted demand of sessions.
6. Implementation

In this section will be discussed what is required to implement the model. Furthermore guidelines will be provided to show what is needed to use the decision tool. The focus will be on implementation of the model on the outpatient clinics within hospitals. Any other purpose is out of scope in this section.

The model cannot always be used because of certain restrictions and limitations. In order to use the model a fixed scheduling strategy is required. In a fixed scheduling strategy, scheduled sessions are returning every time period. This implies that for example every week user A is scheduled in room 3 on Tuesday morning to perform a session. The model schedules a fixed number of sessions per user and the number of scheduled sessions should be precisely aligned with the demand of sessions. Therefore, the demand of sessions should be known in advance and fixed. Moreover, applying the model is most effective when the fixed scheduling strategy includes multiple departments (with users) and multiple locations (with rooms). In the case study the departments only use standardized consult rooms with fixed dimensions. In order to use the model it is necessary that the rooms within the outpatient clinics are flexible and can be used by users of all departments.

In this study the calculations are made in Excel with use of IBM CPLEX optimization studio. If one does not have experience with these software programs, it will be very difficult to use the current elaboration of the model in Excel. Note that the decision tool shall be used by hospital management. For that reason it is advised to develop a tool which can be used without having specific knowledge of CPLEX optimization studio. The following requirements for the tool are identified:

- Easy to use
- Accessible
- The output should be clear and easily interpretable
- Preferred to be implemented in already acquired software

The following parameters must be set for using the model; users, departments, rooms, locations and timeslots. Subsequently the user-to-department and room-to-location allocations must be defined. In addition the specific timeslot preferences per user, required amount of sessions per user and the number of virtual users (equal to the maximum number of rooms allocated to one location) needs to be determined. Finally the relative importance of timeslot preferences, room preferences and defragmentation must be inserted. These values are assessed by hospital management and will determine the balance between the performance indicators.

The decision tool will be useful when a change in situation develops. A change in situation implies one of the following developments: change in session demand (e.g. additional sessions for an already existing user or completely new users), change in time preferences of users or change in priority of performance indicators (e.g. a necessity for space or rooms). In case one of these developments occurs, it will be interesting to use the decision tool. It is advised to apply different weights to the values of the relative importance’s in order to receive information about the possible balances between the performance indicators. Finally the decision tool will generate a feasible integrated baseline schedule.
7. Conclusion and recommendations

In this section the conclusion will be provided to answer the research question described in section 2.3 and reflect on the research assignment stated in section 2.4. Subsequently recommendations for MZH will be provided and recommendations for further research will be given.

7.1. Conclusion

The literature review showed that little research was conducted into space utilization of the outpatient clinics. The question of hospital management was; how can space be more efficiently used in the outpatient clinics? By changing the planning and scheduling of rooms, space can be more efficiently used without making high cost physical changes to the layout of the outpatient clinics. The research was conducted in order to get more insight in the current room utilization and to find a solution for more efficient use of rooms in the outpatient clinics. The aim of this study was to answer the following research question:

*How can a decision tool be developed to assist managers to allocate users to rooms and timeslots in order to make efficient use of room capacity and stimulate efficient work processes while having a minimum change in the current way of working?*

The research question is strongly related to the research assignment. The research assignment was generalized and formulated in a way that it can be used for more alternative problem formulations. The research assignment stated:

*Develop a tool to allocate users to resources and timeslots in order to utilize resources efficiently and maximize resource preferences and timeslot preferences of users*

In order to fulfil the research assignment, a generalized conceptual and mathematical model was developed to allocate users to timeslots and resources. The allocation is based on timeslot and resource preferences of users and defragmentation of remaining available resources. In the model specific timeslot preferences of users are maximized. The resource preferences of users are created by department to cluster allocations. Every user is part of a department and every resource is part of a cluster. If a department is assigned to a cluster, every user of the department will receive preferences for every resource of the cluster. The created resource preferences of users are maximized as well. In addition remaining available resources are defragmented as much as possible on a single cluster on all timeslots, so that the resources which are made available on all timeslots can be used for other purposes. Consequently less resources are required and a higher utilization rate of resources is achieved. Three performance indicators were designed in order to analyse the effects of the allocation method. The designed performance indicators are resource preference violations, timeslot preference violations and defragmentation. Because the three performance indicators cannot always be optimized simultaneously, weights are added. The weights given to timeslot preferences, resource preferences and defragmentation determines the relative importance for optimization. The mathematical model is
elaborated in Excel, representing the tool as stated in the assignment. Excel and IBM CPLEX optimization studio are required for execution of the tool.

To provide an answer to the research question, a case study is performed on the outpatient clinics of MZH. The detailed analysis showed that currently baseline schedules of one week are developed for every department of the outpatient clinics based on the number of rooms allocated to the department. The baseline schedules are repeated every week and therefore the baseline schedules provide transparency and reliability to the users, making it a strong scheduling strategy. The developed conceptual and mathematical model can be used for deriving an integrated baseline schedule considering multiple departments and multiple locations with rooms representing resources, medical staff representing users and timeslots representing day parts.

Three scenarios were discussed with respect to the designed performance indicators. In the first scenario current demand of sessions was considered with regular durations of sessions (average of 3,3 hours). In the second scenario forecasted demand of sessions was used as input for the model. In the third scenario demand of forecasted 4-hour sessions was used as input for the model. The results of the case study show us that if the model would be applied on the scenario with current demand, 19% less room capacity would be required and 28,2% more sessions would be performed in rooms on the same location as where the reception of the department is positioned, which will increase the efficiency of work processes by less movement of medical staff and increased stimulation of communication. However, for this solution 7 sessions have to be scheduled on another timeslot than the preferred timeslot of the specialist (4,3% resource preference violations).

Furthermore, for all three scenarios it was not possible to optimize the three performance indicators simultaneously. In scenario 1 and scenario 2 only 1 performance indicator could be fully optimized. The optimization of one performance indicator was always at the expense of the other 2 performance indicators. In scenario 3, timeslot preferences were in all situations fully optimized. However in the third scenario it was not possible to optimize resource preferences and defragmentation simultaneously.

The decision tool to assist managers is represented by the model for the allocation of users to resources and a timeslots. In section 6 a manual is provided which explains what is required for managers to use the decision tool. The model gives insight in the minimum amount of resource violations and the minimum amount of timeslot preference violations possible. In addition the model shows what the consequences are of defragmentation for the other two performance indicators. The model is elaborated in Excel. In order to use the decision tool, Excel and IBM CPLEX optimization studio are required for executing the model.

7.2. Recommendations for MZH

The data-analysis on the emergency consults showed us that if an aggregate planning system would be used for scheduling emergency consults, only one room would be sufficient for handling the emergency consults of all departments. Therefore, it is advised to include one room dedicated fully for handling the emergency consults of all departments.
Currently 21 rooms in the outpatient clinics are used by the departments geriatrics, neurology, internal medicine and pulmonary diseases. In total 46 sessions performed by those departments are performed in rooms not on the same location whereas the reception of the department is positioned (28,2% resource preference violations).

It is advised to implement one of the provided possible solutions of scenario 2 or scenario 3. Scenario 2 and scenario 3 both take into account the forecasted demand retrieved from hospital management. Hospital management received clear signals that some departments (e.g. geriatrics) do currently not have sufficient scheduled session time in order to process demand of consults. The forecasted session demand will provide sufficient session time for the departments and thereby presumably remove the signals of shortage of rooms.

In scenario 2, even with increased forecasted demand it is possible to use 20 rooms, instead of the current situation where 21 rooms are used. In addition resource preference violations can be reduced from 46 to 2 without having any consequence on the timeslot preference violations. Thus the current preferred timeslots of sessions can be maintained fully. Resource preference violations can be further minimized to 0, however this would be at the expense of 2 timeslot violations. In other words, 2 more sessions can be performed in rooms on the location where the reception is positioned, but in order to do so 2 sessions will have to move to another timeslot.

In scenario 3, the required amount of rooms can be further reduced to 17. The current baseline schedules are based on 21 rooms. However, all session durations must be standardized to exactly 4 hours. Implementing a 4-hour session system will require a large change in current way of working for specialists, because specialists have complex agenda's with many other dominant tasks. For all possible solutions of scenario 3, specialists can maintain working on the preferred timeslots of sessions. Furthermore the resource preference violations will be reduced from 46 to 3. It is even possible to reduce resource preference violations to 0. However, in that case 18 rooms would be required and only 3 rooms could be defragmented fully available.

The decision on the trade-off between resource preference violations, timeslot preference violations and defragmentation has a large influence on the complexity of the implementation. Specialists perform sessions on specific fixed timeslots in the week. Moving a session to another timeslot is very difficult due to other tasks in the agendas of specialists. Therefore it is recommended to minimize timeslot preference violations.

7.3. Recommendations for further research
This study provided insight in room capacity utilization of outpatient clinics and a model to allocate users to resources and timeslots in order to optimize resource utilization and satisfy timeslot and resource preferences. In literature little was found about room utilization in outpatient clinics. Often room utilization is assumed to be subordinate to the utilization rate of specialists, because time of specialists is more expensive. However, this does not alter that space is often a fixed asset and needs to be utilized as
best as possible to facilitate sessions of specialists. Space occupation of outpatient clinics is an active topic in many hospitals and therefore more research into this area is important.

One of the limitations in this study is that the developed model did not promote users to be scheduled in the same room. In the model users from similar departments were scheduled as much as possible on similar locations. However, within the location the model did not make a distinction to what room the user was specifically allocated. Scheduling users consistently in the same room would provide better transparency to the users. Adding consistent room allocation preferences to the model could be interesting in practice.

This study did not consider flexible receptions. It could be interesting to conduct a study into the allocation of users to resources and timeslots considering flexible department to cluster allocations. In this study it was not considered that receptions have the possibility to change from location between timeslots. When receptions can be changed from location between timeslots, locations will have variable room capacities. Variable room capacities of locations can result in better alignment of supply and demand of rooms.
References


*Frontline Solvers*. (sd). Opgeroepen op August 30, 2014, van Frontline Solvers:


Appendix 1: Services of Servicebedrijf Pantein

Management Service bedrijf

Secretary

Staff
- Consultancy and execution M&V
- Consultancy construction
- Strategic purchasing
- Project management
- Policy and consultancy

ICT
- Workplace and Servicedesk
- System and network management
- Information management
- Application management
- Telephony and accessibility
- Information security management
- Consultancy

Technical Maintenance and Logistics
- Technical services
- Medical electronic services
- Warehousing
- Logistics
- Frontoffice, reception and security
- Repro, post and archive
- Consultancy

Business Administration
- Financial administration
- Salary administration
- Debtors' ledger
- Purchasing and credit management
- Consultancy

Facilitating service
- Cleaning service
- Roomservice
- Logistics
- Greenservices
- Consultancy

Meals and Catering
- Meal preparation VPA MZH
- Meal preparation restaurant MZH
- Exploitation Grand Café MZH
- Meal preparation for people at home (Tafeltje Dekje)
- Space and catering for internal and external customers
- Consultancy
Appendix 2: Employee structure of Servicebedrijf Pantein
Appendix 3: Specialism’s of Maasziekenhuis Pantein

- Anaesthesiology
- Cardiology
- Dermatology
- Surgery
- Internal medicine
- Otorhinolaryngology
- Children medicine
- Geriatrics
- Pulmonary diseases
- Gastrointestinal and liver diseases
- Microbiology
- Neurology
- Nuclear medicine
- Obstetrics and gynaecology
- Ophthalmology
- Orthopaedics
- Pathology
- Radiology
- Radiotherapy
- Rheumatology
- Rehabilitation medicine
- Urology