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„**Staff Scheduling for the Red Cross blood drives in Vienna, Lower Austria and Burgenland**"

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Staff Scheduling for the Red Cross blood drives in Vienna, Lower Austria and Burgenland

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Abstract

This work provides an initial solution for a real world problem in the area of staff scheduling for blood collection drives executed by the Red Cross in Austria. The Red Cross operates blood drives in Lower Austria, Vienna and Burgenland and assigns the required employees manually to them. The tasks at a blood drive require that employees from different professional groups and within one professional group with different skills can be found. The staff scheduling involves legal and contractual requirements which must be satisfied. The Red Cross additionally defines the minimum number of personnel for each blood drive and guarantees that the necessary transportation is provided. The overall objective is to create feasible schedules for all employees while covering demand at the blood drive and minimizing the total personnel costs. Furthermore, the generated schedules must be created in compliance with legal regulations and contractual requirements of the employers.

The hard constraints of the problem are identified and cost minimization is defined as the objective function. A mathematical model is formulated and implemented in C++ and tested on real world examples. Nine examples are solved and compared. The solutions and costs are tested for increasing numbers of blood drives and temporary shortfalls of personnel. The results of the examples and the variations are presented and compared.

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List of Abbreviations

MIP	Mixed Integer Programming
WH	Working Hours
BC	Blood Collection

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1 Introduction

1.1 Problem description

The Austrian Red Cross is primarily responsible for the secured supply of blood and blood products in Austria. More than 400,000 units of blood are needed every year in Austria's hospitals. To secure this amount of required blood, the blood donation centres throughout Austria undertake blood collection drives. This paper concentrates on the blood donation centre in Vienna, which is responsible for drives in Vienna, Lower Austria and Burgenland. The employees in Vienna organize more than 1,400 blood collection drives every year within these three provinces. For each drive, an estimated number of participants or volunteers are given as well as the duration of each blood drive.

The number of employees that are needed to fulfil the different tasks during such a drive can be calculated with the Red Cross intern distribution key in combination with the above-mentioned number of expected participants and the duration of the blood drive. There are three different types of employees, doctors, graduate nurses and medical staff. Each of them has different skills, different contracts and different availabilities (for example weekend-contracts). The main aim of this paper is to create a model that schedules each employee to a blood drive where the skills of this employee are required, and providing that no legal or contractual regulations are violated. At the moment, the personnel scheduling is done manually every three weeks and occupies the time of two employees for two days. This should be changed through a correct staff scheduling program.

The scope of the work is to find individual schedules that guarantee full demand coverage while minimizing additional costs of overtime and weekend working hours. Further, a solution is only feasible if the complex legal requirements such as week and weekend rest times and the individual contractual restrictions for each employee are satisfied.

The objective of the presented model is to assign employees with the right skills to blood collection drives, where they and their skills are needed, while minimizing additional personnel costs. The goal is to reduce inefficient assignments of workers with an "old" (i.e., more expensive) contract and to minimize overtime costs. The waiting time for the participants and/or donors should at least remain stable.

The upcoming paper is structured as follows: First, the blood donation sequence will be introduced in section 2. Next, a classification of this problem is given as a part of the literature review in section 3, which also describes work in this field done so far. Section 4 concentrates on the analysis of the provided data about the blood collection drives and the employees. Section 5 starts with the pre-arranging and pre-processing of the needed input data for the model. The mathematical model is then presented in section 6 together with the solution method while section 7 concludes the paper and ends with an outlook for further research.

2 Blood donation process

2.1 Professional groups, tasks and donors

The Red Cross employs three different professional groups. To these groups belong doctors, graduate nurses and medical employees. The actual contract agreements can be divided into old and new contracts, which apply to every professional group. This means that doctors can have either an old or a new contract depending on their hiring date. This is true for graduate nurses and medical employees as well.

The blood donation process consists of six tasks. These are: medical briefing, testing, puncture, blood collection, being the "Teamer" and giving out refreshments. There are two additional tasks which are called "Tagesteamverantwortlicher (TTV)" and "Vorortleiter". These two additional functions, which are designated by the Red Cross, are not scheduled separately. The reason for this is that the responsible person for the day (TTV) is an additional qualification that mainly applies to all graduate nurses who execute the puncture. This is also true for the person who is the contact person for the hosts and the team, the so-called "Vorortleiter" (VOL). Most of the medical staff is able to execute this role. These two functions are considered desirable by the Red Cross, but they do not involve an extra scheduled person, because a missing TTV or VOL would not prevent the drive. Because they are not relevant for the scheduling of Red Cross employees to blood collection drives, these tasks will not be further addressed here.
The relevant tasks within the blood donation sequence and the corresponding employees who have the skills to fulfil these tasks are presented in Table 1.

The most important players during a blood donation process are the volunteers. The Red Cross calls the willing donors participants and after a participant donates blood, he/she becomes an actual donor. In the following descriptions the total numbers of people coming to donate are called participants or volunteers or willing donors, but the actual people who finally donate blood are described as donors from here on.

Professional group	Skills/Tasks
Doctor	**Medical briefing**; decision of acceptance/rejection
Doctor **OR** **Graduate nurse**	**Test:** blood pressure; body temperature M < 38°; F <37.5°; haemoglobin level M ≥ 13.5g F ≥ 12.5g
Graduate nurse	**Puncture**
Medical staff	**Blood collection**
Medical staff: Teamer	orders the blood samples and counts them
Graduate nurse: TTV (Tagesteamverantwortlicher)	Normally the person who does the puncture
Medical staff: VOL (Vorortleiter)	Additional qualification of a medical staff

Table 1: Tasks per professional group

2.2 Blood donation sequence in the Blood Donation centre in Vienna

The following explanations have resulted from a one-day observation period in the blood donation centre in Vienna (Wiedner Hauptstraße 32, 1040 Vienna). The centre is open from Monday to Friday with different opening hours where willing donors can come and donate their blood if it is allowed according to Austria's blood donation regulations. First of all, the detailed steps until the actual blood donation takes place are described, based on the stations within the centre. Building on this detailed information, the blood donation sequence in Red Cross donation buses and buildings outside the centre will be examined.

The blood donation process in the centre in Vienna is in some points different to the outside activities across Vienna, Lower Austria and Burgenland. However, all the upcoming described stations also exist during blood collection drives outside the centre.

As already mentioned, all the people arriving and willing to donate are called participants and the actual number of participants who are finally allowed to donate are called donors. Generally, approximately ten percent of the participants are rejected during one day in the centre or during a blood collection drive outside the centre. Reasons for rejection are very broad, for example, vacations abroad and use of pharmaceuticals are the most frequent reasons. The five main stations a participant who later becomes a donor has to pass through are called as follows:

1. Medical Donor Questionnaire
   - Questionnaire must be filled in and blood pressure measured (done by a medical staff)
2. Anamnesis or Testing (done by a DGKS = Diplomierte Gesundheits-u. Krankenschwester; graduate nurse)
   - Body temperature and haemoglobin level (=red blood cells) are measured
3. Medical briefing (done by a doctor)
4. Blood donation (done by a graduate nurse and medical staff)
5. Donor Café (done by a medical staff)

These five main stations are now described in more detail. Each station has the same number as in the short overview and the same station numbers are mentioned in Figures 1 and 2 for illustrating the blood donation process. Figure 1 shows the total process and Figure 2 concentrates on the number of participants per professional group at the time.

1. In the blood donation centre in Vienna there is a large entrance hall where the participants take a medical questionnaire, sit down and fill it in. During this time a medical worker helps with any questions and checks on the completeness of the questionnaire. Furthermore, this employee pays attention to the hydration level of the participant and offers drinks. Last but not least, the employee measures the blood pressure and offers the participant glucose in case of low blood pressure. The participant must be able to understand, read and answer all the questions on the questionnaire. The employees are not allowed to help answering the questions and they are also not allowed to translate the questionnaire written in German into any other language. On average, the first station takes three to four minutes.

2. a) Once the questionnaire is filled in, the participant is allowed to go to a separate room where a graduate nurse performs a medical test. The participant must show a valid photo identification document (like a driver’s license or passport) and his/her donation card, if

he/she has one. If the participant has no valid photo ID then he/she is not allowed to donate. This circumstance causes an immediate rejection of the participant.

b) If the participant has a valid photo ID, the process continues. The graduate nurse takes the questionnaire and the valid photo ID and enters the full name of the participant into the computer. The employee goes through the questionnaire with the participants and asks about recent vacations, stays abroad, use of pharmaceuticals, recent surgeries and diseases. The graduate nurse has a list of countries visited, surgeries performed and pharmaceuticals taken within specific time windows for which the participant is not allowed to donate blood. If, as a result of these rules, a participant is not allowed to donate blood, his/her questionnaire is so marked and the participant has the possibility to talk to the doctor or to end the blood donation process and come back after a prescribed waiting time. Otherwise, if the questionnaire is complete and no other problems occur, the graduate nurse measures the body temperature and the red blood cell level of the participant. There are different thresholds in both cases for men and women. The body temperature must be below or equal to 38 degree Celsius for women and below or equal to 37.5 degree Celsius for men. On the other hand, the haemoglobin level must be higher than or equal to 12.5 grams per deciliter (g/dl) for women and for men the value must be higher than or equal to 13.5 g/dl. If the temperature is too high, the participant has again two options. He/she would be allowed to see the doctor, because the doctor can make the final decision about donation. Otherwise, the process ends at this point for the participant. In case the haemoglobin level is too low, the participant has the possibility to obtain a blood count where the haemoglobin value is measured again, but with a more exact medical device. If the value is also too low with this additional measurement, then the participant has to talk to the doctor, who makes the final decision about how to proceed. This second and more precise haemoglobin test is only available in the blood donation centre in Vienna and is not possible outside the centre.

All anomalies that the graduate nurse observes and which are relevant for the blood donation are noted on the questionnaire. Therefore, the doctor is able to ask the right questions very quickly and can come to a final decision. The duration of this second step is around 2.5 minutes for people with a donation card and around 5 minutes for first-time donors. The following section describes some real life situations that occur within the second station.

Participant A: A first-time donor arrived at the centre, filled in the questionnaire and went to the graduate nurse for testing. The full name, the birth date and the ID card number was entered into the computer. This person had an open wound and therefore the graduate nurse sent the potential donor directly to the doctor without testing. The doctor rejected this person because of the open wound and noted the reason for the rejection on the questionnaire. The questionnaire came back to the graduate nurse where it was scanned and stored under the participant's name. This is a classical example of a participant who does not become a donor.

Participant B: This person was several times a donor and already had a blood donation ID card. The graduate nurse asked about drugs and vacation or trips outside of Austria. The graduate nurse had a full list of countries and regions which are in malaria regions or countries with lower hygiene standards than Austria. This potential participant was on vacation in Turkey and had been back for two weeks. The list says that four weeks must pass between a stay in Turkey and a blood donation, because Turkey is a country with lower hygiene standards than Austria. As a result, the willing participant was sent to the doctor and the doctor rejected the person and noted that it would be possible to donate after an additional period of two weeks. This information was written on the person's questionnaire and again scanned and archived.

These examples show the work that a testing employee, whether a graduate nurse or a doctor, has to do and the details to which particular attention must be paid regarding the different reasons why a person cannot donate. It also demonstrates that the graduate nurse often knows after a talk with the participant that the person would be not allowed to donate, whereas the final decision about rejection is always made by the doctor. This station is described in the next paragraph in more detail. The one case where the graduate nurse can also reject a participant is when the person carries no valid photo ID. In this case, the graduate nurse can reject the participant immediately without further intervention from the doctor.

3. A decisive station within the blood donation process is the interview with the doctor, which is also called the medical briefing. The doctor reads the notes of the graduate nurse and asks specific questions based on the notes. For example, the graduate nurse is allowed

to ask which drugs the participant takes, but the doctor is responsible for asking why, for how long and for what reason/illness the participant is taking them. If this interview ends with a final rejection, the participant is advised about how long he/she should wait before coming again. This date is also noted by the doctor on the questionnaire. The questionnaire with all notes is brought back to the graduate nurse for storage. If the medical briefing ends positively and the participant is allowed to donate, he/she proceeds to the blood donation room.

4. The accepted participant is assigned to a bed and a medical worker takes care of them. The medical worker checks the questionnaire, asks for the participant's full name and birthday and scans the serial number on the questionnaire, which was assigned in station 2. The medical employee prepares seven ampoules per donor. They are marked with a barcode as well as the preserves and get scanned. This process makes it possible to assign the ampoules to the donor. The actual puncture is performed by a graduate nurse. A blood reserve consists of 450 ml blood and it takes around 12 minutes to fill. After this time, the graduate nurse removes the needle and the medical worker puts a bandage around the arm of the donor. Also the medical worker takes the preserves and brings them to a collection station or gives them to the "Teamer" along with the questionnaire. At the end of the day, the teamer is responsible to ensure that the exact same number of questionnaires and preserves are there. The "Teamer" is a medical worker with a specific training and usually more experience.
5. After a successful blood donation, the donor is invited to eat and drink at the donor Café.

As mentioned before, the following section discusses the stations and the differences in a blood donation bus as well as in locations outside the centre. This is because the stations in a bus collection and in local locations are different, compared to the centre. Altogether, there are three slightly different blood donation sequences, but the core tasks and employees required to fulfil these tasks remain the same.

2.3 BUS Blood Collection Drive

The following description is based on observations made during the bus collection drive in Ravelsbach, Lower Austria, on the 12th of August 2016.

A blood collection drive involving a blood donation bus follows a slightly different procedure. The first station only includes the filling in of the questionnaire. Normally, there is no designated employee scheduled for this first station. The questionnaires are placed at the end of the bus and participants are invited to take them and fill them in. Because of the reduced dimensions of a bus, the stations 2. – 3. are combined into one station. This second station is controlled by a doctor, who does the testing (which is normally done by a graduate nurse) and the medical briefing at the same time. After this step is done, there is a separate room where the doctor carries out the medical briefing plus testing. The doctor checks if all the blood values are within the allowed thresholds and notes everything important on the questionnaire. The questionnaire gets scanned and archived in the centre in Vienna, when the blood drive is over and the bus has returned. A regular bus is filled with four beds and the scheduled employees consist of one graduate nurse who does the puncture and two medical workers who are in charge of the blood collection, each of them for two donors simultaneously. As in the centre, there is also an employee with the role of “Teamer” who takes care of all blood donations and questionnaires. After the blood donation is finished, a refreshment station is established for the donors at the other end of the bus. Either the hosts organize such a station on their own, outside the bus, or the Red Cross brings something to eat and drink. In both cases, the host has to request a person from the Red Cross to provide the refreshments, if someone is needed. In that case, a medical worker gives out the refreshments.
As can be seen, the sequence in a bus is shortened and generally a doctor performs two tasks instead of one. Also, the first station takes place without any supervision and the participants have to fill in the questionnaire on their own.

2.4 Blood Collection Drives in Vienna, Lower Austria and Burgenland

The following blood collection drive took place in Langenlois, Lower Austria, on the 17th of August 2016. The collection drives using teams and team cars instead of buses have the same stations as the centre in Vienna. The only difference is that no staff is there to help with the questionnaire and/or measuring the pulse at the beginning of the process, which also happens during bus collections. The blood collection drive in Langenlois is one of the biggest collections of the year. There are usually around 220 participants and a large number of Red Cross staff is needed. In this example, five testing graduate nurses were required, along with two doctors and two graduate nurses doing puncture; nine blood-collecting colleagues took care of 18 donors simultaneously. The questionnaire is available at a table at the entrance area of the provided location, and it must be filled in without any supervision. Afterwards, a graduate nurse performs the testing and sends the participant to the doctor for the medical briefing. If the doctor decides that the participant is able to donate, the participant comes to an extra area for blood donation. A medical worker takes care of the donor and brings him/her to an available bed. A graduate nurse does the puncture and the medical worker takes care of the blood reserve and all the other samples, as described in detail in the blood donation procedure in the centre. The teamer collects the blood reserves, stores them properly and checks the completeness of the questionnaires and corresponding blood reserves. After the completed blood donation, the donor is invited to have some refreshments. These refreshments are either given out by a medical worker or by a person who is provided by the host organization of the location. Figures 1 and 2 show the blood donation process in the centre in Vienna and for the blood collection drives with team cars.

Non-acceptance
Noted in the system

Fill in the **questionnaire** 1

Test (Graduate nurse)
Checks:

No

Photo ID 2 a

Yes

Further Checks:

- Questionnaire
- Asks about stays abroad, holidays in foreign countries, drugs
- blood pressure
- body temperature M < 38°; F < 37.5°
- haemoglobin level M ≥ 13.5g F ≥ 12.5g

2 b

Approx. 10% get rejected

Medical briefing (Doctor)
Evaluates the notes from the Pretest
<u>Makes the final decision</u>

3

Not allowed to donate

Allowed to donate

Donation
Puncture **(Graduate nurse)**
Blood collection **(Medical staff)**
Teamer **(Medical staff)**

4

Refreshment
(**Medical staff)**

5

Figure 1: Blood donation process

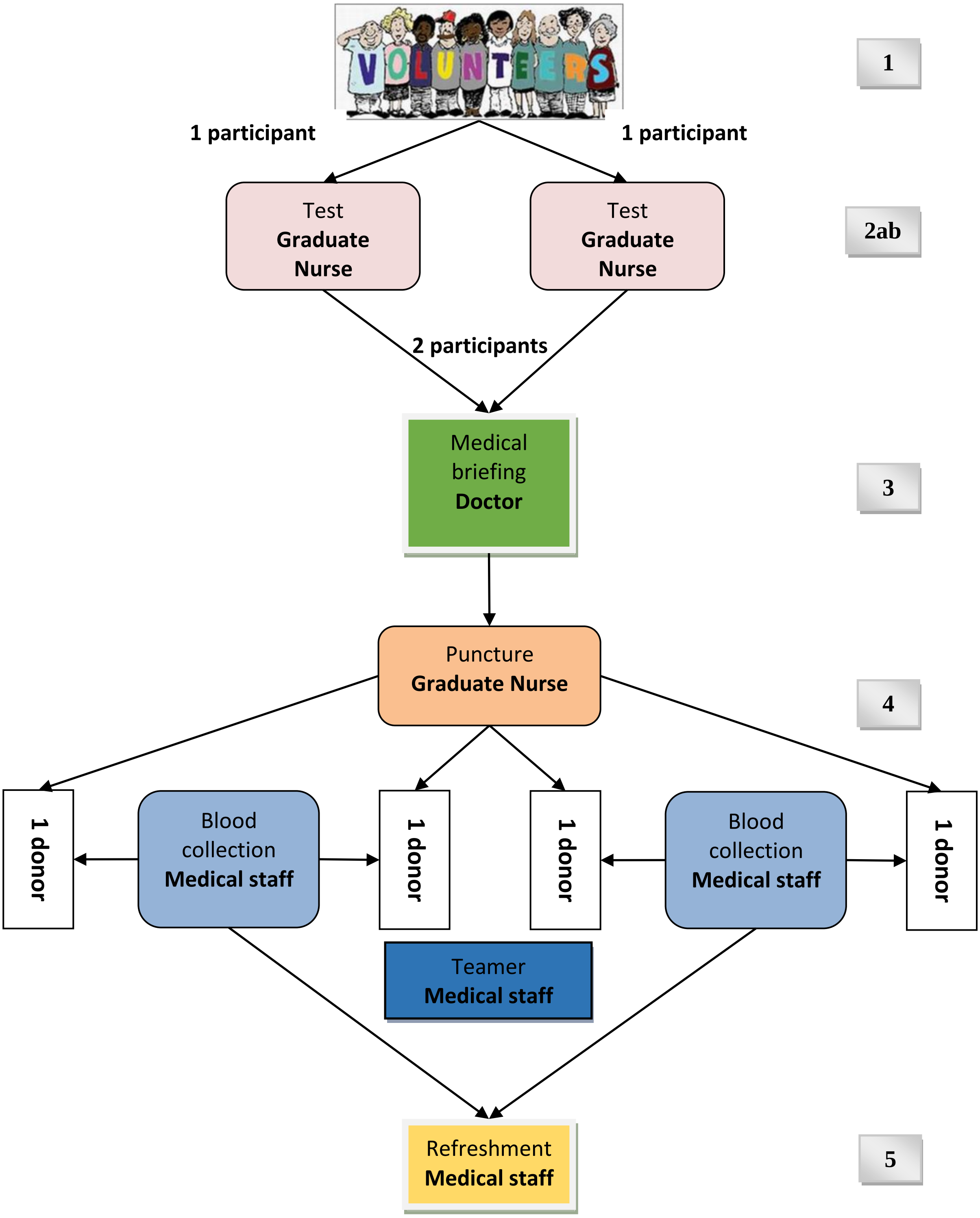

Figure 2: Blood donation sequence - Participants per tasks and professional group

3 Literature Review

3.1 Classification

The scheduling or rostering problem is a very well-researched topic. The first studies took place in the 1950s, where Dantzig [7] evaluated the work of staff scheduling in toll booths to avoid traffic delays. The only requirement was that the needed number of toll booths was staffed with a worker for a time period *t*. Each worker had the same skills and shifts and was either assigned to a toll booth or not. Since that time, the staff scheduling problem has become more complex.

The restrictions have emerged because the companies were confronted with full- and part-time contracts, paired with employee preferences. On the other hand, there are economic incentives to implement a cost-efficient staff assignment program which satisfies the demand and employee needs. Due to the fact that personnel costs are the main component of company expenses, the staff scheduling problem occurs in nearly every industry. In addition, the Red Cross as a non-profit association tries to reduce its costs and attempts to satisfy their donors in the most effective way possible. Since the Red Cross has its own constraints and restrictions, it is difficult to find comparable literature. Each staff scheduling problem includes so many different aspects that standardization of this problem is not easy to find.

The work of Van den Bergh et al. [13] clusters the existing literature into personnel aspects, considered constraints, used solution methods and areas of application. The majority of research papers that consider personnel characteristics only deal with full-time contracted workers; only a few studies take part-time workers into account. A real-world problem like the Red Cross scheduling problem must be implemented using a mixed workforce because this is the actual case. Hand-in-hand with the contract types one must consider the skills of the employees. There are papers where all workers have the same skills; some deal with a hierarchical structure and further papers deal with skills that only specific workers can execute. This paper falls into the last group because within the Red Cross there are different professional groups; each group can generally do specific tasks, but also within such a professional group there are differences between existing and missing skills. Theoretically, the problem belongs to the hierarchical skills group, because a doctor can do the same tasks as a graduate nurse, but in a hospital this is not the general rule and from an economic standpoint, it does not save costs if higher skilled workers with higher wages carry out lower-level tasks. The second characterizations are constraints, either hard or soft constraints. The absolute key constraint throughout the literature is the demand coverage constraint. The presented model in this paper includes this as a soft constraint. The goal is to get the minimum needed level of staffing available at each blood collection drive and it gets penalized if staff is missing. The maximum number of assignments, the maximum number of consecutive working days and the time between assignments are just a few of the time-related constraints that can be found in the literature, and these also occur in the presented problem. The health-care industry and its nurse scheduling problem are the main areas of application. Such real-world problems lead to very specific and individual constraints and solutions.

Another classification comes from Causmaecker and Van den Berghe [4] and is based on the $\alpha/\beta/\gamma$ notation. Category α includes all relevant personnel data, like general availabilities, contract types, max./min. amount of working hours and preferences for days off or specific tasks. Category β concentrates on the different kinds of shifts, such as early or night shifts and also the time intervals of these shifts. The goal behind studying this category is to schedule shifts to fully cover the demand. This category is not considered for the presented model. In the Red Cross case, there are no fixed shifts, because the blood collection drives start and end every day throughout the year at different times, which means that it is very unlikely that an employee would work the same amount of hours every day in the same time window. The goal is the same, because the minimum number of necessary workers has to be scheduled to fully satisfy the demand during a blood drive. The final category γ provides information about the optimization objective, which is in our case the minimization of additional costs for overtime and costs coming from contractual differences, which can be summarized as a minimization of additional personnel costs.

3.2 Staff scheduling

An early model, developed by Jaumard et al. [10] in 1998 already used linear programming for the nurse scheduling problem. That paper worked with nurses, but included also different skills and delivered a very good starting point for the formulation of the problem presented in this work.

The model presented by M. Rocha et al. [12] comes also very close to the presented model in this paper. They described a mixed integer programming model which was solved using the

CPLEX solver. These two facts are also applicable to the staff scheduling problem of the Red Cross. Furthermore, they consider that the start- and end-times are given, from which the durations can be derived. Moreover, the needed workforce is known in advance and two constraints guarantee that the minimum and maximum number of consecutive working days is applied. The main differences to this problem are that the workers have one identical skill and all have full-time contracts. Also the objective function seeks to minimize the number of assigned days, which is not a goal in the presented problem.

The paper of R. Cuevas et al. [6] works with multi-skilled employees instead of single-skilled workers. The study presents also a mixed integer programming model, but runs through different stages than the presented one. The first part schedules the workers to days off. After that, random shifts are created, these shifts are assigned to workers and, in the end, and each shift gets assigned to an activity. In addition, the objective function does not have the goal of minimizing costs in the work of R. Cuevas. Instead, a utility function is created with the goal of maximizing demand coverage.

The work from G.J. Lim [11] concentrates on nurse scheduling in the healthcare system of the United States. This paper shows that the objective function can consist of multiple objectives. Along with the mainly-used cost minimization objective, nurse or employee preferences can also be considered. This kind of objective is implemented by means of penalty costs for the assignment of a nurse to an unpopular shift. Other objectives include, for example, penalty costs for scheduling inefficiencies or consideration of fairness standpoints, such as balancing overtime hours between all employees. The fairness aspect and the satisfaction of employees also play a big role for the Red Cross, but as long as different contract types with different remunerations are present, the focus remains on cost reduction.

Due to the fact that the staff scheduling problem is a widely researched and investigated topic, the key sectors such as health care systems, home care systems or hospitals have still not implemented automatic planning. The work of Causmaecker et al. [5] analysed six different organisations and their personnel planning system and came to the result that simple software tools like Excel were used to present the final timetables to the employees, but are not used to fill them. Moreover, data sets in hospitals are too big and complex that Excel is not the capable tool for such planning tasks. Also Eiselt and Marianov [8] point out that the consequences of wrong assignment include not only financial losses. The employee satisfaction, in case of fairness aspects and workload matters are main considerations in staff scheduling. Next to the legal regulations which must be included, are maybe some reasons for the small implementation of automatic scheduling systems.

The following chapter gives an overview about the data presented by the Red Cross. A set of information was given about the blood collection drives as well as of contracts and regulations of each employee. To be able to create a useful model, it was necessary to first understand the data given and later develop relevant constraints, which work in the right way with the given inputs.

4 Data Analysis

The following descriptive analysis concentrates on the basis data received from the Red Cross. The data sets contain information about the blood collection drives and all relevant details about employees currently under contract. The main data files were Microsoft Excel sheets, but to fully understand the diverse agreements with the employees, many emails and discussions with the scheduling staff of the Red Cross were necessary.

At the beginning of this chapter is found a short overview of the blood collection drives presented. Important numbers will be presented and analyzed in terms of the total drives carried out in 2015 (where most drives happened). These data show on which weekdays drives occurred, how many donors were handled, how the smallest Red Cross team was composed and how the recommended workload level per hour looked for each professional group.

After that, a closer look will be taken at the employees concerned. Questions will be answered such as how many employees the Red Cross has on hand for the collection drives which skills and training they have and when they are available. The cost factor is a very important point within the paper, leading from the problem description to the model and the presented solution. Therefore, a large part of the employee data analysis concentrates on the specific characteristics that have direct influence on the costs of the Red Cross.

4.1 Blood Collection Drives Analysis

The Red Cross carried out 1453 blood collection drives in 2015. As mentioned in the beginning, these drives can take place via the blood collection bus which is specially designed for blood collection and which is equipped with beds and separated “rooms” or areas for the confidential interview with the testing doctor. At the bottom of such a bus is a large storage space which is cooled and designed for the storage and transportation of blood conserves. For the drives in Vienna, Lower Austria and Burgenland, two blood collection buses are available. On the other hand, there are the drives which take place via team cars. The buildings where these blood collections take place are in villages, cities or on companies’ properties. This is very specific and depends very much on the host. The Red Cross Base in Inzersdorf, Vienna, offers eight team cars and three other smaller buses with eight seats. Furthermore, there are also three mini-trucks with four seats available. The number of seats excludes the driver who is counted extra, because the Red Cross staff scheduling department has no influence over the drivers. Another company is responsible for the transportation and for the availability of a driver every time a blood collection drive takes place. The emphasis between these two possibilities is mainly on drives with team cars. More than 80 percent, in total 1,205 drives, were done by teams in 2015. Compared to this number, less than 20 percent of all blood collection drives in one year are performed with the special blood collection buses.

The next paragraph takes a closer look at the individual blood collection drives. Statistical numbers will be presented such as the minimum and maximum numbers of donors, number of drives per location, arrival times, total duration times, etc. The goal is to give a general overview of the different circumstances and the resulting complex and different needs and requirements at each blood collection drive. All the following information, especially the expected number of donors and the duration of a drive is crucial for scheduling the Red Cross employees.

The richest month in terms of collection drives was November 2015 with 138 drives. Compared to that, the least productive month was April 2015 with only 108 drives. On average, 121 drives are completed each month. For more details about the number of drives per month, consult Table 2. The maximum number of drives to one single destination was in 2015 – 36 drives were carried out in the “Donau Zentrum” in Vienna, which is one of the largest shopping and entertainment malls in Vienna. Generally speaking, the main locations are fire departments, barracks, schools such as the “HTL” and also schools for higher education in Austria, which are called “Fachhochschulen” as well as Universities. Barracks are the second most common group with, on average, six blood collections per year. On the other side, there are many public and private companies, for example the "Pensionsversicherungsanstalt", a retirement pension insurance, with six drives and one of the biggest telecommunication companies in Austria, namely "A1 Telekom Austria" with eight collections in 2015. Without the multitude of drives to villages and cities with a huge number of repeated donors, the Red Cross could not reach the number of nearly 1500 blood collection drives per year.

Another important factor within the blood collection business is that the most intensive working day is Sunday. Many drives take place on a Sunday, which represents the maximum number of 339 drives. This means that on a typical Sunday, more than six different blood collection drives are happening simultaneously. Compared to most other weekdays, Monday is the least intensive working day with the minimum total number of only 142 drives in 2015, which reflects a statistical number of two drives on average per Monday. A detailed look at the distribution of all blood collection drives per day of the week is given in Table 3.

In summary, the Red Cross blood collection drive teams for Lower Austria, Vienna and Burgenland carried out 12,644 hours of work, which results in an average duration of 8.5 hours per drive. It should be noted that the maximum working time for Red Cross employees due to a special regulation is limited to 13 hours for one day, compared to the conventional limitation of ten working hours at maximum for most industries.

The distribution of start and end times per drive and the durations structured into subcategories are presented in Figures 3 to 5. Figure 3 presents the possible starting times divided into weekdays and weekends. Most drives started at 7 or 8 in the morning; this is true for weekdays and, with a frequency of 37 percent, it was the top starting time for weekends. In comparison, Figure 4 shows the different ending times, all including travelling time back to the point of departure in Inzersdorf. These are also grouped per weekday and weekends. The earliest ending time was 11:45 am on a Friday; the corresponding starting time was 7 in the morning. The latest ending times are after 11 pm. These drives started in the afternoon and the travel time lasted around four hours. Figure 5 presents the duration times in hours divided into weekdays and weekends. It can be seen that drives on the weekend have clearly longer durations than drives on weekdays.

The longest drives happened ten times in 2015 with a total duration of 12 hours and 45 minutes which included the legal half hour break after six hours of continuous work time. These top drives in terms of duration took place in only six different destinations. The front runner with three drives of 12 hours and 45 minutes is Behamberg. The travel time to Behamberg is one and a half hours and the blood collection was done at the fire station or the kindergarten. Amstetten and Groß Gerungs had also two blood collections with such a long duration. On the other hand, there are secondary schools and training schools like the “BHAK Hetzendorf” or the “Berufsschule Hütteldorferstraße” with the shortest durations of fewer than five hours. Due to the fact that schools have mainly first-time donors, the output of such a drive is not very high. For example, the training school in Hütteldorf had four blood collections with duration of four hours and 45 minutes and there were on average 40 donors with 20 people being rejected due to a handful of different reasons. The Red Cross Team are aware of this problem and are prepared for the handling of first-time donors. Table 4 presents the average, minimum and maximum durations of blood collection drives partitioned in days. All these number includes the travel time to and back from the location where the blood drive took place.

Month	Drives per month
January	121
February	119
March	130
April	108
May	134
June	115
July	110
August	112
September	122
October	136
November	138
December	108

Table 2: Total number of drives per month

Weekday	# of drives/day
Mon	142
Tue	161
Wed	151
Thu	182
Fri	187
Sat	291
Sun	339

Table 3: Distribution of drives per day

	Duration of drive (hh:mm)		
Weekday	Average	Min	Max
Mon	08:29	04:45	12:15
Tue	08:00	04:45	12:15
Wed	08:10	04:30	12:15
Thu	08:08	04:45	12:45
Fri	08:32	04:45	12:30
Sat	08:42	05:30	12:45
Sun	09:48	05:30	12:45

Table 4: Average/Min/Max durations of drives per day

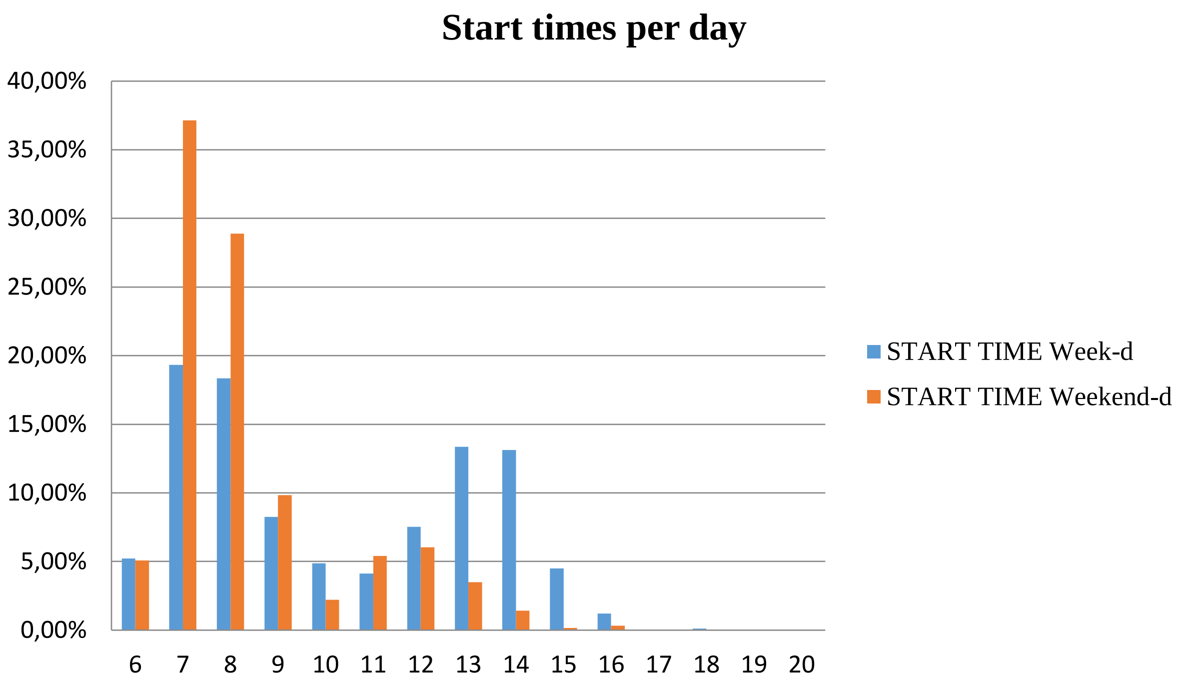

Figure 3: Start times per week- and weekend day in hours

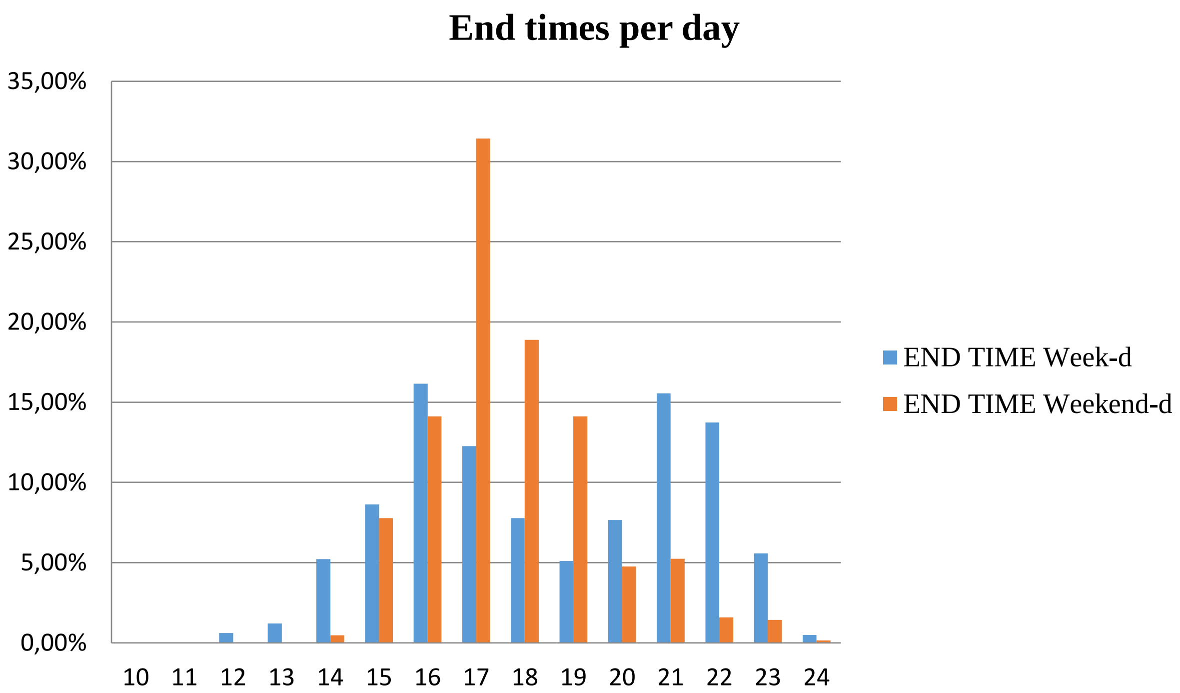

Figure 4: End times per week- and weekend day in hours

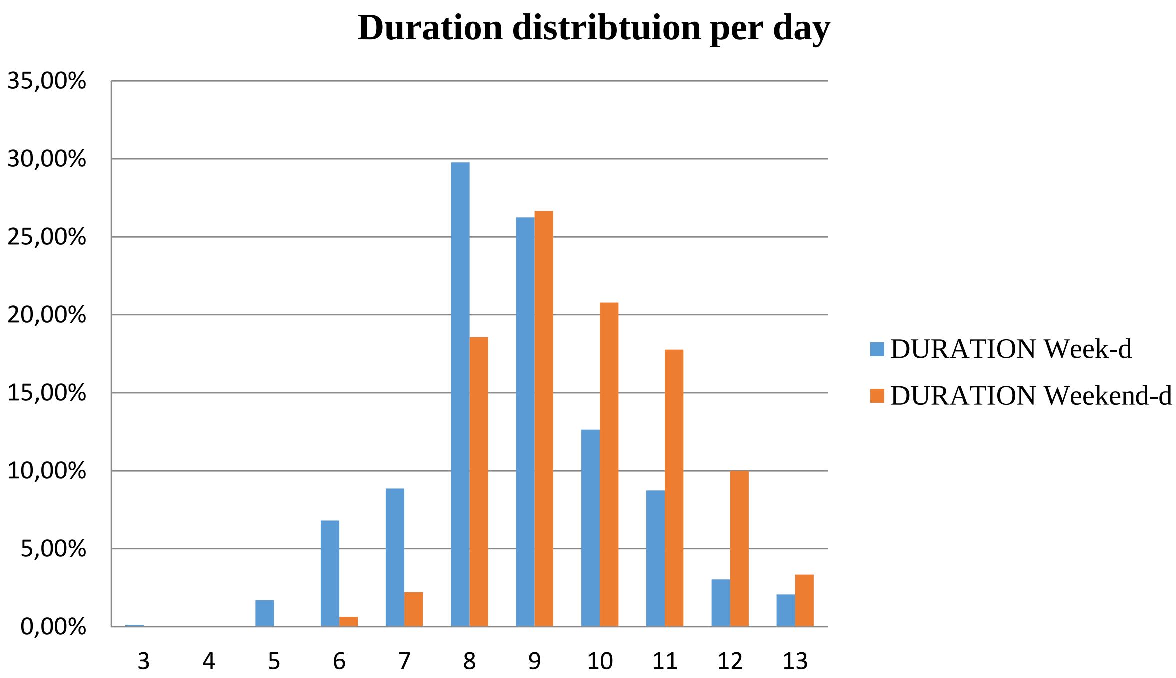

Figure 5: Durations per week- and weekday in hours

The most donors in a single drive were at the Federal Ministry of National Defence and Sports. The actual numbers of participants was 424 and from them only 29 people were rejected, which led to an actual number of 395 donors. The third highest number of donors was reached in the community where the longest collections took place, namely Groß Gerungs. The predicted numbers of expected donors and the actual number of donors were very close with 300 expected and 296 actual donors. The fourth and fifth highest numbers of donors were reached both times in Langenlois, which was forecasted and it was therefore not surprising that the highest number of Red Cross employees were present on these collections. In total, there were 21 doctors, graduate nurses and medical workers present. On a single day, nine blood collection employees, two doctors, five testing nurses, two graduate nurses for puncture and two teamers were working on average nine hours during these blood drives. This highest number of 21 scheduled employees happened six times in Langenlois. The second highest number was in Eggenburg with usually 18 employees. The drives there lasted on average over nine hours and the donor number was between 200 and 210 actual donors.

On the downside, there are collection drives with a very small number of actual donors, often under 15 people. There were four drives with such a low number of donors. Two of them were carried out by a blood donation bus and not with team cars. The other two drives took place in schools and had a lower than average duration of around six hours. These two factors, mainly first-time donors and the shorter collection time may have resulted in a low number of actual donors. The journey to the collection location counts as working time and the longer that time is, the longer is the working time of the Red Cross employees and this makes it more likely that these employees have to work overtime. As mentioned before, the maximum working time per day is 13 hours, but overtime hours start normally after eight hours of work. The longest arrival plus departure times were between four hours and 15 to four hours and 45 minutes and this was the case for 136 blood collections. These numbers show that these 136 drives must have duration of less than 4 hours to not result in overtime work. This is a very crucial point in the scheduling of the right employees, in terms of overtime and cost minimization, because overtime hours are expensive and for “older” employees they are even more expensive.

On the other side, there is a minimum journey time of half an hour, which is often possible with the blood donation bus within Vienna. Another important financial factor is the number of rejected participants, in other words, volunteers who want to donate blood, but are not chosen for a variety of reasons. This is a financial factor, because the scheduled employees have to be paid even if the workload falls widely under expectations and this will happen when much more than the average of ten percent are rejected. The highest numbers of willing but not acceptable people are in military barracks. There are exclusively young men and there is often a kind of group pressure to donate and these mainly first-time donors are not able to donate the necessary amount of blood. For example, 190 participants were rejected out of 251 in the military barracks in Zwölfaxing. Another barracks in Horn had only 58 actual donors out of 232 willing donors. Both of these blood collections lasted nine hours and on average 15 employees from the Red Cross were at the locations, because the graduate nurse who does the testing and the doctor who is responsible for the final decision are provided on the basis of estimated willing donors.

Theoretically, the minimum team consists of three people, namely one testing doctor, one medical staff doing the blood collection and one graduate nurse, who is responsible for the puncture, but this graduate nurse must have an additional qualification for being a teamer. In theory, the team of three people can only be responsible for up to 13 participants per hour, because the maximum workload per hour for one testing doctor is 13 participants. This low number of donors is very unrealistic, which is a possible explanation for why there was no drive in 2015 with only three Red Cross employees scheduled. In the 2015 blood collection drives, the minimum team usually includes one testing doctor, one graduate nurse for puncture, one teamer and one medical staff for the blood collection, which is a total of four people. This minimum team of four employees did 48 drives in this constellation with a usual duration of eight hours per drive and with 60 participants on average.

The next paragraph concentrates on the workload of each professional category. There is a predefined number from the Red Cross of how many donors a doctor, a graduate nurse or a medical staff can handle per hour, if the employee follows their normal working steps.

On average, eight employees were assigned per blood collection drive in 2015. This leads to a nominal composition of three medical staff members doing the blood collection, one doctor, one teamer, one graduate nurse for the puncture and most of the time two graduate nurses doing the testing. Only one third of the drives needed a refreshment person provided by the Red Cross. This depends mainly on the blood donation tradition of the countryside and the places and days the collections took place. Often on weekends and in community buildings, people from the corresponding villages donate their time and manpower and give out the refreshments to the participants.

In Table 5 the recommended workload is presented. It shows how many donors a professional group can handle during one hour. This distribution key is used by the Red Cross to generate the needed numbers of doctors, graduate nurses and medical staff and is also used for the calculation of the scheduled personnel in this paper.

Profession	**Workload – *normal circumstances*** (participants/hour)	**Workload – *special circumstances*** (participants/hour)	**Task**
Doctor/ Graduate Nurse	13/ 15	12/13	Pre-test
Doctor	30	*25*	Medical briefing
Graduate Nurse	25	25	Puncture
Medical staff	7	7	Blood collection
Medical staff	35	35	Teamer
TTV (Tagesteam-verantwortlicher)			Already scheduled
VOL (Vorortleiter)			Already scheduled

Table 5: Distribution key

The table presents the maximum number of donors per employee under normal circumstances and shows slightly different numbers for blood collection drives under special circumstances. Special circumstances mean, in this context, that a higher number of first-time donors are expected than usual. This happens in military barracks and schools in general. This fact results from the age limit for blood donation of 18 years in Austria. Furthermore, the numbers are identical for blood collection drives with the Red Cross donation bus or team cars.

First of all, the tasks per occupational group will be described and after that the differences between the workload numbers will be more closely examined.

If a doctor only needs to perform the medical interview with a volunteer, where he/she goes through the questionnaire and looks at the notations and numbers from the pretest, the doctor would be able to handle more than twice as many people than if he/she is also responsible for carrying out the pretest. In the collection drive with the Red Cross bus, it is typical that the doctor also does the pretest, due to the space constraints of a bus. On the other hand, the pretest is mostly done by a graduate nurse if the drive is done by a team.

Regarding the different numbers under special circumstances, only the first two numbers are different. The explanation is that all willing volunteers get tested and have their medical interview with the doctor who decides if the volunteer becomes a donor or not. Under special circumstances, more first-time donors are present and all of them get tested, but many of them are, for various reasons, not able to donate blood, but the run-through time of the first two stages of pretesting and medical briefing applies also for these rejected participants. First-time donors are inexperienced; they often need help with the questionnaire and are also often nervous, which has negative effects on their blood pressure. These special volunteers need more time and attention and therefore the number of participants per hour is slightly lower than under normal circumstances in companies or in the countryside.

The Red Cross estimates the number of willing donors according to historical data from previous years, but also based on experience from their hosts around Vienna, Lower Austria and Burgenland. These estimates are crucial because they lead directly to the number of employees needed per professional group. It is not efficient if the number of willing volunteers is overestimated because then too many employees are scheduled for this blood collection drive, and this costs money for the Red Cross and does not help the donors in terms of a faster processing. Alternately, if the expected number of volunteers exceeds the previously defined number, the employees have to work more and sometimes longer to be able to handle the higher number of participants, which in turn leads to longer waiting times for the volunteers and a higher dissatisfaction level on both sides. Table 6 shows the accuracy of the estimations done by the Red Cross for the year 2015.

The table shows eleven levels of accuracy. For example, if 100 people were planned and in total 95 persons were present, then the accuracy level would be 95 percent. The middle rows of the table show accuracy levels between 80 and 120 percent; in other words, the expected number of participants was between 80 and 120 percent of the actual number of participants on that day. In total 964 out of 1453 drives were in this range, which means that more than 66 percent of all blood drives in 2015 used very good estimates in terms of planned donors. As described earlier, the cases where more donors arrive than planned are more important regarding overtime costs, overworked employees and dissatisfied volunteers. This last reason is also very important for an organization like the Red Cross which is 100 percent dependent on their voluntary donors. The number of serious over- or underestimates is very low. Only 7 percent of all drives had estimates with greater than 20 percent deviations from the actual level of participants present.

Level of Accuracy - Planned vs. Actual participants	# of drives	in %
≤50 %	29	2.00%
50%< LoA ≤60%	46	3.17%
60%< LoA ≤70%	105	7.23%
70%< LoA ≤80%	205	14.11%
80%< LoA ≤90%	302	20.78%
90%< LoA ≤100%	296	20.37%
100%< LoA ≤110%	236	16.24%
110%< LoA ≤120%	130	8.95%
120%< LoA ≤130%	68	4.68%
130%< LoA ≤140%	20	1.38%
>140%	16	1.10%

Table 6: Estimation accuracy

Figure 6 shows the deviations in total numbers of planned versus actual participants, where the X-axis represents the estimated number of participants. In case of smaller blood collection drives, the planned number of participants was higher than estimated, as it can be seen for small drives with between 20 and 60 estimated participants. For cases where the planned number of willing donors was between 80 and 160 participants, the planned number lies above the actual number.

This deviation from the small drives is also shown in Figure 7, which draws a line of estimation accuracy between planned and actual participants. This line should be close to 100 percent, which would mean that the actual number of participants is in agreement with the planned number. The planned number of participants is the same as shown in Figure 6 on the X-axis. There are bigger fluctuations at the levels of 180, 220 and 280 participants. At 180 and 280 the planned participants were underestimated and at the level of 220 participants there was an overestimation in terms of planned participants.

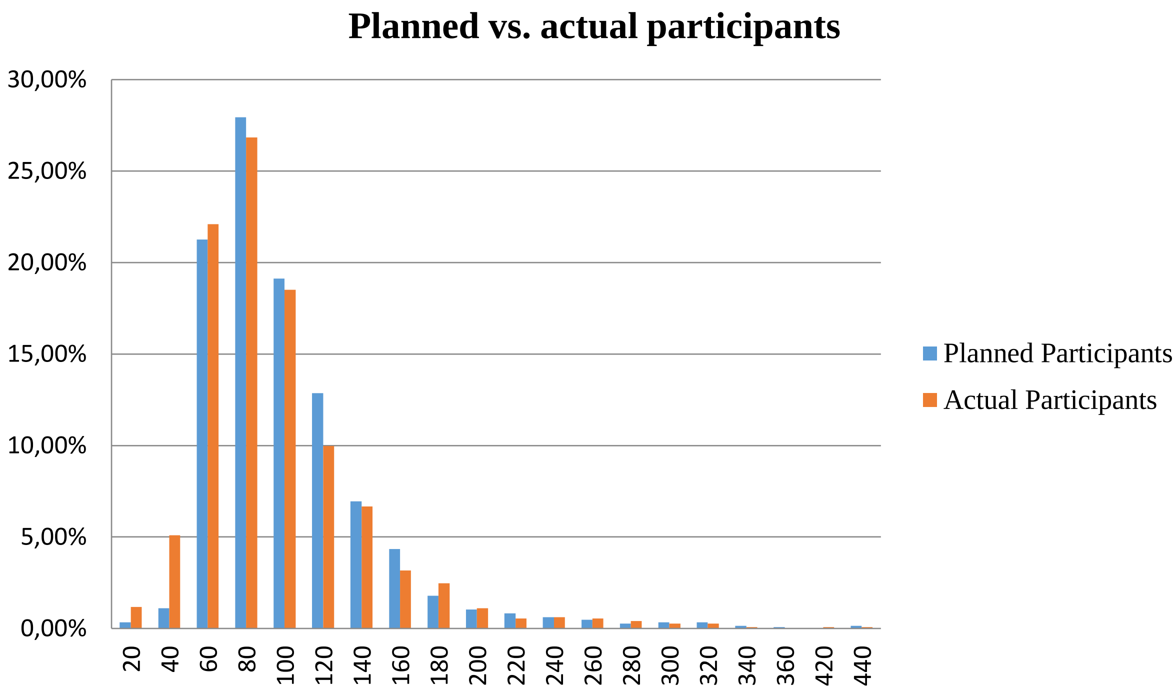

Figure 6: Comparison planned/actual participants

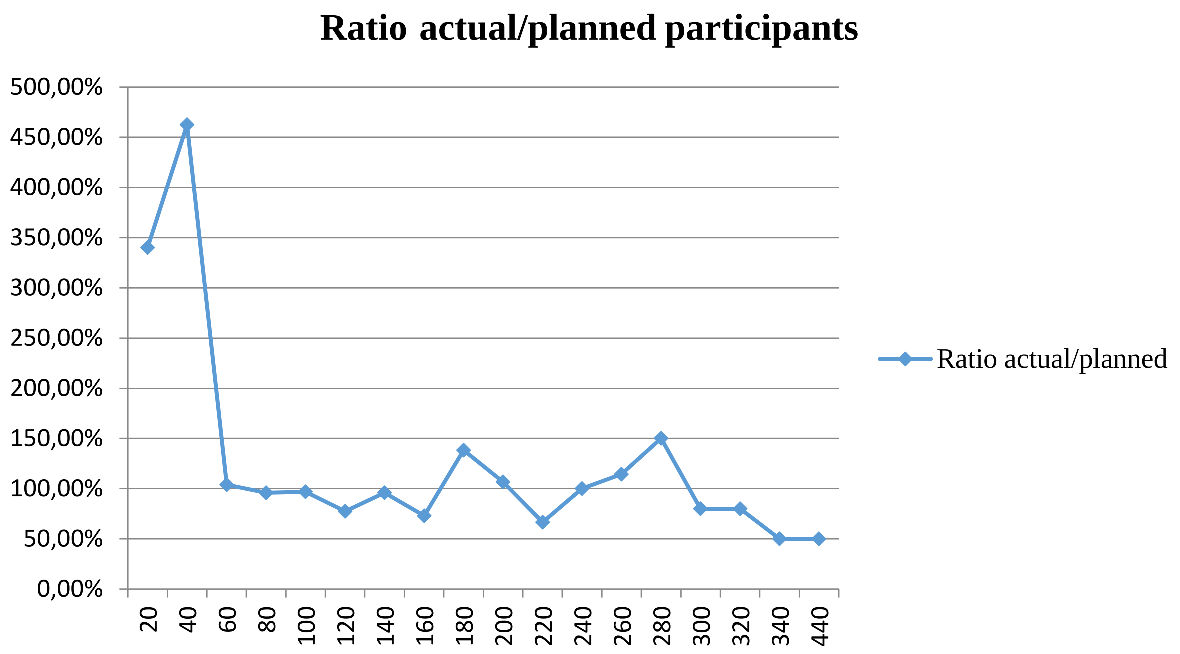

Figure 7: Ratio between actual and planned participants

A very bad example with a difference of over 124 percent above the estimated number of participants occurred in Hollabrunn. There were 110 persons expected, but actually 246 volunteers arrived. Regarding workload per employee, this drive would have needed from every profession one person more to handle the amount of people within the planned time and without having greater waiting times for the volunteers.

At the other extreme, there was a blood collection where only 60 percent of the estimated people came. In May 2015, there was a drive in Krems and 110 people were planned, but instead only 66 willing donors were present. The workload for the doctor, the teamer and the graduate nurse doing the puncture was not easy to evaluate because there was only one person in each case scheduled, which is the minimum level because one doctor and one teamer are always needed. However, considering the actual number of donors, there was one person too many for testing and one person too many for blood collecting whose capacities were not fully used.

Table 7 reflects the different skills during a blood collection drive and how many times one or more persons additionally would have been needed to handle the actual amount of volunteers on this day. For example, only at six blood drives one additional doctor for medical briefing would have been needed to work under normal conditions with normal time windows for each volunteer. Compared to that number, in more than 27 percent of all drives in 2015 one or more graduate nurses for testing would have been necessary to handle the actual amount of volunteers coming to these 398 blood collection drives. All in all, in just one third of all collections in 2015, there were one or more professional groups understaffed and therefore the workload was higher for the other employees in this professional group. However, Table 7 shows clearly that graduate nurses with the skill testing are a scarce resource. In comparison, Table 8 shows that graduate nurses and medical staff are on average not fully utilized. Table 8 presents the average workload levels per hour divided into tasks per employee.

The tasks testing and puncture are done by a graduate nurse and blood collection is done by a medical employee. The teamer is also a medical employee. These numbers are taken from the comparison of possible workload per hour per task, coming from the distribution key in Table 5, with actual workload per hour per task. According to this comparison, it appears that employees doing testing or blood collection are the most highly utilized workers.

The average number of participants and donors per hour plays an important role in terms of the average workload. As can be seen in Table 9, for example, on average 16 donors have to be handled in one hour, which means that at least three blood collecting workers have to be at this drive, because one medical employee can only handle seven donors per hour. However, this would mean that these three medical employees could handle 21 donors per hour, but where only 16 are present; this is an explanation for the average workload level of only 82 percent for blood collection. If the Red Cross would schedule only 2 blood collecting workers, they could handle only 14 donors per hour, which would lead to longer waiting times for the donors and higher workload for the employees.

Understaffed per Task					
	Blood collection	Testing	Puncture	Medical briefing	Total
# of drives	67	398	16	6	487
in %	4.61%	27.39%	1.10%	0.41%	33.52%

Table 7: Understaffed

Professional group	Average workload per hour
Medical Briefing	75%
Testing	81%
Puncture	68%
Teamer	43%
Blood collection	82%

Table 8: Utilization level per task

	Average	Min	Max
Participants/hour	19	1	71
Donors/hour	16	1	66

Table 9: Participants/donors per hour

The next section highlights the details of the employees, the different groups, the different knowledge and skills and the different cost structure per employee group.

4.2 Employees Information Analysis

There are many distinctions between the employees, but there are two main differences. On the one hand, there is the professional group and the second distinguishing feature is the contract type. The different professional groups differ in terms of education, training, additional qualifications and those basic skills and tasks which everyone can fulfil. There are three professional groups, namely the doctors, the graduate nurses and the medical staff.

At the moment, the Red Cross operates with two different contract types. Of course, the contract for every professional group is different, but in terms of simplification and relevance for this paper there are only two contract types. There are contracts that were negotiated decades ago and therefore favourable to the employees and against employers' wishes. These contracts are from now on called "old" contract types.

On the other side, there are new contracts with the standards from the actual collective agreement, which are negotiated more fairly for employers and employees. For example, the blood collection drives happen mainly on weekends and therefore Monday is a very calm working day. Old contracted employees get supplements for work on weekends or they get extra pay if the drive is outside Vienna, which is in two thirds of the time the case. Workers with a new contract do not get supplements or extra fees for weekends or drives to Lower Austria and Burgenland.

The reason for the new contracts is simply that the job of blood collection happens mainly on weekends and is connected with longer journey times; this is the rule and not the exception and therefore no extra fees are paid for these standard working conditions. The exact cost differences will be explained in the upcoming section.

Employees with an old contract have a lot of additional benefits. They are entitled to receive hardship allowances (Erschwerniszulagen), because they have to set up and remove the equipment they need for their work. For example, the beds where the blood donation takes place have to be carried and build up and also taken down after a collection drive. Moreover, they receive Sunday and holiday allowances (Sonn- und Feiertagszulagen), which is a very important cost factor; because the collection drives mainly take place on weekends.

The third additional payment for old contracts is a monetary reward for drives which take place outside of Vienna. That is again a very crucial cost factor for the Red Cross, because drives in Lower Austria and the Burgenland make up a good proportion of the total drives per year. Adding to the additional costs for employees with older contracts, the basic salary of older contracts is fundamentally higher.

All these cost do not apply for employees with new contracts. Therefore, the Red Cross emphasized that it would be preferable to schedule as few as possible old contracted employees on weekends and on overtime to prevent a lot of allowances and the higher basic salary for overtime working hours. Table 10 shows the different basic cost rates per hour for each professional group, subdivided into contract types. These are just the rates for one normal working hour. The calculation of overtime hours and the calculation of costs per weekend hour are shown in chapter 5.2 in more detail.

Professional group	Contract type	Basic cost rate/hour in EUR
Doctor A	"old"	69
Doctor B	"new"	43
Graduate Nurse A	"old"	29
Graduate Nurse B	"new"	23
Medical worker A	"old"	21
Medical worker B	"new"	19

Table 10: Basic salary per hour per employee

Next to the monetary information, the availabilities of each employee are very different. Doctors often have weekend contracts, which means that they are only available for drives form Thursday to Sunday or even from Friday to Sunday. For example, there are four doctors in old contracts, two out of them can be freely scheduled every day of the week and two doctors have weekend contracts. There are also eleven doctors in new contracts, where only five can be scheduled the whole week, two have weekend contracts and four have special agreements that they have one fixed day off. This fixed day off is different for all four employees.

In the case of graduate nurses, the situation is as follows: Eleven nurses in old contracts and nine employees in new contracts can be allocated the whole week from Monday to Sunday. Five graduate nurses have a weekend contract from Thursday to Sunday, and five from Friday to Sunday; both groups have new contracts.

The biggest group of employees with old contracts happens to be the medical staff. In total 37 old contracted medical employees can be divided freely over the whole week; only one person has Saturday and Sunday as fixed days off. Only 19 medical employees are in new contracts and can be scheduled throughout the week.

Table 11 presents the total numbers of each professional group and their availabilities during the week, along with the average working hours available per week shown for all days. It can be seen that the total number of employees increases throughout the week and has its peak on the weekend starting from Friday to Sunday. In addition, the availabilities of new contracted employees rise throughout the week. For example, there are between seven and nine new doctors available from Monday to Thursday and starting on Friday the number increases to eleven available workers. The same can be seen for graduate nurses with new contracts. Their numbers increased drastically from only nine up to 19 from Friday to Sunday. The reason for the stable number of medical staff of 20 is explained by the fact that exactly 20 medical employees are covered by new contracts.

		Mon	Tue	Wed	Thu	Fri	Sat	Sun
Total Workers	#	87	88	89	94	101	101	101
	mean WH/week	29.0	28.9	28.9	28.9	28.1	27.9	27.9
Doctors total	#	9	10	11	11	13	14	14
	mean WH/week	28.3	27.0	27.3	27.3	25.0	24.6	24.6
Doctor old	#	2	2	2	2	3	3	3
	mean WH/week	30.0	30.0	30.0	30.0	23.3	23.3	23.3
Doctors new	#	7	8	9	9	10	11	11
	mean WH/week	27.9	26.3	26.7	26.7	25.5	25.0	25.0
Grad. Nurses total	#	20	20	20	25	30	30	30
	mean WH/week	26.0	26.0	26.0	26.6	25.5	25.5	25.5
Grad. Nurses old	#	11	11	11	11	11	11	11
	mean WH/week	25.9	25.9	25.9	25.9	25.9	25.9	25.9
Grad. Nurses new	#	9	9	9	14	19	19	19
	mean WH/week	26.1	26.1	26.1	27.1	25.3	25.3	25.3
Med. staff total	#	58	58	58	58	58	57	57
	mean WH/week	30.2	30.2	30.2	30.2	30.2	30.0	30.0
Med. staff old	#	38	38	38	38	38	37	37
	mean WH/week	31.1	31.1	31.1	31.1	31.1	30.8	30.8
Med. staff new	#	20	20	20	20	20	20	20
	mean WH/week	28.5	28.5	28.5	28.5	28.5	28.5	28.5

Table 11: Available workers & working hours per week per day

Another differentiating feature is the diverse weekly working hour arrangements. From 40 working hours per week, down to five working hours per week, more or less every time agreement is incorporated. The next specific characteristic comes with contracts having 40 working hours per week in combination with an old contract type. These employees have additionally minimum working hours per day, which no other employee has, and also the maximum working hours per day are different from all others.

These kinds of employees have to work between seven and nine hours because these are the minimum and maximum working hour agreements, respectively. This means that they are only available for scheduling if the blood collection drive lies within this duration; otherwise these employees are excluded from consideration.

Last but not least, every professional group is not able to execute the same tasks. For example, not every doctor does the testing. That means that a doctor who is not doing testing at all, but medical briefing, cannot be scheduled for a bus collection drive, because these need only doctors who are able to do both tasks. The most tasks for one professional group can be performed by medical staffs, which basically are employed for blood collection, but can also be trained to be a teamer and can also be willing to give out refreshments at the end of a donation.

A detailed look at the different skills and which tasks can be fulfilled by which employee, can be found in Table 12. Furthermore, an overview about the exact working hour agreements are also presented in Table 13. As you can see, the most working hour agreements are with 30 working hours per week with 44 employees. In second place are 20 working hour arrangements with 22 workers, while 40 hours a week arrangements are only in third place with 12 out of 13 people mainly within the medical staff group.

Task/Skills	*Doctors*	*Graduate nurses*	*Medical staff*
Medical briefing	1		
Medical briefing+Test	14		
Test		2	
Puncture (P)		4	
Test+P		22	
Test+P+Teamer		2	
Blood Collection (BC)			6
Teamer (T)			0
Refreshment (R)			1
BC+T			9
BC+T+R			24
BC+R			18

Table 12: Skill distribution

Contract agreements/# of E	*Doctors*	*Graduate nurses*	*Medical staff*
40 hours/week	-	1	12
35 hours/week	-	1	5
30hours/week	7	11	26
25 hours/week	2	5	6
20 hours/week	3	11	8
15 hours/week	1	1	-
10 hours/week	2	-	1
5 hours/week	-	-	1

Table 13: Working hours' agreements

5 Pre-processing

The Red Cross provided data about the blood collection drives in 2015. They also presented all necessary information about their available employees. These data were used to generate instance files to test the code on real-life data and to get timetables for all employees for all 28 days which represents one month in this paper.

In the following chapter the input or instance files will be described, for example what information was given and which information was used. Based on this information, two main matrices are generated which are the key players for the model. These matrices connect the input information from the drives with the information about the employees. The reason for the calculation of additional matrices besides the input files is that the assignment of employees to blood collection drives is covered by specific restrictions. For example, not every employee is available for every drive, which depends on the individual employee contract agreements and on the combination of consecutive blood collection drives and this in turn is affected by the legal restrictions on rest time.

These complex relationships between blood drives and employees are described in the following section by means of the generated matrices.

5.1 Test instances - Input data

5.1.1 Blood collection drives $j \in \mathcal{J}$

In case of blood collection drives, all relevant data was given, down to the unique address of each drive. A sample of the row data coming from the Red Cross is presented in Appendix A. First of all, for the model, every drive needed a unique index to clearly distinguish a single blood collection drive from another. The next information used is the day of the month on which the drive takes place, which was indicated by a d. The planning horizon in this paper is 28 days, which mirrors a whole month with four weeks of seven days, including four weekends. The first day of each generated test instance is a Monday and the 28th day is a Sunday. The information about the weekday on which the drive takes place is very important in combination with the employee information, because every employee is available on certain days and not on others. For example, some doctors have each Monday off because of their contract agreement. This is mostly the case where doctors also work at the hospital and have ambulance hours.

Next to the weekday is the starting s_j and ending time e_j of a drive and the duration t_j in hours. The starting and ending times are only necessary to calculate the minimum legal rest time between two blood collection drives, which must be at least 11 hours. The duration on the other hand, is necessary for more than one calculation. First of all, the duration had to be calculated from the information about the travelling time plus the productive time of the blood collection drive. Furthermore, the employees with 40 hours a week contracts are only allowed to work a minimum of seven hours and a maximum of nine hours, which means that drives with longer or shorter durations are not possible to assign to these employees. On the other hand, there is the duration required for the calculation of the total sum of working hours per week and the resulting total working hours per month. These numbers reveal if the employees are equally utilized and if every employee for him/her is utilized in a balanced way during the four working weeks and from month to month. The input data duration is also needed for the calculation of plus hours at the end of each month.

Plus hours u_e are working hours above the contractual agreements and must be paid at the end of each month. In comparison, overtime o_e counts as a working duration above eight hours. That is the next point within the input file. The overtime hours are calculated out of the duration data; if the duration is longer than eight hours, the difference of the total duration minus eight hours is taken as input and is called plus duration in case of overtime t_j^+. If the length of a blood drive is less than or equal to eight hours, no overtime hours arise. The last part of each input data on collection drives deals with the amount of required personnel, which is further structured into professional groups.

5.1.1.1 Required staff level calculation

For the calculation of the required personnel it is necessary to consider two factors. Firstly, there is the total duration of a drive and the expected number of participants and secondly there is the expected number of actual donors. The difference between the number of participants and donors are the rejected participants, which are on average 10 percent, but this can be given by the Red Cross, based on their experience. They know, for example, if it is likely that more first-time donors will come and the rejected donor number will be higher than usual compared to the case where a stable number of donors can be expected every year. For the calculation of necessary doctors and testing personnel, the participant number and the duration are used, combined with the distribution key as described in Table 5.

The information about whether a doctor for medical briefing and a graduate nurse for testing are wanted or only a testing doctor is required, is indicated by the type of blood drive. Bus collections have only a testing doctor and when team cars go into action, these two tasks get subdivided between two or more employees. This information is filtered in advance and the input file only states if a doctor or a graduate nurse is needed for testing. If the blood collection is executed by bus or by team cars, this fact is not especially mentioned or indicted in the input file. This information comes from the row data, but is not used for the input files.

The numbers of required graduate nurses for puncture, the number of needed teamers, the quantity of blood collecting personnel and the number of staff who give out the refreshments is calculated from the number of expected real donors, the duration of the drive and the distribution key. When the calculation comes to the solution that three blood collecting workers are required, the number three is indicated in the field under required number of blood collecting personnel.

A sample test instance with real blood collection drives taken from the data provided by the Red Cross and the above information which was used for the model presented in this paper is shown in Section A. Moreover, this information is the foundation for the matrix “Allowed blood collection drive combinations” $(f_{jj'})$, which will be described in more detail in the subsection Generated Matrices.

5.1.2 Employee data $e \epsilon \mathcal{E}$

Regarding the Red Cross employees, all relevant contract details, agreements and arrangements are taken into account, because the availabilities of the employees can be can be deduced from this information and used for scheduling. As in the drives input files, the employee input file also provides unique indices e for every single employee. Compared to the generated drives instance files for every month, the employee information input file exists only once, because the availabilities within a week, the working hour agreements and the contract types do not change during and over the months. In reality, it could be possible that an employee gets fired or a new worker gets employed, then it would be necessary to slightly adjust the input file and delete or add an employee.

In addition to the index for every employee, a code for availability on every weekday is created to identify if the worker is available on this weekday or not. This means that for every worker, each weekday is marked with the number 1, which stands for general availability on this weekday. The opposite meaning is indicated with a zero, which means that the employee is not available on this weekday for the whole month. For example, a graduate nurse with a 20 hour contract per week has a fixed day off on Fridays, which means that this specific graduate nurse can never be scheduled on a Friday. Next to the availability information, are the main contract details such as working hours per week, as well as the working hours per month $h_e^{m,max}$ and the minimum and maximum working hours per day. The total working hours per month are taken into account when the plus hours at the end of each month are calculated. These plus hours are the difference between the actual working hours and the working hours per month coming from the input file, for each employee.

The minimum and maximum working hours per day are the boundaries for the general availability of the employees. For example, if there is a blood collection drive on Tuesday in the first week of a month and the duration of this drive is ten hours then graduate nurse X who is available on Tuesdays could be initially scheduled for this drive. The maximum working hours per day for graduate nurse X are limited to nine hours, which means that the duration of this drive above nine hours excludes this graduate nurse from assignment.

The input file also contains the information about which education and qualification each employee has and classifies them into the key tasks: medical briefing, testing and medical briefing, only testing, puncture, teamer, blood collection and giving out refreshments. For all the tasks an individual employee can be scheduled based on the worker having the necessary education or training, the number 1 is indicated. If a worker does not have the necessary qualifications, it will be indicated with the number zero. For example, a doctor Y can do medical briefing and testing + medical briefing, but for all other tasks he lacks qualifications such as being the teamer, or such tasks are simply not included in his job description, like giving out refreshments.

The most important input information in regard to the objective function are the costs of overtime hours c_e^{ot} and the costs for hours worked on weekends c_e^{we} , namely Saturday and Sunday. The cost rates are different for each professional group, but they also vary in terms of contract type. People with old contracts have generally higher basic cost rates than workers with new or more recent contracts. The exact differences and the costs rates used are explained in detail in the upcoming section.

The last information included in the worker information input file is the existence of a weekend contract. It is a hard constraint that one full weekend in four weeks has to be off for each employee who does not have a pure weekend contract. In other words, each employee works a maximum of three weekends within a four-week time frame. Employees who work only on weekends do not have this restriction, because they only work on weekends, otherwise they would never reach their monthly working hour agreements. This information is used in CPLEX to exclude these employees with weekend contracts from the restriction to work on a maximum three out of four weekends. To restrict weekend contract workers from working on weekends would be counterproductive. An extract of the worker information file used is also presented in Appendix A.

5.2 Cost rate by professional group

The cost rates per working hour are input parameters within the employee information data file and are crucial for the calculation of the objective function. The objective function in this paper has the goal to minimize the additional costs which occur for worked overtime hours and weekend hours; the latter applies only to employees with old contracts.

As described in the Data analysis chapter, the workers with older contracts have a higher basic salary and are paid extra for different things such as hardship allowance or Sunday and public holiday surcharges. These costs mainly occur on weekends and holidays and hardship allowances are only paid if the blood drive is performed with a team car and not if the drive is performed with a bus. There are also no hardship allowances if the employee is scheduled in the blood donation centre in Vienna.

A general request from the Red Cross was that the most expensive employees, those who have old contracts, should be mainly scheduled to the centre in Vienna or to blood drives during the week. The reason is that it should be avoided that these workers are assigned to drives at the weekend, which are expensive in terms of allowances which have to be paid.

To ensure that it is more difficult to schedule such workers for weekend collection drives, an additional cost rate for weekend hours was implemented. The basic cost rates per working hour were provided by the Red Cross and from that the additional costs were calculated. In case of weekend hour costs, the basic cost rates were taken but only for old contract employees. The motivation was that for an employee with an old contract, working at the weekend, additional costs arise for the Red Cross. This is not the case with new contracted employees, because no allowances for weekend work accrue and therefore no additional costs for weekend working hours were taken into account. This result from the fact that the basic cost rates for a working hour during the week is the same as a working hour on the weekend for newly contracted employees.

These different additional costs per contract type and professional group are highlighted in Table 14. The additional costs per weekend hour for old contracts are the basic cost rates per working hour (Table 10). No additional costs arise for new employees working on weekends and therefore a cost rate of zero is taken.

The overtime costs per working hour are classically calculated by the multiplication of 150 percent times the normal cost rate per working hour. There are no different approaches for workers with old or new contracts.

This means, for example, if graduate nurse A with an old contract is assigned to a ten hour long blood collection drive on a Sunday, it would result in ten hours multiplied by the cost rate per weekend hour and two hours of overtime, which would be multiplied by the overtime cost rate per hour. The calculation would be as follows:

Example: Graduate nurse A – 10 hours drive on Sunday

*10 hours * EUR 29 (costs for weekend working hours) + 2 hours * EUR 43.50 (overtime costs) = EUR 377 total costs*

In comparison, graduate nurse B with a new contract would have only EUR 69 additional costs for the same blood collection drive with the same duration. These additional costs arise only from the 2 overtime hours with an overtime cost rate of EUR 34.50 each. No additional costs occur for the weekend for a newly contracted employee. This results in a cost advantage of EUR 308 for exchanging an employee with an old contract with a worker with a new one.

Professional group	Contract type	Overtime costs/hour (Cost rate per hour*1,5) in EUR	Cost rate/weekend hour in EUR
Doctor A	“old”	103.50	69
Doctor B	“new”	64.50	0
Graduate Nurse A	“old”	43.50	29
Graduate Nurse B	“new”	34.50	0
Medical worker A	“old”	31.50	21
Medical worker B	“new”	28.50	0

Table 14: Additional costs per employee

5.3 Staff requirement at the centre in Vienna

The total number of 102 employees is not only required for the blood collections drives. They are also required at the centre in Vienna during the week. The centre in Vienna is open from Monday to Friday with different opening hours. On Monday and Friday the blood collection is open for nine and a half hours, from Tuesday to Thursday twelve hours from 8 am to 8 pm in the evening.

The Red Cross estimates that, on average, there will be 70 donors on Mondays and 110 people on the other weekdays. This reduces the number of available personnel for blood collection drives. Moreover, the demand in the centre must be also satisfied. For that reason, additional "blood collection drives" were implemented within the input data of the blood collection drives for every instance.

Table 15 shows the needed persons for each weekday and for which duration. As can be seen, on Mondays and Fridays the doctors for medical briefing are only needed for five working hours. In comparison, from Tuesday to Thursday one doctor has to work six hours and the second doctor has to work six and a half hours. Also the number of other employees can be divided by two, for example, in total four graduate nurses doing the testing are needed, but one graduate nurse has to work seven hours and the other one seven and a half. This is true for all the other professional groups from Tuesday to Thursday. The numbers of required employees are the same the whole week, but the durations are different, which reduces the contracted working hours per week for blood collection drives.

	Mo & Fr		**Tue to Thu**	
Profession/working hours	5 hours	8 hours	6 & 6.5 hours	7 & 7.5 hours
# of Doctors	2		2	
# of Graduate nurses (Test)		4		4
# of Graduate nurses (Puncture)		2		2
# of Teamer		2		2
# of Medical staff (BC)		10		10
# of Medical staff (Refreshment)		4		4

Table 15: Weekly staff requirements in Vienna

The particular conditions in the centre are such that there are no overtime hours possible, because generally enough personnel are present and the opening and closing hours are strict, compared to blood collection drives. If many volunteers are present at one drive and not enough personnel are there, then the duration is extended until all volunteers are taken care of. In the centre, it is not possible to extend the hours.

Furthermore, the travel time to the centre does not count as working time and no additional fees are paid for old contracted employees, because the blood collection takes place in Vienna on weekdays and the equipment, such as beds, are already installed in the building. This means that if an employee with an old contract is scheduled for blood collection in the centre it will be cost-neutral for the Red Cross. This is also the reason why the Red Cross started to schedule the old employees in the centre and the new contracted workers to blood collection drives as often as possible. This was also desired from the Red Cross for this master thesis, which was actually taken into account. By attempting to minimize the costs, it should be avoided as much as possible the scheduling of employees with old contracts for weekends and for overtime work.

The next paragraph explains how solutions and timetables from the previous month affect the solution generated for the actual month.

5.4 Rolling planning horizon

Every time a planning horizon of 28 days comes to a solution, not only the optimal cost value is found, but, more importantly, timetables for every one of the 102 employees are found. Furthermore, all blood collection drives within the planning horizon are supplied with the needed number of employees from the required professional group. To start the calculation of the subsequent month without encountering important legal constraints, further input data are needed. A third input file is filled with information from the previous month which is included into the calculation of the next month.

The main information taken from the previous solution concentrates on the employees and their rest-time requirements as well as their maximum allowed number of consecutive days of work. It is required by law that employees have a rest time of at least eleven hours between the end of work and the start of work the following day. Consequently, the information about the end time of each worker on the 28th day of the previous month needs to be documented. The 28th day of each problem instance is a Sunday and the associated end time is used to calculate the earliest possible start time on the first day of the next planning period, which is always a Monday. If worker X has no assignment on the last Sunday in the previous month, then he/she can be freely scheduled according to his/her individual restrictions taken from the input file “Employee information”, e.g. availability or minimum and maximum working hours arrangements. Otherwise, the time between the end time of the last day in the previous planning horizon and the start time of the first drive on Monday in the next test instance must be at least eleven hours.

The additional data that used from the previous month is needed to control that the maximum number of nine consecutive working days is not exceeded. This is done by checking the last nine days of the previous month. Each worker who was scheduled the last nine days of a test instance is not allowed to work the first day of the next test instance, because this would violate the constraint of maximum nine consecutive working days. These two input data sets connected with the corresponding employee index are used for the calculation of the matrix "Allowed employee-drive combinations" (a_{ej}) , which will be described in the next section.

5.5 Generated Matrices

All information from the two input files about the blood collection drives and the employees are used as constraints for the objective function in the model. Some details are first used to create other matrices of needed information to solve the scheduling problem. The first matrix is called "Allowed employee-drive combinations" (a_{ej}) , which means that it is checked if it is generally possible to schedule specific employees to specific blood collection drives. First of all, the used information from the input data compare the duration of a drive to the corresponding minimum and maximum working hours per day and per employee.

On the other hand, the weekday on which the drive takes place is taken as input and is compared with the weekday availability of each worker taken from the employee input file.

Next, the importance of the weekday information will be explained. Each employee is only available for assignment if he/she also works on the weekday when the drive is executed. There are also weekend contracted persons, which are only available for scheduling for weekend blood collection drives. This is the first condition which gets checked. The second condition verifies that the duration of the drive, which is on a chosen weekday, is longer or at least equal to the minimum working hour's restriction for each employee. The final condition goes hand in hand with the previous one. It controls that the duration of the drive is less than or equal to the maximum working hours agreement per day for each employee.

In summary, it means that an employee is only available for a blood collection drive under the following conditions: On the weekday the drive takes place, the worker is generally available and the duration of the drive is not longer or shorter than the maximum or minimum allowed working hours, respectively. When these circumstances are fulfilled, then the matrix contains the value 1, indicating for worker e that he/she is generally available for assignment to a specific blood collection drives$j$. Otherwise, if the conditions are violated, then the matrix also indicates this information for the scheduling algorithm, resulting in an entry of 0. Algorithm 1 shows the steps for generating the matrix "Allowed employee-drive combinations" (a_{ej}) calculated out of the input data from drives and employees.

Allowed employee-drive combinations (Part 1)

```
Indicate if the employee can be scheduled to the drive (Step 1)
    for e = 0 to numberOfEmployees
        for j = 0 to numberOfBloodCollectionDrives
            if employee e is available on weekday AND duration of drive is between min
            AND max number of working hours
                Fill AllowedEmployee-DriveCombinations with Yes/1
            Else Fill AllowedEmployee-DriveCombinations with No/0
            j = j + 1
        End for
    e = e + 1
End for
```

Algorithm 1: Generating possible Employee-Drive combinations

The possibility that an employee is available for scheduling can be overruled by the restrictions coming from the solution of the previous month. It is not allowed that an employee work nine consecutive days and it is forbidden to have a rest time of less than eleven hours. These two conditions are only of concern for the first day of the actual month for the next algorithm and must be respected. Generally speaking, the rest time constraint and the non-existence of nine consecutive working days must be true for every single day and for every employee, but this is done with constraint (14) in the LP model and the following matrix called "Allowed blood collection drive combinations" ($f_{jj'}$).

Concerning rolling data, the information about the last nine days, whether a worker was scheduled or not, is stored in the input data of the previous month. If a worker was assigned the last nine days, this employee is not available for the first working day of the actual month.

Next, the time between the end times of the drive of the 28th day, the last day of the previous month, and the starting time of the drives on the first day of the actual month is calculated. Consequently, if a worker is not scheduled on the last day, he/she is generally available for the first day in regard to the nine working days restriction and the rest time restriction, but only if algorithm 1 comes to a positive result. The calculated time is compared with the legal restriction of eleven hours and if the time is greater than or equal to this threshold. Algorithm 2 shows the second step to find the final possible employee-blood collection drive combinations.

All in all, in case of the availability on the first day of the actual month, the following conditions must be fulfilled: The employee was not scheduled to drives the last nine days in a row and if the worker was scheduled on the last day of the previous month, he/she must have a rest time of at least eleven hours between the end of work and the start time of the next drive on the following day.

Allowed employee-drive combinations (Part 2)

Indicate if the employee can be scheduled to the drive on the first day (Step 2)
    for e = 0 to numberOfEmployees
        for j = 0 to numberOfBloodCollectionDrives
            if drive j is on the first day **AND** nine days worked in a row == TRUE
                Fill *AllowedEmployee-DriveCombinations* with No/0
            if drive j is on the first day
                if $24 - e_j\ endTime_j + s_j$ startTime$_j < 11$
                    Fill *AllowedEmployee-DriveCombinations* with No/0
            $j = j + 1$
        End for
      $e = e + 1$
    End for

Algorithm 2: Rolling data for possible Employee-Drive combinations

The second matrix generated out of the input files is called “Allowed blood collection drive combinations” ($f_{jj'}$). This matrix is provided to give certainty about the possibility for an employee to serve two consecutive drives j and j'”, mainly regarding rest time restrictions. First of all, the Red Cross does not schedule an employee on one day to two different blood collection drives. Theoretically it would be possible, if there is a short drive of four hours and another short drive on the same day also with duration of four hours.

By analyzing the data from the blood collection drives, it turned out that the shortest drives in 2015 lasted 4 hours and 45 minutes and this only in seven cases. Again theoretically it would be possible, but practically it would result in overtime hours every time and, most importantly, it was not desirable for the Red Cross. Therefore, algorithm 3 checks initially if drive X and drive Y are on the same day.

Allowed blood collection drive combinations

Indicate if the employee can be scheduled to both drives
for *j1 = 0* to numberOfBloodCollectionDrives
    for *j2* = 0 to numberOfBloodCollectionDrives
        if drive *j1* is on the same day as *j2*
            Fill *AllowedBloodCollectionDriveCombinations* with No/0
        else if drive *j1* is on *d* before/or after *j2*, meaning two consecutive days
            if drive *j1* is before *j2*
                rest time = $24 - e_{j1}$ EndTime *j1* + s_{j2} StartTime*j2*
            else if drive *j1* is after *j2*
                rest time = $24 - e_{j2}$ EndTime *j2* + s_{j1} StartTime*j1*
            if rest time < 11 hours
                Fill *AllowedBloodCollectionDriveCombinations* with No/0
        if drive *j1* equals drive *j2*
            Fill *AllowedBloodCollectionDriveCombinations* with Yes
        j2 = *j2* + 1
    End for
  j1 = *j1* + 1
End for

Algorithm 3: Generating possible blood collection drive combinations

The next conditions shown in algorithm 3, handle the rest time constraint of eleven hours between two consecutive drives, which must be satisfied under all circumstances. For example: Drive X ends on the 18th at 8 pm and drive Y starts on the 19th at 7 am in the morning. The time between the end time of drive X and the start time of drive Y are exactly eleven hours. If that is the case, an employee could be generally scheduled to both drives X and Y. If we assume that drive X ends at 10 pm, the calculated rest time would only be nine hours and therefore it would not be allowed for any employee to work on both blood collection drives. In the end, the algorithm checks if the drives in question are one and the same, then the indicated allowed drive combinations would be overruled and set to positive.

6 Modelling and solution method

The scheduling problem will be formulated and solved with a model which simultaneously creates timetables for all employees for 28 days, defines their days off and decides which task they have to perform at which blood collection drive while the individual contractual restrictions and the general legal restrictions are satisfied. The objective of the model is to minimize the additional costs resulting from overtime hours and weekend hours.

Each employee has an employment contract with the Red Cross that defines the basic binding constraints for the model. The contract includes information about: (I) tasks that can be executed and jobs that cannot be performed; (II) the amount of weekly working hours as well as the number of monthly working hours; (III) minimum/maximum working hours per day; (IV) days of the week that must be assigned as days off, i.e. fixed days off or weekend contracts; (V) the employee's availability on every day of a week. This information is stored for each employee e input data file, which was described in Chapter 5.1.2 and is initially read into Visual Studio before the calculation of the model starts. The data file with the relevant information about the blood collection drive j is read into the program immediately after the employee information. Furthermore, restrictions (I)-(V) are basic inputs for the calculation of the first parameter a_{ej} which states if a worker e is generally available to work for a blood collection drive j. Restrictions coming from the legal framework are rest time requirements, weekend-rest and week-rest of at least 36 hours.

A great basis for constraint modelling came from the work of Azaiez and Sharif [1]. They developed a 0-1 linear goal program, which included demand coverage, contractual and legal requirements and also avoided additional costs, like overtime. Further, they also helped a hospital in Saudi Arabia, with an IT-based model, to support their manual scheduling process. The similarities of this problem to the Red Cross staff scheduling requirements, helped to develop constraints like maximum amount of consecutive working days and days off and on, as you can see in the following developed constraints.

Also the work of Ivo Blöchliger [2] supported the development of the right constraints and objective function to reach the desired results.

The problem has the following hard constraints:

- The daily minimum staff level for each blood collection drive must be met. The expected number of participants/donors is given and with the help of the allocation list, the number of needed doctors, graduate nurses and medical staff can be calculated. The required number of employees with the necessary skills to handle the expected number of participants/donors must be present at each blood collection drive.
- Every employee must be assigned to a blood drive or to a day off.
- The employee can only be assigned to a blood collection drive if he/she is available on that day; for example, employees with weekend contracts are automatically only available on weekends. Additionally, the duration of the blood collection drive must be between the minimum and maximum working hours for each employee. This point is fulfilled with parameter a_{ej}.
- Each employee can execute only one skill at a time at a blood collection drive.
- Each employee can only work at one blood drive per day. This point is included in the input parameter$f_{jj'}$.
- The employee can only be assigned to a task if the employee belongs to the required professional group and has the skill to fulfil that task.
- Every employee is allowed to work a maximum of 9 consecutive days per week.

Constraints regarding legal requirements:

- The minimum rest time between two working days is at least 11 hours. For example, if a blood drive ends at 10 p.m. in the evening, it is not allowed to schedule these employees on the following day at 6 a.m., because that would mean that they had a rest time of only eight hours, which would violate the legal regulations. This point is also fulfilled through parameter$f_{jj'}$.
- Week-rest of at least 36 hours is implemented by the rule that each employee must have two consecutive days off per week and a full week is from Monday to Sunday.
- Every employee must have one weekend off during a four weeks period, which represent the legal weekend-rest. The maximum number of consecutive weekend assignments is limited to three within a period of four weeks.

  Excluded from this constraint are employees with weekend contracts.

The proposed mixed integer problem uses the following notation for the generated sets:

6.1 Sets and Indices

$\mathcal{J}$	…	Set of blood collection drives, indices $j \in \{1, \dots, J\}$.
$\mathcal{E}$	…	Set of employees, indices $e \in \{1, \dots, E\}$.
$\mathcal{E}^{We}$	…	Subset of employees with weekend contracts.
$\mathcal{D}$	…	Set of days, indices $d \in \{1, \dots, D\}$.
$\mathcal{D}^{Mon}, \dots, \mathcal{D}^{Sun}$	…	Subsets of weekdays from Monday to Sunday.
$\mathcal{D}^{We}$	…	Subset of weekend-days.
$\mathcal{J}^{d}$	…	Set of blood collection drives on working day d.
$\mathcal{S}$	…	Set of skills, indices $s \in \{1, \dots, S\}$.

The model uses the following parameters:

6.2 Parameters

a_{ej}	…	Binary, indicating whether employee e is available to work at blood collection drive j due to his/her contract (fixed days off, min/max working hours).
$f_{jj'}$	…	Binary, indicating whether both blood collection drives j and j' can be served by the same employee e with respect to rest time constraints.
r_{js}	…	Resource requirements of skill s at blood collection drive j.
b_{es}	…	Binary, indicating whether employee e has skill s.
t_j	…	Duration of blood collection drive j.
t_j^{+}	…	Overtime hours of blood collection drive j. Calculated from duration of blood collection drive j, t_j .
P_j	…	Penalty costs per blood collection drive j where required staff level is not fulfilled.
$h_e^{m,max}$	…	Maximum working hours per month (28 days) per employee e.
F_{max}	…	Maximum amount of allowed consecutive working days (= 9 in the case of the Red Cross).
c_e^{we}	…	Costs rate of weekend hours for employee e.
c_e^{ot}	…	Costs rate of overtime hours for employee e.

The decision variables of the model are as follows:

6.3 Decision Variables

x_{ejs}	…	Binary variable indicating whether employee e is working at blood collection drive *j* in skill *s*.
p_{js}	…	Binary variable indicating whether required skill s at blood collection drive j is unfulfilled.
y_{ed}	…	Binary variable indicating whether worker *e* is active on day *d*.
w_{ed}	…	Binary variable indicating whether worker *e* is active on day pair (*d*, *d* + 1).
z_{ed}	…	Total working hours of employee *e* on day *d*.
u_e	…	Plus-hours or hours above the contract hours within the planning horizon of employee *e*.
h_e^+	…	Total overtime (if duration of blood collection drive >8 hours) per employee *e* within the planning horizon.
o_e	…	Total overtime of worker *e*, o_e = max(u_e , h_e^+).

Having illustrated all relevant parameters and variables, the corresponding objective function of the model can be presented:

$$\min \sum_{e} o_e \cdot c_e^{ot} + \sum_{e} \sum_{d \in D^{We}} z_{ed} \cdot c_e^{we} + \sum_{j} \sum_{s} p_{js} \cdot P_j \tag{1}$$

The objective function has the goal to minimize the additional costs for the Red Cross and consists of three parts: The first part calculates the cost of overtime hours, which is a relatively complex operation within the Red Cross. The overtime hours come from the comparison of blood collection durations above eight hours and hours above monthly contract hours. The larger number is taken and multiplied by the cost rate for overtime for each employee.

The second part of the objective function calculates the additional costs of old contracted employees working on weekends. Therefore the sum of total hours worked on weekends is multiplied by the costs of weekend hours per employee.

The third and last part of the objective function penalizes a missing employee with a certain skill at blood collection drive j. The value of P_j is lower for blood collection drives in the centre compared to drives with buses and team cars. The consideration behind this approach is that the focus in this paper lies on scheduling personal to blood collection drives in Vienna, Lower Austria and Burgenland. Because of the complex structure of overtime and additional working hours in the case of the Red Cross, a detailed explanation of the calculation is now given.

The general rule for full time contracts and part-time contracts is that working more than 8 hours in a day results in overtime. However, there are differences between full and part-time employees.

If, for example, a full time employee with 40 hours per week and 160 hours per month, has the following timetable for one week:

Full-time employee - 40 hours/week		
First week	**Working hr**	**Overtime hr**
Mon	13 hr	5 hr
Tue	10 hr	2 hr
Wed	8 hr	0 hr
Thu	6 hr	0 hr
Fri	11 hr	3 hr
Sat	0 hr	0 hr
Sun	0 hr	0 hr
Total	**48 hr**	**10 hr**
$\boldsymbol{u_e}$	**8 hr**	
$\boldsymbol{h_e^+}$		**10 hr**

Table 16: Overtime calculation for full-time employees

The calculation is explained based on Table 16. Table 16 shows that this employee works 48 hours in total at the end of the first week. The worker is scheduled to three blood collection drives that last longer than 8 hours, which results in overtime hours h_e^+ of 10 hours in total. The employee works also 8 hours more than his/her contract hours committed him/her. This number comes from the calculation of 48 total working hours minus 40 contractual working hours, which gives us a difference of 8 more-hours or “moretime” u_e. The maximum of these two numbers have to be compensated, which is in this case 10 hours, which must be multiplied with the cost rate of overtime for this employee. If these 10 hours overtime get paid out, also the 8 hours moretime are compensated concurrently.

This rule is true for all four weeks within each month and if the employee works less than 40 hours per week, the employer still has to pay the full amount of the salary.

For example, an employee could work 9 hours on one day (1 hour above 8 hours) and in total 35 hours each week. The employee would get 1 overtime hour paid every week in addition to the base salary.

The rules are different for part-time employees. Table 17 gives an example of the overtime calculation for an employee with a 15 hours per week contract. After each week, the more- and the overtime, concerning blood drives with durations longer than 8 hours, get split in two rows. The employee works 18 hours in the first week, which are 3 hours more than the contractual 15 hours per week and 2 hours overtime on the blood collection drive on Tuesday. At the second week, the worker is only scheduled to two short blood drives, which results in total working hours of 13 hours. These 2 minus hours are compensated with the first week and at the end of the second week, this employee would have 1 hour moretime that have to be paid out, at this point in time. At the end of four weeks, 70 hours are worked, which are 10 hours more than the contractual 60 hours per four week. Additionally, the employee worked 9 overtime hours. The maximum out of these two numbers, which are 10 moretime hours get multiplied with the cost rate of overtime for this employee and get paid out at the end of four weeks.

The constraint that identifies the maximum of more- and overtime hours is Constraint (10) which is explained in chapter 6.5.

Part-time employee - Contract: 15 hours/week					
Week	**1.**	**2.**	**3.**	**4.**	
Mon	8 hr		10 hr		
Tue	10 hr	6 hr			
Wed		7 hr			
Fri					
Sat				8 hr	
Sun			10 hr	11 hr	
Total	**18 hr**	**13 hr**	**20 hr**	**19 hr**	***Sum***
Moretime u_e	3 hr	-2 hr	5 hr	4 hr	***10 hr***
Overtime h_e^+	2 hr	0 hr	4 hr	3 hr	***9 hr***

Table 17: Overtime calculation for part-time employees

6.4 Parameter pre-processing

This chapter reviews the parameters which must be pre-processed before the constraints can be applied to the model. Most of them are already explained in detail in chapter 5.

The first input parameter “Allowed employee-drive combinations” a_{ej} shows the availability of all employees. It demonstrates the contractual restrictions, such as weekend contracts or specific fixed days off. It also includes the allowable minimum or maximum working hours for full time contract employees, whose minimum and maximum working hours per day are 7 and 9 hours, respectively. This is possible because the duration of all blood collections within a year have a pre-agreed start and end time. Therefore the total working hours including travel time can be calculated in advance.

$$a_{ej} = \begin{cases} 1 & \Leftrightarrow \text{ employee } e \text{ is available on } d_j \text{ AND duration } t_j \text{ is between the min. and max. working hours possibilities for employee } e \\ 0 & \text{otherwise} \end{cases}$$

The second parameter “Allowed blood collection drive combinations” $f_{jj'}$ handles the legal rest time restriction between two working days and blood collections. Between the end time of a blood collection drive, which includes the travel time, and the start time of the next one, given that the next blood collection drive is on the consecutive day, there must be a rest time of minimum 11 hours. Another possibility could be that two or more blood collections are on the same day and that the same employee is scheduled to both blood drives. Currently, this is not the norm within the Red Cross staff scheduling practice and it is not intended to include this possibility within this work, therefore the parameter $f_{jj'}$ also avoids this possibility.

$$f_{jj'} = \begin{cases} 1 & \Leftrightarrow \text{ the rest time between consecutive blood collections drives } j \text{ and } j' \text{ is equal or larger than 11 hours or } j \text{ and } j' \text{ take place on the same day} \\ 0 & \text{otherwise} \end{cases}$$

The variable t_j^+ is necessary for the calculation of overtime hours which cause additional costs within the objective function and therefore should be minimized. If the duration of a blood collection drive lasts no longer than 8 hours, the variable takes the value of 0. Otherwise, if a drive exceeds duration of 8 hours, it shows the exceeded hours after the 8 hours. For example, if a blood collection drive has duration of 10 hours in total, the variable t_j^+ would display 2. These data are part of the blood collection drives input file, but need to be calculated out of the row data.

$t_j^+ = \max(\, 0, (\, t_j - 8)\,)$

The parameter "Resource requirements" r_{js} is also part of the collection drives input file and this part of the input file is shown in Table 18. For each blood collection drive an individual mix of different tasks and number of employees able to fulfil these tasks is needed. The parameter r_{js} only shows how many workers are required by each task to handle the participant numbers.

j/s	**Medical Briefing**	**MB+Testing**	**Testing**	**Puncture**	**Teamer**	**Blood Collection**	**Refreshment**
1	1	0	2	2	1	3	0
2	0	1	0	1	1	2	1
…	…	…	…		…	…	…

Table 18: Resource requirements

Table 19 shows the parameter "Employee-Task combination" b_{es}. This parameter is compared to the resource requirement parameter included in the employee input data file, because it is specific employee information. This parameter presents the tasks each worker is able to fulfil. For example, employee e = 1 has the skill to execute the tasks medical briefing or medical briefing in combination with testing. With regard to this table, it can also be stated that employee e = 1 belongs to the professional group of doctors.

e/s	Medical Briefing	MB+Testing	Testing	Puncture	Teamer	Blood Collection	Refreshment
1	1	1	0	0	0	0	0
2	0	0	1	1	0	0	0
…	…	…	…		…	…	…

Table 19: Employee-Task combination

$$b_{es} = \begin{cases} 1 & \Leftrightarrow \text{ employee } e \text{ has skill } s \text{ (or can execute one or more task(s) shown in Table 19)} \\ 0 & \text{otherwise} \end{cases}$$

After the parameter pre-processing, the constraints are formulated and included in the model. The following constraints are necessary to satisfy all points of hard constraints mentioned above.

6.5 Constraints

The model's constraints (2) until (14) are now presented. After the upcoming mathematical notation, the tasks and functions of each constraint are explained and described in more detail.

$$\mathcal{Y}_{ed} = \begin{cases} 1 & \Leftrightarrow \quad \sum_{j \in \mathcal{J}^d} z \sum_s \; x_{ejs} = 1 \\ 0 & else \end{cases} \qquad \forall\, e, d \qquad (2)$$

$$\mathcal{W}_{ed} = \begin{cases} 1 & \Leftrightarrow \quad \mathcal{Y}_{ed} + \mathcal{Y}_{e(d+1)} \geq 1 \\ 0 & else \end{cases} \qquad \forall\, e, d \backslash \{D\} \qquad (3)$$

$$\sum_{e} x_{ejs} + p_{js} \geq r_{js} \qquad \forall\, j, s \tag{4}$$

$$x_{ejs} \leq b_{es} \qquad \forall\, e, j, s \tag{5}$$

$$x_{ejs} \leq a_{ej} \qquad \forall\, e, j, s \tag{6}$$

$$\sum_{s} x_{ejs} + \sum_{s} x_{ej's} \leq f_{jj'} + 1 \qquad \forall\, e, j, j' \neq j \tag{7}$$

$$\sum_{j}\sum_{s} t_j \cdot x_{ejs} \leq h_e^{m,max} + u_e \qquad \forall\, e \tag{8}$$

$$\sum_{j}\sum_{s} t_j^{+} \cdot x_{ejs} \leq h_e^{+} \qquad \forall\, e \tag{9}$$

$$o_e = \max(h_e^{+}\ , u_e) \qquad \forall\, e \tag{10}$$

$$\sum_{j\,\in\,J^d}\sum_{s} t_j \cdot x_{ejs} \leq z_{ed} \qquad \forall\, e, d \tag{11}$$

$$\sum_{d=d'}^{d+5} \mathcal{W}_{ed} \leq 5 \qquad \forall\, e, d' \in D^{Mon} \tag{12}$$

$$\sum_{d\,\in\,D^{Sat}} \mathcal{W}_{ed} \leq 3 \qquad \forall\, e \in \mathcal{E}^{We} \tag{13}$$

$$\sum_{d=d'}^{d'+F_{max}} \mathcal{Y}_{ed} \leq F_{max} \qquad \forall\, e, d' \in D\ \{D, D-1, \dots, D-F_{max}-1\} \tag{14}$$

The first two variables count the active days or the days on and the days off. Variable in constraint (2) indicates whether the employee e is working on day d. Variable $\mathcal{Y}_{ed}$ is a binary variable, which shows 0 in case of contractual fixed days off or the legal restriction of two consecutive days off during one week or simply a day with no assigned blood drive. It guarantees also that every employee has to be assigned either to a blood collection drive or to a day off. Furthermore, it is used to count the consecutive working days which must be equal to or less than nine days.

The variable in constraint (3) is built upon y_{ed}. The variable w_{ed} represents a pair of days, for example Monday and Tuesday or Tuesday and Wednesday. The d in variable w_{ed} stands for the first day of the weekday pair. This variable indicates whether one or two days within one day-pair (*d*, *d+1*) are active working days. It is used for the calculation of two consecutive days off per week and additionally to guarantee the legal restriction of one weekend-rest within a four week working period.

Constraint (4) guarantees that the required number of employees with the right skills is working at the blood collection drive *j* were they are needed. It is possible that more than the required number of personnel could be scheduled to a blood drive, but the objective is to minimize the additional costs, which guarantees that only the necessary number of employees is scheduled. Constraint (4) also includes the penalty term, which allows for a maximum of one position per skill s to remain unfulfilled for each blood drive j.

Constraint (5) ensures that each employee e, who is assigned to blood collection drive *j* has the needed skill *s*. The next constraint (6) uses parameter a_{ej} to check if each employee who is scheduled to a blood collection drive to execute skill *s* is available and allowed to work at this drive. Therefore general availabilities of each employee and minimum/maximum working hours per day agreements are reviewed.

Constraint (7) verifies that one employee cannot work at two blood collections, if this is not feasible regarding parameter $f_{jj'}$, meaning these two blood collections violate the legal minimum rest time of at least 11 hours between two blood drives *j* and *j'*. It also checks if two drives occur on the same day.

Constraint (8) sums up the duration t_j of all scheduled blood collection drives *j* for every employee e and counter-checks if the maximum working hours for a month (4 weeks count as a month is this model) are met. If the contractual working hours per month are exceeded, they count as more-hours and are stored in variable u_e. The working hours per month and not per week are taken because it is possible for part-time employees to work less or more than their total weekly working hours. At the end of each month the more and less working hours should be balanced against each other. The remaining more-hours above contractual level have to be paid out at the end of each month and count therefore as additional costs within the objective function.

The other kind of additional costs are costs for overtime hours. Constraint (9) counts the blood collection drives which have a duration of over 8 hours and stores the calculated sum in variable h_e^+. This sum reflects the total overtime hours worked per employee in four weeks.

The variables of constraint (8) and (9) are used for the calculation of constraint (10). Constraint (10) takes the higher number between overtime hours and more-hours and stores the result in variable o_e for every employee e. This variable is part of the first section of the objective function.

Constraint (11) calculates the total working hours or durations t_j per employee and day. The variable z_{ed} indicates how many hours an employee worked on day d. This information is used within the objective function to find out how many weekend hours old contracted employees worked. This in turn is needed for the calculation of additional costs coming from old contracted employees working on weekends.

Constraint (12) and constraint (13) fulfil the week- and weekend-rest time restrictions. Constraint (12) ensures that in each week, starting with day-pair Monday+Tuesday and ending with day-pair Saturday+Sunday at a maximum five such day-pairs are worked. This guarantees that in every week two consecutive days are scheduled with a day off.

The next constraint (13) counts also the day-pairs, but only the weekend day-pairs, to check that only three out of four weekends are worked. This constraint excludes the employees with weekend contracts.

Constraint (14) ensures that the maximum amount of nine consecutive working days is not exceeded. Therefore, the active days stored in variable $\mathcal{Y}_{ed}$ are used.

After the detailed explanation of all implemented constraints, the composition of the objective function will be shortly described. The first part of the objective function comes from constraint (10) which is the amount of relevant overtime hours. This number is multiplied by the different cost rates for overtime per employee in variable c_e^{ot}. The second part uses the total working hours on weekends stored in variable z_{ed}, which was calculated in constraint (11) and is multiplied by the costs for weekend hours, taken from variable c_e^{we}. The last part of the objective function calculates the penalty costs for each blood drive in parameter P_j with the binary variable p_{js}, which was filled in constraint (4).

7 Computational results

Due to the unique constraints of the Red Cross staff scheduling problem and the test instances created directly from real-world data, there are no accurate problems in the literature with comparable solutions. Therefore, nine test instances were created out of the real world data received from the Red Cross and compared. The test instances are named after the months where the main information was taken from.

For example, the first test instance is January and starts with the 5th of January 2015 and the instance ends after 28 days with the 1st of February. The other test instances, up to the month September, are created according to the same rule. The first instance is calculated as the basic instance without any data coming from the previous month. Test instance February is the first instance which has the information about the previous month January included in its calculation. This rolling horizon data includes the information about the assignment of the last nine days of the previous month and the end time of the assigned drive on the last day of the previous month. These data are saved after each solution generation of each test instance and used for the solution calculation of the next test instance.

After the calculation of the real world problem instances, some possible scenarios are created in terms of other information within the instances and compared to the basic solutions. The first scenario takes the month March and changes the input files slightly. The scenario includes an increase by a certain percentage of blood collection drives. The objective hereby is to see the changes to the total costs compared to the initial solution. Furthermore, at a certain point with too many drives, it is not possible to execute every collection drive, but the decision about which drive should be cancelled is interesting for the Red Cross.

Another scenario will include the shortfall of different employees in different professional groups and the consequences with regard to overtime hours or penalty costs for not fulfilling the required level of staffing.

The above presented constraints and objectives are applied to all sets of test instances. The algorithm was written in C++ and implemented in CPLEX 12.7.1. The calculation was done on a computer running under Windows 10, with an Intel(R) Core(TM) i3-3217U CPU @ 1.80GHz processor with 4.00 GB RAM. The output is created using .txt files. These are then copied to Microsoft Excel and transformed to readable timetables for the employees.

There was no run time limit specified for each run and CPLEX was restricted to a single thread.

7.1 Solution evaluation

This section takes a closer look at the individual solutions for each test instance also indicated as months. Each test instance represents 28 days starting with the 5th of January and ending with the 20th of September, grouped into nine testing months. Each month has 102 employees available for scheduling, which results into 11,440 total working hours offered by these employees per month (planning horizon). This is the sum resulting from adding up all contracts working hours of the 102 employees.

Table 20 shows the months January until September and their corresponding solutions. The second column counts how many blood collections drives were executed in this month and therefore have to be scheduled with the right number of employees with the right skills. This number includes also the “drives” within the centre in Vienna. For the centre in Vienna, 88 “blood collection drives” were created. This number reflects the sum of four “drives” from Monday to Friday and in total two “drives” on a weekend for a period of four weeks, which gives a total of 88 “drives”. This means that in the month of January only 116 real blood collection drives took place.

The daily blood donation process within the centre was included in the model to come to comparable results, because out of the available 102 employees the staff requirements in the centre must also be satisfied. Right after these numbers are the total offered working hours of the employees and next to that are the required working hours given. The required working hours are calculated by adding the number of required personnel multiplied by the duration of the corresponding blood drive. It is assumed that the gap between offered and required working hours has an impact on run time and objective value. The more offered working hours compared to required hours there are, the faster should a solution be found with a lower objective value compared to months with a small difference between these two numbers. Clearly this should be one impact, but the run time and the objective value also depend on the distribution of needed skills per blood collection drive, which can be seen e.g. for August and June. August has the highest gap of 1,538 more offered working hours than required, whereas on the other side, June has only 987 more working hours to offer than needed. In terms of run time, August was the fastest solved month with 25 seconds, but in terms of costs and objective value it was June which came to the lowest cost solution of 33,703.80 Euros within a relatively fast run time of ~ 8 minutes. The reason for this results from the costs for weekend hours worked by old contracted employees. In June only 46 blood collection drives took place on Saturdays and Sundays and 262 employees were necessary to handle these drives, respectively. Altogether, 54 blood collection drives took place on weekends in August and therefore a number of 312 employees were necessary to do these drives. This difference leads to higher costs on weekends for August and ends up in a higher objective value, because the second cost driver, the overtime costs, are comparable in both months.

The number of estimated participants corresponds negatively with the gap between offered and required hours, because the more participants are expected the more Red Cross personnel is needed and the higher is the number of required working hours. Again, this can be seen for the month of August, where the lowest number of participants is expected and the highest gap results between offered and required working hours. The following two columns represent the run time until the optimal solution was found in seconds and in minutes. Beside these columns is the corresponding objective value to reach the optimal solution, with no time constraint.

The objective value is calculated from the sum of costs per weekend hour plus overtime costs and penalty costs, which are shown in the subsequent columns. Penalty costs are charged when not all necessary employees can be scheduled to a specific blood drive. In more detail, the constraint is so defined that only one person per task can fail at a maximum. Moreover, the penalty costs for missing personnel in the centre in Vienna is lower than for real blood collection drives. This results from the fact that this paper concentrates on the process of scheduling personnel to blood collection drives and the personnel requirements in the centre are a side factor, which must be considered in order to generate reliable solutions, but is not the main problem which should be solved here. The penalty term was implemented to find faster feasible solutions, but was not filled with costs in the end, because each month more working hours were offered than required.

Only two months had penalty costs in the first initialization. In January, it was the 6th of January where penalty costs accrued and on the 6th of April. On the 6th of January there were six blood collection drives and five of them had overtime hours up to four hours. In more detail, three drives had durations of around eleven hours, two of nearly twelve hours and only one lasted eight hours. In total, 53 employees were required just for these six drives on one day. Moreover, nine graduate nurses for testing had to be scheduled and therefore the program omitted having one testing graduate nurse on this day in the centre. More or less the same problem occurred in April. There were also six blood collection drives on the 6th of April with durations mostly greater than eleven hours and also 54 employees were necessary for these drives. This timetable led again to not having enough employees for the centre in Vienna, which resulted in penalty costs. However, the 6th of January and the Monday of Easter, the 6th of April, are national holidays in Austria and therefore the centre in Vienna was closed on those days. After removing the needed personnel on these days from the centre, the program came to a solution without penalty costs, which can be seen in Table 20.

The next column in Table 20 shows the generated number of solutions until the optimal solution was found. The last three numbers concentrate on the run time until the first time the objective value was found, without optimality being proven until this point. The last column shows the MIP gap tolerance level where the objective value was found for the first time. For example, in May there was an optimal solution found after 116 minutes run time, but the final objective value was already found after 42 seconds and proved to be within 3.58 percent of optimal. This is a very interesting point, because it shows that, on average, after 1.49 minutes all nine test instances came to the optimal solution within an average MIP gap of 1.92 percent. This means that it is not necessary to wait for total optimality, because good and also final solutions can be reached much earlier, which saves time and cost.

The next chapters try to construct real-life scenarios for the Red Cross and show how the presented model can solve these problems or in other words help to make consolidated decisions. For example, the main part of blood collection drives is planned a half-year ahead. There are generally no sudden changes or villages that want a blood collection drive from one day to the next. However, there are companies that are new or growing and they think about holding a blood collection drive within their company properties. If they call the Red Cross one month ahead and not half a year, the Red Cross tries to give a valid statement based on their longstanding experience. Also in this case, the presented model in this paper can help to find out if the additional collection drive is first of all possible without any shortfalls at other drives and secondly how much would the costs increase, if this additional blood drive would also be carried out. To illustrate this problem, scenarios 1 and 2 were created. In both scenarios, randomly selected blood collection drives in the month of March will be copied and added to the month.

Another problem occurs when employees are absent due to sickness or vacation. This means that the offered working hours per week or month are reduced and skills are no longer available for a temporary period. The model can also calculate the changes in scheduling and costs by simply putting the relevant employees in the status of non-availability on all days for a month. The outcomes regarding run time and objective value are presented in scenarios 3 until 5.

Month	BC Drives	Offered WH	Req. WH	Difference offered/ required	Est. Participants	CPU (s)	CPU (min)	OV	Costs/ WEH	OT costs	P. costs	# of solutions	CPU (s) until OV	CPU (min) until OV	OV at MIP gap (%)
January	204	11440	11120	320	13620	269.64	4.49	51,223	17,524	33,699	0	22	52.56	0.88	0.87
February	206	11440	11193	247	15310	423.97	7.07	51,541	19,538	32,003	0	40	53.55	0.89	1.34
March	208	11440	11049	391	13180	478.20	7.97	47,620	19,491	28,129	0	24	249.97	4.17	0.02
April	190	11440	10111	1329	11825	28.06	0.47	40,958	13,232	27,726	0	11	22.92	0.38	0.21
May	202	11440	10718	722	12640	6960.63	116.01	38,316	10,332	27,984	0	57	42.22	0.70	3.58
June	200	11440	10453	987	12215	491.81	8.20	33,704	9,317	24,387	0	23	54.12	0.90	2.25
July	197	11440	10174	1266	12185	29110.89	485.18	41,608	18,372	23,236	0	52	38.12	4.34	4.34
August	184	11440	9902	1538	11760	25.30	0.42	46,035	20,305	25,730	0	8	25.19	0.42	0.97
September	199	11440	10365	1075	12140	63.53	1.06	47,358	20,587	26,771	0	12	43.72	0.73	3.74

Table 20: Computational results, real world instances

7.2 Scenarios 1 and 2: Adding blood collection drives

Within scenarios 1 and 2 randomly chosen blood collection drives were copied from the month of March and added to the test instance. The additional blood drives were generated with an Excel function that gives you random numbers within a defined range. Up to 15 blood drives were added this way. Which drives were added can be seen from Table 21. The first column indicates the index number from the blood drive in the original test instance. The rest of the data is designed in the same way as the input files. The duration of each drive is shown in t_j and also the resulting overtime hours, next to the estimated number of participants. The last seven columns show the extra needed personnel to satisfy these additional blood collection drives. The added drives are identical in each scenario; they only get increased by one or more drives each time. The numbers of the original test instance plus ten, 13, 14 and 15 additional blood drives are presented, analyzed and compared with each other.

Index of copied drive	Day	Week-day	Start time	End time	t_j	Est. Part.	OT	# of MB	# of MB&T	# of P	# of Test	# of Teamer	# of BC	# of R
13	4	Fri	6	14.25	7.75	150	0	2	0	2	3	1	5	1
109	26	Sat	11.75	20.5	8.25	120	0.25	1	0	1	2	1	3	0
13	4	Fri	6	14.25	7.75	150	0	2	0	2	3	1	5	1
12	3	Thu	13	20.5	7	60	0	0	1	1	0	1	2	0
107	25	Fri	14.25	19.5	5.25	70	0	1	0	1	2	1	3	0
46	11	Fri	15.25	20.5	5.25	65	0	1	0	1	2	1	3	0
10	3	Thu	12	20	7.5	50	0	0	1	1	0	1	2	1
116	27	Sun	6.5	18.25	11.25	150	3.25	1	0	1	2	1	4	0
53	12	Sat	13.25	20.5	6.75	80	0	1	0	1	2	1	3	0
51	12	Sat	7.25	15.5	7.75	60	0	1	0	1	1	1	2	0
with +13														
20	5	Sat	12.25	20.25	7.5	60	0	0	1	1	0	1	2	0
87	20	Sun	7.5	16.25	8.25	65	0.25	1	0	1	1	1	2	0
85	20	Sun	6.5	16.25	9.25	85	1.25	1	0	1	2	1	3	0
with +14														
83	19	Sat	11.5	22.75	10.75	120	2.75	1	0	1	2	1	4	0
with +15														
25	6	Sun	7	16.75	9.25	100	1.25	1	0	1	2	1	3	0

Table 21: Original March plus 10, 13, 14 or 15 blood collection drives

The first scenario adds only ten drives, which increased the number of originally 208 drives in March up to 218 drives. The number of employees stayed unchanged, as well as the offered working hours of all employees. Due to the increased number of collection drives, the required working hours rose accordingly. Table 22 shows these changes in percentage in the row called Diff. #1, which stands for scenario number 1. In the first scenario there was a shortage of 235 working hours, which must be either compensated with overtime hours or, if it is not possible to schedule all necessary employees to a specific drive, with penalty costs.

From Table 22 can be seen that it was possible to run ten more blood drives in March with a ~ 30 percent increase in total costs. In detail, the costs for employees in old contracts, who have to work on weekends increased by 30 percent and the people who worked over their contracted hours cost 36,431 Euros, which is more than 29.5 percent of the original test instance with 208 drives. The total number of solutions increased to an amount of 49 compared to 24 at the original instance. Interesting is that the objective value was found relatively quickly, compared to the total run time. However, the run time until optimality was proven was with 46 minutes more than 480 percent longer than the original run time of 7.97 minutes. Overall it can be said that the costs for weekend hours and overtime hours grew at an equal rate by 30 percent each, compared to the original solution.

The second scenario tries to test how many blood collection drives can be added before penalty costs for missing personnel come in. During testing of scenario 2, it happened that the original test instance plus 13 and 14 added drives were also run. These two solutions are not analyzed in detail, but Table 23 shows the solutions, namely the objective value, which is further split into costs per weekend hours and overtime costs. Furthermore, the run time in seconds until the optimal solution was found is also presented in Table 23.
Also the difference between the extended test instance and the original test instance “March” is shown. Therefore it can be clearly seen that with each additional blood collection drive, the total costs increase. In both cases, the costs rise for old contracted employees who are working on weekends quicker than the costs for overtime hours. The run time also increases drastically with 1 hour and 5 minutes if there are 13 drives added and 1 hour and 55 minutes for 14 additional drives. The run time until the optimal solution was found took only 8 minutes for the original test instance with 208 blood collection drives.

Returning to scenario 2, the intention was to get decision help from the model about running or not running an additional blood collection drive. We saw with the test instance that it would be possible to do 14 more drives without being unable to put all necessary workers to the needed collection drives. The employees have to work a large amount of overtime hours and many old contracted workers have to be scheduled for weekend drives and therefore the workload per employee would rise and the costs for the Red Cross would also increase significantly, but it would be possible to do these drives.

The tipping point is reached with the inclusion of the 15th additional blood collection drive. This drive happens to be on a Sunday with duration of 9 hours and 15 minutes. One doctor is needed, as well as three graduate nurses for testing and puncture and three medical workers for blood collection and one medical worker has to be scheduled as the teamer. This information is also shown in Table 22.

The total costs increase up to 103,620 Euros including 3,000 Euro of penalty costs. These penalty costs arise because it is not possible to schedule the required amount of testing personnel for drive number 23 and also the required number of graduate nurses for testing and puncture at drive number 28. It would be theoretically possible to execute drive number 28, because two graduate nurses for doing the puncture are necessary and only one can be assigned. Also three graduate nurses are necessary for the testing, but only two can be scheduled. Therefore blood collection drive number 28 could take place with fewer personnel, but the remaining employees would have a much higher workload per hour than intended.

On the other hand, drive number 23 only requires one graduate nurse for testing and this graduate cannot be scheduled if a 15th drive is added. This would mean that, for example, the assigned doctor has to do also the testing, but, in general, the blood collection drive number 23 must be skipped, regarding this solution.

Table 24 presents all relevant blood collection drives on this Sunday and the required personnel level. The last row shows the 15th drive that is added and the needed personnel for this drive, respectively. It is easy to see that the additional blood drive needs three graduate nurses, one for doing the puncture and two for testing. One graduate nurse for puncture is taken from blood drive number 28 and one graduate nurse, who is assigned for testing, gets assigned to the additional drive also for testing. The second graduate nurse is relocated from drive number 23 to the newly added drive. All in all, the model can also act as a decision tool in situations where the Red Cross has to decide if they want or even can do additional blood collection drives, based on the increased overtime and weekend hour costs and the feasibility of an additional drive.

Month	Scenario	BC Drives	Offered WH	Req. WH	Difference offered/ required	Est. Part.	CPU (s)	OV	Costs WEH	OT	P. costs	# of solutions	CPU (s) until OV	OV at MIP gap (%)
March	Basic	208	11440	11049	391	13180	478.2	47,620	19,491	28,129	0	24	249.97	0.02
March #1	#1	218	11440	11675	-235	14135	2783	61,794	25,363	36,431	0	49	356.42	0.06
	Diff. #1	4.81%	0%	6%	-160.10%	7.25%	481.97%	29.76%	30.13%	29.51%	0%	104%	43%	200%
March #2	#2	223	11440	11997	-557	14565	3770	103,620	33,220	67,400	3,000	68	695.28	8.49
	Diff. #2	7.21%	0%	9%	-242%	11%	688%	118%	70%	140%	-	183%	178%	42350%

Table 22: Scenario 1 and 2 - Adding BC drives

Added drives	OV	Costs of WEH	OT costs	CPU (s)
March +13	67,925	29,407	38,518	3933.22
Diff. to Original	42.64%	50.87%	36.93%	722.51%
March +14	72,137	31,866	40,271	6902.7
Diff. to Original	51.49%	63.49%	43.17%	1343.48%

Table 23: Solutions for original instance plus 13 or 14 drive

Index of drive	Day	Week-day	Start time	End time	*d*	Est. Part.	OT	# of MB	# of MB&T	# of P	# of Test	# of Teamer	# of BC	# of R
23	6	Sun	7.25	17.5	9.75	80	1.75	1	0	1	~~1~~	1	2	0
24	6	Sun	7	16.75	9.25	220	1.25	2	0	2	3	2	6	1
25	6	Sun	7	16.75	9.25	100	1.25	1	0	1	2	1	3	0
26	6	Sun	7	16.25	8.75	80	0.75	1	0	1	2	1	3	0
27	6	Sun	7.75	16.75	8.5	90	0.5	0	2	1	0	1	3	0
28	6	Sun	6.25	17.5	10.75	240	2.75	2	0	~~2~~ 1	~~3~~ 2	2	6	1
#15	6	Sun	7	16.75	9.25	100	1.25	1	0	1	2	1	3	0

Table 24: Bottleneck of personnel by adding the 15th drive

7.3 Scenario 3-5: Shortage of employees

The scenarios 3 until 5 show the changes in costs if one, two or four employees are absent. Within scenario 1, a doctor with a new contract was not available for scheduling. This doctor has a contractual agreement of 30 working hours per week, which means a shortage of 120 working hours per month for this scenario. Furthermore, the doctor was available for scheduling the whole week and had no weekend contract. The doctor was also trained to do medical briefing and had the qualification to work during a blood drive with a blood donation bus and handle the testing in combination with the medical briefing. Table 22 has a row which is called Diff. #3 that shows the difference to the original solution for scenario number 3. The solution shows that the doctor with a new contract will be substituted at some drives for old contracted employees, because the costs for working hours on weekends rose by 2.39 percent. The objective value increased insignificantly, but the run time until optimality increased drastically by 72 percent.

The fourth scenario presents a higher increase in total costs compared to the third scenario. Within the fourth scenario a graduate nurse with an old contract is absent in addition to the doctor form scenario 3. This graduate nurse has a 25 working hours per week agreement, is available every day and does only the task testing. Now only 100 employees were available and the total costs increased by 8.2 percent in this constellation.

This time the increase in overtime costs rose drastically from originally 28,129 Euros to 31,575 Euros, which represents a rise of more than 12 percent.

The last scenario excludes two medical employees in addition to the doctor and the graduate nurse form scenario 3 and 4. One medical staff has a new contract with 120 working hours per month and the other medical worker has an old contract with the same working hour regulation. The old contracted employee is only available for blood collection, but on every day. The new contracted worker is also available every day and has qualifications for blood collection, being the teamer and giving out refreshments. This time more working hours are required than offered, in total 69 hours. The overtime hours just slightly increases from scenario 4, but the working hours on weekends of old contracted employees rose by 5.5 percent from the fourth scenario to the fifth.

In total, the objective value increased again to 52,620 Euros and the run time until optimality was found was equally high as in scenario 3 at 14 minutes. All in all, it was possible to compensate four missing employees within one month if the offered working hours lie clearly below the required number of hours.

During these extension of the basic instances and the increased number of drives or the shortages of employees, was it relatively clear to see that some weekdays during a week require a higher total sum of working hours and other days not. In the basic analysis of all nine test instances presented in Table 20, the months January, February and March have the highest number of required working hours compared to the fixed number of offered working hours per week or month. The following table presents the required working hours per month, split into weekday requirements and compares them with the offered working hours per weekday. It can be seen from Table 25 that for Sundays in January, February and March the most working hours are required. Also the requested working hours for Mondays and Fridays are relatively high. It can also be clearly seen that too many working hours are offered on Saturdays where, on average, only half the number of hours would be sufficient to fulfil the staff requirements for these blood drives. The result of this analysis indicates that the Red

Cross should try to acquire more employees for Sundays or make the work on a Sunday more attractive compared to Saturday work. It could also try to allocate more available workers on Mondays and Sundays, because the high number of offered working hours in the middle of the week are ineffective and cannot be used for the current distribution of drives throughout the week.

	Requ. WH per Month			**Offered WH**	**Difference btw. offered/required**		
Weekday	Jan	Feb	March	each Month	Diff Jan	Diff Feb	Diff March
Mon	1580	1642	1268	2525	**946**	**883**	1257
Tue	1605	1490	1478	2540	935	1050	1063
Wed	1414	1461	1617	2570	1156	1109	953
Thu	1607	1384	1595	2715	1108	1331	1120
Fri	1741	1869	1842	2840	1100	**971**	**998**
Sat	1485	1383	1513	2820	**1336**	**1438**	**1307**
Sun	1974	2241	2032	2820	**846**	**579**	**789**

Table 25: Required WH per day compared to offered WH

8 Conclusion and future research

This work presented a mixed integer programming model which was implemented using CPLEX solver to generate useable solutions for the staff scheduling problem of the Red Cross blood donation drives. The real world origin of the problem made the modelling work of constraints complex, but the reality should be reflected as accurately as possible. The most important restrictions were included and the computational results showed that the problem was solvable in a relatively short amount of time and that applicable timetables for employees can be created. This paper offers a model which helps the Red Cross in their daily business of scheduling the right employees to the needed blood collection drives. The different scenarios in chapter 7 show the versatile application options of the model. It serves as a decision making aid in case of employee shortages and requests of additional blood drives, by delivering cost and benefit comparisons to make cost-based decisions.

The objective function and the results can be only compared between the different months. Even though, the cost rates for working hours came directly from the Red Cross, real costs per month would show the possible improvements of using the model instead of manual scheduling.

Further research could be focused on more flexibility. The flexibility can come from the scheduling of one employee to different tasks or one worker to more than just one blood collection drive per day. Furthermore, the fluctuations in demand could be used for better utilization. Weekly timetables could be generated in advance and would be adapted if demand levels or available workforce level changes, which is one extension also mentioned in Ernst et al. [9]. Another future research field is mentioned in Ernst et al. concerning queuing theory. This theory tries to forecast the arrival of donors so the required staff level can be flexibly adjusted to the peaks and low demand periods during a blood collection.

Another approach is coming from Brummelen et al. [3] which take waiting time predictions during all stations of a blood donation process into account, to generate schedules that include staff level fluctuations to minimize costs for staff capacity by minimizing waiting times to maximize donor satisfactions.

Other ways of improvement could lie in flexible work shifts. This includes overlapping work shifts at high demand periods and single work shifts at low demand periods. The transportation of teams could be also changed, if it possible to allocate more cars arriving at the donation location at different times and also leaving at different times. Also the blood collection drives could be implemented as flexible, in terms of date and duration. For example, if it is possible to do a single blood drive on either a Saturday or a Sunday, it would make sense to schedule the drive on the day where more required workers are available. Therefore, the ability of executing more blood collection drives could rise.

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Supplements

A Sample instances

A.1 Row data of blood collection drives in 2015

Datum	Adresse	Team oder Bus	Abfahrt Vormittag	Beginn VM	Ende VM	Rückfahrt VM	Abfahrt Nachmittag	Beginn NM	Ende NM	Rückfahrt NM	…
02.01.2015	Schloßplatz 4	Team					13:15	16:00	20:00	22:00	…
02.01.2015	Franz-Nagl-Gasse 20	Team					14:15	15:30	18:30	19:15	…
02.01.2015	Hauptstraße 14	Team					12:45	15:00	19:30	21:00	…
03.01.2015	Nr. 158	Team					09:45	12:30	17:00	19:00	…
03.01.2015	Franz-Nagl-Gasse 20	Team	07:45	09:00	12:00			13:00	16:00	17:00	…
03.01.2015	Zwettler Straße 5	Team					10:00	13:00	17:00	19:15	…
03.01.2015	Hauptstraße 32a	Bus					11:30	12:30	16:00	17:00	…
04.01.2015	Zwettler Straße 5	Team	06:30	09:00	16:00	18:15					…
04.01.2015	Nr. 102	Team	06:45	09:00	11:30			12:30	14:00	16:00	…
04.01.2015	Bergwerkstraße 1	Team	06:45	09:00	12:00	14:30					…
04.01.2015	Erlenaugasse 28	Team	07:15	09:00	13:00	15:00					…
04.01.2015	Hofstatt 9a	Team	07:45	09:30	12:00			13:00	14:30	16:00	…
05.01.2015	Franz Zant Allee 3 - 5	Team	06:00	07:30	11:30			12:30	13:30	14:45	…
05.01.2015	Nr. 44	Team	06:45	09:00	12:00			13:00	17:00	19:00	…
…	…	…	…	…	…	…	…	…	…	…	…

Table 26: Row data of drives 2015

A.2 Test instance: Blood collection drives in January

j	day	Week-day	starting Time	end Time	duration	planned Participants	t_j^+	ReqMB	ReqMBTest	ReqPunc	…
0	0	0	12	19.5	7	40	0	0	1	1	…
1	0	0	7.5	18.25	10.25	60	2.25	1	0	1	…
2	1	1	7.75	16.25	8	80	0	1	0	1	…
3	1	1	7.5	15.75	7.75	95	0	1	0	1	…
4	1	1	7.75	16	7.75	120	0	1	0	1	…
5	1	1	6.75	13.5	6.25	70	0	1	0	1	…
6	2	2	12.25	22.5	9.75	110	1.75	1	0	1	…
7	2	2	13.75	23.5	9.25	80	1.25	1	0	1	…
8	2	2	14.75	22.5	7.25	55	0	1	0	1	…
9	3	3	13	21.25	7.75	100	0	1	0	1	…
10	3	3	12	20	7.5	50	0	0	1	1	…
11	3	3	6.75	14.5	7.25	100	0	1	0	1	…
12	3	3	13	20.5	7	60	0	0	1	1	…
13	4	4	6	14.25	7.75	150	0	2	0	2	…
14	4	4	6.5	14.25	7.25	100	0	1	0	1	…
…	…	…	…	…	…	…	…	…	…	…	…

Table 27: Input data: Drive information

A.3 Test instance: Employee information

e	**Mon**	**Tue**	**Wed**	**Thu**	**Fri**	**Sat**	**Sun**	**Working Hours Per Week**	**Working Hours Per Month**	**Min Working Hours Per Day**	**Max Working Hours Per Day**	**…**
0	1	1	1	1	1	1	1	30	120	0	13	…
1	1	0	1	1	1	1	1	30	120	0	13	…
2	1	1	1	1	1	1	1	30	120	0	13	…
3	1	1	1	1	1	1	1	30	120	0	13	…
4	1	1	1	1	1	1	1	30	120	0	13	…
5	1	1	1	1	1	1	1	30	120	0	13	…
6	1	1	1	1	1	1	1	30	120	0	13	…
7	1	1	1	1	1	1	1	25	100	0	13	…
8	0	1	1	1	1	1	1	25	100	0	13	…
9	1	1	1	1	0	1	1	20	80	0	13	…
10	0	1	1	1	1	1	1	20	80	0	13	…
11	0	0	0	0	1	1	1	20	80	0	13	…
12	0	0	0	0	1	1	1	15	60	0	13	…
13	0	0	0	0	1	1	1	10	40	0	13	…
14	1	1	1	1	1	1	1	40	160	7	9	…
…	…	…	…	…	…	…	…	…	…	…	…	…

Table 28: Input data: Employee information

B Deutsche Zusammenfassung

In der vorliegenden Arbeit bietet eine Initiallösung für das Problem der Personaleinsatzplanung zu Blutspendeaktionen beim Roten Kreuz. Die Blutspendezentrale für Wien, Niederösterreich und das Burgenland plant mobile Blutspendeaktionen in den genannten Bundesländern während des ganzen Jahres. Um diese Blutspendeaktionen ausführen zu können bedarf es geschulten Personals mit unterschiedlichen Fähigkeiten, welche wiederum nur spezifische Tätigkeiten ausführen können oder dürfen. Die richtige Zuteilung des Personals zu den im Voraus fixierten Aktionen stellt ein komplexes Optimierungsproblem dar.

Zu allererst muss der Personalbedarf je Berufsgruppe in Abhängigkeit von der erwarteten Spenderanzahl, der benötigten Fähigkeiten und der möglichen Arbeitsbelastung je Mitarbeiter definiert werden. Darauffolgend muss entschieden werden, welche Mitarbeiter zu welchen Blutspendeaktionen zugeteilt werden. Gleichzeitig muss entschieden werden, welche Tätigkeiten die Mitarbeiten bei der zugeteilten Aktion übernehmen muss. Dabei gilt es, die gesetzlichen Rahmenbedingungen einzuhalten. Zusätzlich können die Mitarbeiter nur entsprechend ihren vertraglichen Vereinbarungen eingesetzt werden. Gleichzeitig zu den gesetzlichen und vertraglichen Restriktionen, sollen die zusätzlichen Personalkosten, wie Überstunden, minimiert werden.

Nach einer ausführlichen Datenanalyse der Blutspendeaktionen und der vertraglichen Vereinbarungen der bestehenden Mitarbeiter wurde ein mathematisches Modell formuliert. Dieses Modell beinhaltet als Zielfunktion die Minimierung der zusätzlichen Kosten des Personals, zusätzlich werden alle relevanten gesetzlichen und vertraglichen Restriktionen als Nebenbedingungen in das Modell aufgenommen. Das Modell wurde mithilfe der Programmiersprache C++ in Visual Studio implementiert und durch CPLEX Solver gelöst.
Neun Testinstanzen wurden generiert, die als Monate Januar bis September gekennzeichnet wurden, basierend auf den Originaldaten der Aktionen aus dem Jahr 2015. Das Modell wurde an diesen Instanzen getestet und erbrachte in allen neun Monaten brauchbare Lösungen mit Einsatzplänen für jeden Mitarbeiter, unter Berücksichtigung aller Nebenbedingungen. Die Lösungen der Testinstanzen wurden hinsichtlich definierter Charakteristiken untersucht und Vergleiche bezüglich Lösungsqualität und CPU-Performance wurden aufgestellt.