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Abstract

Fighting the COVID-19 pandemic involves an extensive testing strategy. As part of it, potentially infected persons and their contact persons need to undergo a Polymerase-Chain-Reaction (PCR) test in a timely manner. The PCR tests are either carried out in a test-centre, to which potentially infected persons travel themselves, or they get visited by a mobile test-team at home. After having conducted a test, the swab needs to be transported to and evaluated in a laboratory.

This scenario analysis aims at providing managerial insights on how different numbers of available test-centres, while keeping the number of available mobile test-teams constant over all scenarios, influence the total cost of operating test-centres and routing mobile test-teams.

The analysis is based on the Contagious Disease Testing Problem (CDTP), solved with a large neighbourhood search metaheuristic. An extensive computational study focusing on three scenarios with different numbers of available test-centres was conducted. For each scenario, three different phases of the pandemic were investigated to take into consideration the fluctuating number of PCR tests which must be conducted as per official order on a given day.

Moreover, a comparison of the impact varying numbers of available test-centres have on an urban and a rural setting was achieved by applying the scenarios to the Austrian federal states of Vienna, representing an urban area, and Upper Austria, representing a rural area.

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Table of Contents

List of figures iii

List of tables iv

List of Abbreviations v

1. Introduction 1

2. Problem Description and Solution Method 3

2.1 The Contagious Disease Testing Problem 3

2.2 Large Neighbourhood Search 4

2.2.1 Destruction Heuristics 5

2.2.2 Repair Heuristics 6

2.2.3 Local search 7

2.2.4 Initial solution 7

2.2.5 Acceptance and penalty 8

2.3 Scenario analysis 8

3. Computational study 9

3.1 Time periods under analysis 9

3.2 Demand 10

3.3 Sample 11

3.4 Scenarios 12

3.5 Problem instances 13

3.6 Large Neighbourhood Search 14

4. Computational results 17

4.1 Results for scenario 1 18

4.2 Results for scenario 2 21

4.3 Results for scenario 3 23

5. Conclusion and answers to the research questions 26

5.1 Reflection of results 27

6. References 29

7. Attachment 31

Attachment I: Daily number of PCR tests conducted as per official order in the months under analysis. 31

Attachment II: Numbers of daily PCR test conducted as per official order forming the sample 32

Attachment III: Feasible solutions included in analysis 33

Attachment IV: Detailed computational results 34

Attachment V: Deutsches Abstract 36

List of figures

Figure 1: Screenshot of AGES (2021a): Epidemic curve – new confirmed cases per day Austria……….…………………………………………………………………..10
Figure 2: Scenarios Upper Austria – Test-centre locations ………………………………….13
Figure 3: Scenarios Vienna – Test-centre locations………………………………………… 13

List of tables

Table 1: Number of days per category ……………………………………………...…….11

Table 2: Number of days per category forming the sample ……..…………………………..11

Table 3: Categories used for analysis ………………………………………………………..12

Table 4: Runtime limits per category ………………………………………………………..15

Table 5: Average results for scenario 1 for Upper Austria ………………………………….18

Table 6: Average results for scenario 1 for Vienna ………………………………………….18

Table 7: Average results for scenario 2 for Upper Austria ………………...………………..21

Table 8: Average results for scenario 2 for Vienna ………………………………………….21

Table 9: Average results for scenario 3 for Upper Austria ………………………………….24

Table 10: Average results for scenario 3 for Vienna ………………………………………..24

List of Abbreviations

AGES	Austrian Agency for Health and Food Safety Ltd.
BMSGPK	Federal Ministry of the Republic of Austria for Social Affairs, Health, Care and Consumer Protection
CDTP	Contagious Disease Testing Problem
LNS	Large Neighbourhood Search
ORF	Austrian Broadcasting Corporation
PCR	Polymerase-Chain-Reaction
WHO	World Health Organisation

1. Introduction

We are currently living in the most recent pandemic. A new coronavirus, namely the SARS-CoV-2, has been detected in the Chinese City of Wuhan on December 31st, 2019, for the very first time, according to the World Health Organisation (WHO) (2021). The COVID-19 disease spread around the whole world and was declared a pandemic on March 11th, 2020 (WHO, 2021).

Austria's response to fighting the COVID-19 pandemic includes an extensive testing strategy (BMSGPK, 2020). As part of this strategy, persons with symptoms, persons who recently had contact with an infected person and employees in case there is an onset in a company, undergo a Polymerase-Chain-Reaction (PCR) test as per official order to determine whether the person is infected with the SARS-CoV-19 virus. The WHO (2020) equally advises persons with symptoms and persons who had close contact with an infected person to get tested. The aim pursued is to prevent a fast spreading of the virus by isolating every infected person as soon as possible. The variety of tests detecting the SARS-Cov-19 virus is broadening. Nevertheless, the PCR tests, which are also referred to as tests hereafter, are considered the most reliable ones on the market, as the Federal Ministry of the Republic of Austria for Social Affairs, Health, Care and Consumer Protection (BMSGPK) (2020) describes since their accuracy has proven to be best so far. There are two ways in which a PCR test can be performed, as described by the BMSGPK (2020). On the one hand, a nasopharyngeal swab can be taken by medical personnel. On the other hand, there is the possibility of using a gurgle test, which does not require medical personnel. The accuracy of test results has been researched as being similar for both tests if they are conducted correctly (BMSGPK, 2020). Moreover, to ensure PCR test results' accuracy all laboratories chosen to analyse the specimens must be CE-certified (BMSGPK, 2020).

The BMSGPK (2020) stresses that it is of major importance to keep the time frame from learning about a suspected case to knowing the result of the test as short as possible to prevent the virus from spreading uncontrolledly. As the city of Vienna published, it may take up to 48 hours to have the test result (Stadt Wien, 2021a).

Moreover, there are two different options on where to conduct a PCR test. On the one hand, there are test-centres to which potentially infected persons travel themselves. On the other hand, there are mobile test-teams who visit those potentially infected persons, who cannot travel to a test-centre due to their health status or a too long way to the closest test-centre, at home.

One challenge resulting from the extensive testing strategy is how to minimize the total cost when taking the required specimens in test-centres and by mobile test-teams as well as analysing them in laboratories afterwards, while having test results ready at a maximum of 48 hours after suspected cases arose. From a logistics point of view, the questions of how many test-centres and mobile test-teams are required arise. Moreover, it needs to be looked into how to plan the test-teams' routes to work cost efficiently. Furthermore, once the tests are taken it needs to be determined which laboratory analyses which specimens. A major difficulty in planning the required numbers of test-centres and mobile test-teams is that the daily number of PCR tests as per official order strongly fluctuates (ORF, 2021a).

The aim of this master thesis, therefore, is to answer the following research questions:

1. How does the fluctuating rate of PCR tests, which have to be conducted as per official order, influence the number of test-centres required when keeping the number of available mobile test-teams constant, in order to minimize total cost, while ensuring that test results are available at a maximum of 48 hours after the upcoming of a suspected case?
2. How does a rural or urban setting influence the number of test-centres required when keeping the number of available mobile test-teams constant, in order to minimize total cost, while ensuring that test results are available at a maximum of 48 hours after the upcoming of a suspected case?

In the following, the literature review outlines the theoretical background this master thesis is built on. To do so, the Contagious Disease Testing Problem (CDTP) as well as the Large Neighbourhood Search (LNS) metaheuristic are introduced. Next, the scenario analysis is described before the computational study and its results are presented. Lastly, the research questions are answered with the help of the conclusions drawn by the computational study.

2. Problem Description and Solution Method

This chapter introduces the theoretical framework of this master thesis. Therefore, the next sections present the CDTP as well as the LNS metaheuristic, which has been applied to solve the CDTP (Wolfinger et al., 2021). To answer the above-stated research questions, a scenario analysis, which will be introduced as part of the literature review, was performed.

2.1 The Contagious Disease Testing Problem

The CDTP, which has been developed by Wolfinger et al. (2021), is formulated as an NP-hard arc-based mixed-integer linear programming model. It is the first model to "combine facility location, vehicle routing and scheduling decisions" (Wolfinger et al., 2021, p. 6f). The mathematical formulation for the CDTP can be found in the unpublished manuscript (Wolfinger et al., 2021).

The CDTP's objective is to minimize the total cost of using test-centres and mobile test-teams to take all required specimens and evaluate them in a laboratory. The cost of using a test-centre is translated into a fixed cost per available test-station of an opened test-centre multiplied by the fixed cost of a mobile test-team (Wolfinger et al., 2021). The cost for mobile test-teams comprises fixed cost per working test-team and travel cost based on the tour length. While minimizing the total cost, the CDTP's constraints ensure that each potentially infected person undergoes a PCR test within a defined time span after being declared as suspected case, whether the test is conducted in a test-centre or by a mobile test-team, and receives the test result within a certain maximum time window from when the specimen is taken (Wolfinger et al., 2021). Further constraints of the CDTP ensure that potential cases, which get tested in test-centres, are assigned to an operating test-centre, which can be reached within a defined maximum time, as per Wolfinger et al. (2021). Moreover, the CDTP includes constraints assuring that the opened test-centres' capacities resulting from parallel test-stations are not exceeded as well as that each specimen taken in a test-centre or by a mobile test-team gets feasibly allocated to an evaluation run in one of the laboratories while respecting the evaluation runs' capacities (Wolfinger et al., 2021). The specimens taken at test-centres are transported to a laboratory by additional personnel and vehicles, whereas the operating mobile test-teams include the stops at laboratories to deliver the specimens taken into their tour. There are also constraints ensuring that no specimen is transported out of the laboratories. In addition, the CDTP guarantees through constraints that each vehicle in use begins and ends its tour at the depot and that each potential case not qualifying for a test in a test-centre does get tested by a mobile test-team, according to Wolfinger et al. (2021).

The computational study presented in the manuscript draft concludes that relaxing the time restrictions for taking and evaluating the specimens decreases cost to a considerable extent, while at the same time the goal of quickly disrupting the chain of infections, cannot be attained anymore (Wolfinger et al., 2021). Therefore, in this master thesis, the time constraints for performing the test and receiving the test result will not be relaxed.

2.2 Large Neighbourhood Search

The LNS metaheuristic goes back to Shaw (1998), who described it as being "based upon a process of continual relaxation and re-optimization" (p.418). Making use of a large neighbourhood to destroy and later repair a solution considerably increases the likelihood of finding an improved solution, according to Labadie et al. (2016). Regarding the applied destruction and repair heuristics, the LNS metaheuristic is restricted to the extent that only a certain number of destruction and repair heuristics, which's application is allowed to achieve a better solution, can be made use of (Pisinger and Ropke, 2010).

Once an improved solution is found it becomes the new current solution and the LNS starts around this new current solution again. This process is repeated until a stopping criterion is met (Labadie et al., 2016). One considerable advantage of the LNS is that it is an exact method. However, looking for an improvement within a large neighbourhood is very time consuming (Pisinger and Ropke, 2010).

The CDTP is solved by applying a LNS metaheuristic implemented in C++ (Wolfinger et al., 2021). The pseudocode for the LNS solving the CDTP can be found in Wolfinger et al. (2021). The suitability of working with a LNS metaheuristic was proven in the manuscript draft by comparing the results with those of a MIP-solver. The results of the LNS always came to an equally good or better solution.

Both, the destruction heuristic as well as the repair heuristic, which improve the current best solution in one iteration, are chosen randomly out of a pool of destruction and repair heuristics for solving the CDTP. Each iteration performed in the LNS makes use of one destruction heuristic and one repair heuristic (Wolfinger et al., 2021). The destruction heuristics included in the LNS for the CDTP by Wolfinger et al. (2021) are the following: *random removal, worst removal, related removal, smallest route removal, least utility test-centre removal,* and *test-centre opening removal*. After the application of a destruction heuristic follows the utilisation of the *test-centre insertion* heuristic combined with the *random best insertion* heuristic or the *regret-k insertion* heuristic *with* $k \in \{2,3,4\}$ (Wolfinger et al., 2021).

After a destruction and a repair heuristic have been applied, the solution is compared to the current best solution. If the new solution is better than the current best solution, the current best solution is updated, and the process starts again with a destruction heuristic. This process is repeated until the runtime limit is met. The last best solution is then returned as best solution. Lastly, the new solution's further improvement is reached by conducting a local search applying the *Or-opt* operator (Or, 1976, as cited in Wolfinger et al., 2021).

2.2.1 Destruction Heuristics

In the following, all applied destruction heuristics being part of the LNS are briefly explained. As per Wolfinger et al. (2021), the number of n potential cases, whereby n is set to comprise between 10% and 30% of all potential cases, are removed from the current solution within each iteration. These n potential cases define the "degree of destruction" (Pisinger and Ropke, 2010, p.407). Removing a potential case from the solution includes two removals, as it is removed from the test-centre or the tour of a mobile test-team and from the assigned evaluation run in a laboratory. The choice of which destruction heuristic is applied is based on a uniform probability distribution (Wolfinger et al., 2021).

As the name of the *random removal* heuristic suggests, a number of n potential cases, which are randomly selected, are removed from the solution (Wolfinger et al., 2021).

For the destruction heuristic of *worst removal*, all suspected cases allocated to a mobile test-team or a test-centre are put in order according to their cost saving associated with their removal, as the main objective of the CDTP is to minimize total cost. In a next step, n suspected cases are removed from the current solution. The higher the cost assigned to a suspected case, the higher the chance for it to be removed from the solution (Wolfinger et al., 2021). In other words, the probability for a potential case, which is to be visited by a mobile test-team, to be removed from the current solution is higher than for a potential case being assigned to a test-centre as the cost for conducting a test through a mobile test-team is higher.

Which n suspected cases are removed from the current solution in the *related removal* heuristic depends on the level of relatedness of two suspected cases. This heuristic has been introduced for the Capacitated Vehicle Routing Problem by Shaw (1998, as cited in Pisinger and Ropke, 2010). In general, the higher the relatedness, the greater the chance that a suspected case is chosen to be removed (Wolfinger et al., 2021). The relatedness in the LNS for solving the CDTP is composed of three factors as per Wolfinger et al. (2021), namely the distance between two suspected cases, the difference of when the tests of two suspected cases are conducted as well as whether the test is performed by a mobile test-team or in a test-centre.

As the name of the *smallest route removal* heuristic indicates, the route covering the fewest potential cases is removed from the solution. Thus, all *n* suspected cases lying on this tour are removed from the solution and allocated to other tours (Wolfinger et al., 2021). This heuristic was included to cut down the number of vehicles in use, as Wolfinger et al. (2021) describe since fewer vehicles represent a decrease in cost, which in turn is in line with the main objective. The *least utility test-centre removal* heuristic is the equivalent for test-centres of the *smallest route removal* heuristic. It determines the test-centre with the lowest number of suspected cases assigned to it and removes them from the current solution (Wolfinger et al., 2021).

The *test-centre opening removal* heuristic has been derived by Wolfinger et al. (2021) from Hemmelmayr et al.'s (2012) *satellite opening* heuristic (as cited in Wolfinger et al., 2021). The first step this heuristic performs is to choose one of the closed test-centres to open it. Next, *n* suspected cases are randomly removed from the current solution. However, the closer a suspected case is located to the newly opened test-centre, the more likely it is to be removed (Wolfinger et al., 2021).

2.2.2 Repair Heuristics

The *n* suspected cases, which have been removed from the solution by one of the above-described destruction heuristics, are reinserted into the solution by means of a repair heuristic throughout its iterations. The stopping criterion of the repair heuristics is met when all suspected cases are assigned to either a test-centre or a mobile test-team and the specimen is allocated to an evaluation run in one of the laboratories (Wolfinger et al., 2021). The LNS for solving the CDTP comprises three repair heuristics as per Wolfinger et al. (2021): the *test-centre insertion* heuristic, the *random best insertion* heuristic, and the *regret-k insertion* heuristic. The *test-centre insertion* heuristic is always applied as first repair heuristic since potential cases assigned to an opened test-centre do not increase the solution's cost (Wolfinger et al., 2021). If not all suspected cases can be covered by the *test-centre insertion* heuristic, it is combined with the *random best insertion* heuristic or the *regret-k insertion* heuristic, whereby $k \in \{2,3,4\}$, based on a uniform probability distribution (Wolfinger et al., 2021).

An uncovered suspected case is allocated to the next possible timeslot in the closest test-centre per iteration in the *test-centre insertion* heuristic (Wolfinger et al., 2021). To do so, if it is possible to test the uncovered suspected case in more than one test-centre, the options are listed in ascending order regarding their distance to the potential case. This list is worked through while evaluating the available timeslots. The earliest feasible insertion is chosen. The pseudocode of this heuristic is provided in Wolfinger et al. (2021).

The *regret-k insertion* heuristic focuses on the regret value, which is "the cost difference between the best insertion position and the second best "(Hemmelmayr et al., 2012, p. 3219). The mathematical formulation on how to determine the regret value is presented in Wolfinger et al. (2021). The idea behind the *regret – k insertion* is that uncovered suspected cases having the highest regret value do get inserted at their best insertion position to maximise the cost savings. The LNS for solving the CDTP includes the *regret-k insertion* heuristic with $k \in \{2,3,4\}$ (Wolfinger et al., 2021).

The *random best insertion* heuristic randomly picks one of the uncovered suspected cases per iteration and includes it into the solution at its best place (Wolfinger et al., 2021). The best place is defined as the one with the lowest cost attached to meet the main objective. As Wolfinger et al. (2021) describe, this heuristic starts by determining the additional cost that an insertion of the uncovered suspected case would cause into each of the vehicles in use. If the case cannot be included into the tour of a vehicle due to feasibility reasons, the *random best insertion* heuristic checks whether an additional laboratory visit next to including the case in the tour would be possible to achieve a feasible allocation or whether starting a new tour with a vehicle that is not in use in the current solution with a visit to a laboratory afterwards would be an option (Wolfinger et al., 2021). For the pseudocode of this heuristic, please refer to Wolfinger et al. (2021).

2.2.3 Local search

Every new solution is further improved with the *Or-opt* operator (Or, 1976, as cited in Wolfinger et al., 2021), as long as it is within 0.5% of the best solution (Wolfinger et al., 2021). The *Or*-opt operator is a substitution method exchanging a certain number of consecutive vertices p=1, 2, 3, …, n. (Vahrenkamp, 2014). For the CDTP $p \in \{2,3,4\}$, meaning that a sequence of up to four inter- or intra-route vertices are relocated where "moves are performed in a first-improvement manner as long as improvements can be found" (Wolfinger et at., 2021, p.20). If one of the vertices is responsible for a laboratory visit, it is skipped (Wolfinger et al., 2021).

2.2.4 Initial solution

The LNS starts with an initial solution which is then improved throughout the iterations. This initial solution is generated by making use of the above-described insertion heuristics (Wolfinger et al., 2021). To do so, the *test-centre insertion* heuristic is applied in a first step. Afterwards, it is tried to reach a feasible solution calling the *random best insertion* heuristic (Wolfinger et al., 2021). In case no feasible solution is found, finding an initial solution starts from scratch again, opting for the *regret-k insertion*, with $k = 2$. The value of k is increased if no feasible initial solution can be derived. In case no initial solution is found, the one with the lowest number of uncovered suspected cases is used as initial solution (Wolfinger et al., 2021).

2.2.5 Acceptance and penalty

To prevent from getting stuck in local optima, a new solution is also accepted if it does not exceed a 0.05% increase in total cost compared to the current solution's total cost (Wolfinger et al., 2021).

Moreover, if not all potential cases, which have been removed from the solution by a destruction heuristic, can be reinserted by the called repair heuristic, the LNS still allows an infeasible solution (Wolfinger et al., 2021). If this is the case, the total cost is increased by a penalty (Wolfinger et al., 2021). Another aspect to improve the solution quality included in the LNS is the randomly added noise, as Wolfinger et al. (2021) specify in their manuscript. The approach of how to calculate the noise in case it is added, is described in detail by Wolfinger et al. (2021).

2.3 Scenario analysis

To answer this master thesis' research questions, a scenario analysis was chosen as method since the development and analysis of different scenarios can be used "to help […] adapt to […] rapidly changing environments" (Roper et al., 2011, p.178). To conclude, the concept of uncertainty plays a large role in the field of scenario analysis (Roper et al., 2011). In other words, a scenario analysis is used to prepare for an unknown future, in which external circumstances, that cannot be fully controlled, change quickly. Moreover, Varum and Melo (2010) mention that the capability of quickly adapting a strategy to changing conditions is of major importance. Therefore, as they state, having the data of more than one scenario at hand considerably improves decision making. Also, the UK's Department for Business, Innovation and Skills (2011) summarises that, "[s]cenarios are a way to structure, think about, and plan for, future uncertainties "(as cited in Stewart et al., 2013, p.682).

Before being able to conduct a scenario analysis, different scenarios need to be created. Roper et al. (2011) suggest an approach, which comprises several steps. First, the variables present need to be determined before measurement levels are established. In the next step, the variables are evaluated according to their level of significance, based on with the scenarios for the analysis can be developed (Roper et al., 2011).

3. Computational study

The computational study comprises a scenario analysis in the field of test logistics. The uncertainties, which need to be considered are the fluctuating rate of PCR tests as per official order on the one hand and the decision about how many available test-centres would lead to the lowest total cost in combination with the required mobile test-teams. Besides, the differing conditions linked to whether the testing strategy has to be developed for a rural or an urban area should be taken into consideration.

To determine how different numbers of available test-centres influence the total cost of the testing strategy, the scenario analysis is performed for two Austrian federal states, namely Vienna and Upper Austria. By choosing these two federal states, the comparison of a rather rural region (Upper Austria) with an urban region (Vienna) can be made. The population density of Upper Austria in 2020 is registered at 124/km^2 (Land Oberösterreich, 2021a), whereas Vienna's population density based on the tentative number of inhabitants for 2020 lies at 4,607/km^2 (Stadt Wien, 2021b). Of course, the population is not evenly spread throughout the federal states. It should, however, be mentioned that the discrepancies in Upper Austria are considerably higher resulting from a bigger difference between the population density in cities and on the countryside. These differences between the federal states let the Austrian Red Cross opt for differing testing strategies related to the sizes and numbers of test-centres as well as the numbers and sizes of vehicle fleets for the mobile test-teams, as described by Wolfinger et al. (2021).

In a first step, the periods under analysis are derived prior to determining the demand for PCR tests which must be conducted as per official order in Vienna and Upper Austria for the periods in question. Next, the different scenarios are introduced before the generation of problem instances is explained. Finally, the results of the LNS and the resulting managerial insights are presented in the next section.

3.1 Time periods under analysis

As previously mentioned, this master thesis aims at exploring how to minimize total cost of operating test-centres and mobile test-teams throughout different phases of the pandemic. These different phases are characterised by a high variance in terms of daily new infections and a therewith fluctuating number of suspected cases, which needs to be represented in the problem instances. Figure 1, which was published by the Austrian Agency for Health and Food Safety Ltd. (AGES) (2021a), therefore shows the epidemiological development since the beginning of the pandemic in Austria until the end of May 2021. It is clearly shown that the number of new infections varied considerably over the months. This master thesis concentrates on three time periods to illustrate the differences in terms of test logistics in a phase of low, medium, and high number of new infections to determine their influence on the number of available test-centres to minimize total cost. Therefore, the focus of analysis in the computational study lies on the months of June 2020 (low numbers of new infections), November 2020 (high numbers of new infections), and January 2021 (medium numbers of new infections).

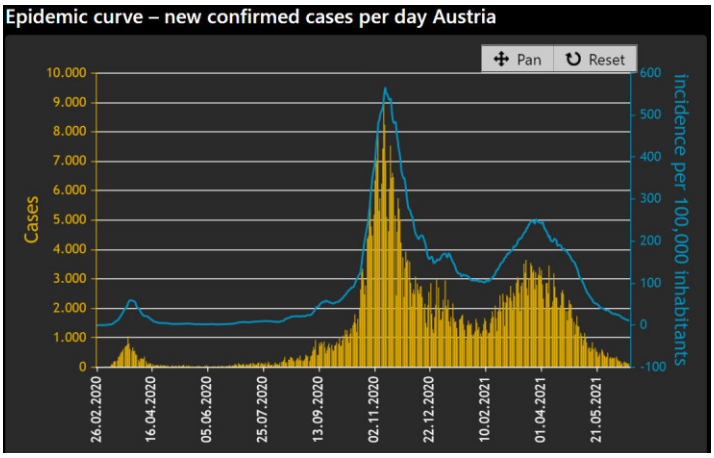


Figure 1: Screenshot of AGES (2021a): Epidemic curve – new confirmed cases per day Austria

3.2 Demand

The Austrian Broadcasting Corporation (ORF) (2021a) provides a graphical representation of all conducted PCR tests as per official order per federal state on their website. For the month of June 2020, however, there are three days in the federal state of Vienna, namely June 1st, June 7th and June 11th, for which the number of conducted PCR tests as per official order is registered with 0. However, on these days, AGES (2021b) did register new infections. To overcome the lack of data for those three days, the average number of PCR tests throughout the month was calculated for Vienna and used for those three days in question. The same proceeding was applied to determine the number of tests conducted on the days of January 2nd and 3rd for Vienna and January 2nd for Upper Austria.

As for the months of June 2020 and November 2020, the numbers of conducted tests were used as demand apart from the exceptions mentioned above. From January 13th, 2021, on, however, the represented tests also include the conducted antigen tests as described by the ORF (2021a). Moreover, it should be mentioned that the provided data of conducted PCR tests as per official order for January 12th, 2021, is more than 115 times higher than the average number of conducted PCR tests from January 1st to January 11th in Vienna and more than 143 times higher in Upper Austria. From January 13th, 2021, on, there is no data regarding the number of conducted PCR tests available. Therefore, the demand for the remaining days of the month of January 2021 was determined differently. As the data for January 12th, 2021, was not considered reasonable, the below-described method of determining the demand of PCR tests was used from January 12th, 2021, on. To begin, the average positivity rate of the months of June 2020, November 2020 and the first 11 days of January 2021 was determined. In a second step, the number of registered new infections per day were multiplied by the average positivity rate to determine the daily demand for PCR tests. The table with the daily numbers of PCR tests conducted as per official order, which build the basis for the sample, can be found in attachment I.

3.3 Sample

For both federal states under consideration, 21 days (seven days for each of the three months) were included in the analysis. The number of potentially infected persons throughout the 91 days ranges from 357 to 14,900 in Vienna and from 188 to 14,637 in Upper Austria.

To determine the 21 days, which form the sample for Vienna and Upper Austria, all 91 days were grouped into different categories regarding their number of conducted PCR tests as per official order. The grouping took place for each month per federal state separately. Please find a tabular representation of the grouping in table 1. Table 2 shows the number of days per category that were used for the analysis based on the percentual distribution. The days within the categories were chosen randomly. Attachment II provides the list of days, which are included in the sample.

# Conducted PCR tests as per official order	June 2020		November 2020		January 2021		Total	
	Vienna (# days)	Upper Austria (# days)	Vienna (# days)	Upper Austria (# days)	Vienna (# days)	Upper Austria (# days)	Vienna (# days)	Upper Austria (# days)
0-999	3	30	0	1	2	7	5	38
1000-1999	9	0	0	2	2	21	11	23
2000-2999	14	0	1	3	14	2	29	5
3000 - 4999	4	0	5	19	10	1	19	20
> 4999	0	0	24	5	3	0	27	5

Table 1: Number of days per category

# Conducted PCR tests as per official order	June 2020		November 2020		January 2021		Total	
	Vienna (# days sample)	Upper Austria (# days sample)	Vienna (# days sample)	Upper Austria (# days sample)	Vienna (# days sample)	Upper Austria (# days sample)	Vienna (# days sample)	Upper Austria (# days sample)
0-999	1	7	0	0	0	2	1	9
1000-1999	2	0	0	1	1	5	3	6
2000-2999	3	0	0	1	3	0	6	1
3000 - 4999	1	0	1	4	2	0	4	4
> 4999	0	0	6	1	1	0	7	1

Table 2: Number of days per category forming the sample

For the analysis, the categories have been reduced to three to increase the number of days in the different categories for a better representation. The categories used for analysis can be found in table 3.

# Conducted PCR tests as per official order	June 2020		November 2020		January 2021		Total	
	Vienna (# days sample)	Upper Austria (# days sample)	Vienna (# days sample)	Upper Austria (# days sample)	Vienna (# days sample)	Upper Austria (# days sample)	Vienna (# days sample)	Upper Austria (# days sample)
0-999	1	7	0	0	0	2	1	9
1000-2999	5	0	0	2	4	5	9	7
>2999	1	0	7	5	3	0	11	5

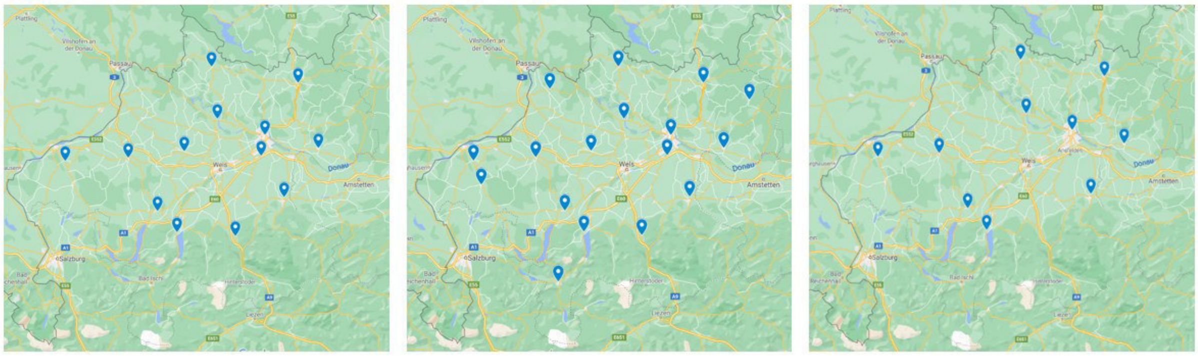
Table 3: Categories used for analysis

3.4 Scenarios

The results of the scenarios will be analysed with the help of the CDTP. They will be compared within each federal state and between the federal states. In the case of Vienna, there are currently three test-centres with four to seven parallelly operating test-stations offering PCR tests for potentially infected persons, whereas in Upper Austria, the currently available number of test-centres, in which the number of test-stations varies between one and six, amounts to 13, as per Wolfinger et al. (2021). This data was provided by the Austrian Red Cross (Wolfinger et al., 2021). To depict whether the number of currently operating test-centres is ideal, scenario 1 will picture the results of the current situation. For the second scenario, the number of available test-centres will be increased to 5 in Vienna and to 17 in Upper Austria, while in scenario 3 the number of available test-centres will be decreased to 2 in Vienna and to 10 in Upper Austria. Originally, it was planned to include a fourth scenario in which no test-centres would be available. However, throughout the first trials of the computational study it was found that this scenario is not worthwhile looking into as finding feasible solutions is a lot harder and takes too much time. As it would be based on using mobile test-teams exclusively for conducting tests, the number of vehicles needed would be unrealistically high.

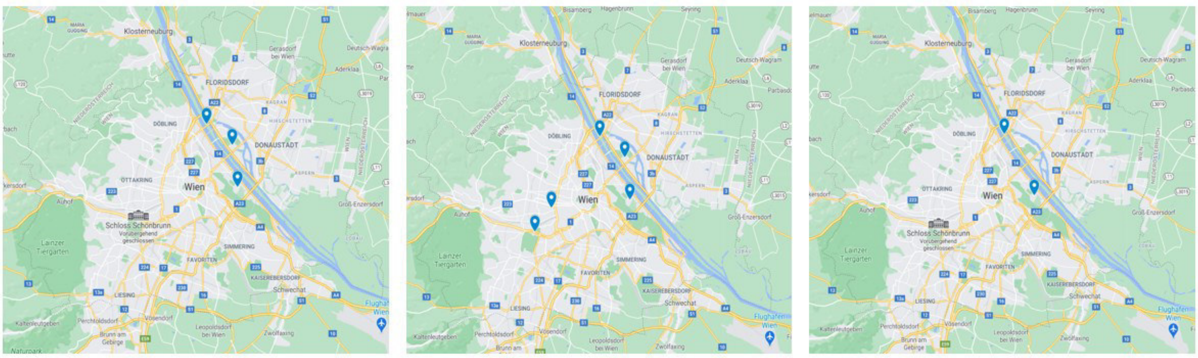
The locations of the test-centres in scenario 2 and scenario 3 are based on the locations of the test-centres in scenario 1. For scenario 2, the geographical locations of the currently operating test-centres were examined. The additional test-centres' locations were determined in a way that the test-centres are as evenly spread over the federal state as possible. As for the exact locations of the four additional test-centres in Upper Austria, the townships' antigen test-centre locations were looked at in a second step to choose the test-centre locations for the LNS. For scenario 3 in Upper Austria, three test-centres were closed in a way that 10 evenly spread test-centres remained.

In Vienna, all three test-centres are located closely to one another (in the 2nd, 21st and 22nd district) along the Danube as can be seen in figure 3. Therefore, the two additional test-centres for scenario 2 were opened in a different part of the city (in the 13th and 15th district). For scenario 3, the test-centre located in between the remaining two was chosen to be closed. The graphical presentation of the geographical test-centre locations, which can be found in figure 2 for Upper Austria and in figure 3 for Vienna, was created using Google Maps. Each blue pin marks the location of an available test-centre.



Scenario 1 Upper Austria: 13 test-centres | Scenario 2 Upper Austria: 17 test-centres | Scenario 3 Upper Austria: 10 test-centres

Figure 2: Scenarios Upper Austria – Test-centre locations



Scenario 1 Vienna: 3 test-centres | Scenario 2 Vienna: 5 test-centres | Scenario 3 Vienna: 2 test-centres

Figure 3: Scenarios Vienna – Test-centre locations

3.5 Problem instances

The computational study was executed in two steps. In the first step, the problem instances for the afore-determined demand have been generated for the federal states of Vienna and Upper Austria by means of a Python script provided by Mag. David Wolfinger, BSc PhD. All problem instances with ≤ 4,000 PCR tests per day have been generated on an AMD Ryzen 5 3500U with 8GB of RAM. The problem instances, for which the number of tests exceeded 4,000, were generated on an Intel cpu with 8 core with 16GB of RAM.

For each of the days being part of the sample, five problem instances were generated per scenario with random coordinates of where and when the suspected cases arise. The coordinates of the suspected cases are identical in one instance over all three scenarios to achieve a good basis of comparison with the varying number of test-centres. As the cost is not presented in monetary values, but in distances due to a lack of real-world data regarding actual cost, the fixed cost per vehicle was manually set to the identical value for each problem instance over all three scenarios. In total, 630 problem instances were generated.

Different data is required to generate the problem instances. Most of the data, such as how much time a mobile test-team requires to conduct a PCR test, how long an evaluation run in a laboratory takes as well as how frequently they take place, was taken from Wolfinger et al. (2021), who in turn received the information, which is not publicly available, from the Austrian Red Cross.

As previously mentioned, the federal states of Vienna and Upper Austria were chosen for this analysis to achieve a comparison of the effect varying numbers of test-centres in an urban and rural region have on the total cost involved. Upper Austria is composed of 18 districts, amongst which the percentage of Upper Austria's population ranged in 2019 from 2.23% in the district of Eferding to 13.87% in the district of Linz (Land Oberösterreich, 2021b).

To represent the unevenly distributed population in Upper Austria, when generating the coordinates of the potentially infected persons, a number between 0 and 1 illustrating the probability of a person living in a certain district is randomly generated. It thus allows to deviate from a strict percentual allocation of suspected cases to reflect the possibilities of clusters.

3.6 Large Neighbourhood Search

In the second step of the computational study, the problem instances were solved with the LNS. For each problem instance, five runs were performed, leading to 25 runs per day per scenario under consideration. Thus, in total, 3150 runs were performed. All runs were executed on the Vienna Science Cluster.

The problem instances of different categories were allowed different runtime limits. Working with the same runtime limit for each problem instance within one category ensures a solid base for comparison of results. After a few test runs with problem instances of different categories, the runtime limits were set to values that enable achieving a minimum of 1000 iterations in most of the runs. These runtime limits per category used are presented in table 4.

# Conducted PCR tests as per official order	Runtime limit (sec)	Runtime limit (h)
0-999	21 600	6
1000-1999	43 200	12
2000-2999	86 400	24
3000 - 4999	129 600	36
> 4999	259 200	72

Table 4: Runtime limits per category

The addressed test runs revealed that a slight modification of the *random test-centre removal* heuristic, with the help of which a test-centre can be closed and another test-centre can be opened within the same iteration, led to further improvements of results. Therefore, the modified version was used for the computational study presented in the next chapter.

To achieve results which illustrate the impact of a varying number of available test-centres on the total cost, not all input data associated with the current situation led to feasible solutions in the test runs with the depicted demand throughout the different scenarios. Therefore, some data was adjusted. When including the assumption that 30% of all suspected cases must be tested by mobile test-teams (Wolfinger et al., 2021), the capacity of mobile test-teams must increase with an increasing number of daily tests. As the number of tests which are covered by one mobile test-team varies with the locations of suspected cases and the region where the test-team operates, the first computations were performed with the given numbers of available vehicles, which amount to 29 in Vienna and to 15 in Upper Austria (ORF, 2021b). The average number of tests covered per vehicle was then used to determine a closer value of how many vehicles would be required in the problem instances with the larger numbers of tests. As average values were used to determine the required number and only 5 runs were performed per instance, a buffer was added, leading to a total of 80 available vehicles for each federal state to guarantee that the vehicles available would not be responsible for infeasible solutions. Moreover, the evaluation run capacities had to be increased to prevent too many infeasible solutions with suspected cases not being allocated to an evaluation run. Therefore, the number of specimens that can be evaluated per evaluation run was set to 300.

All other values set by Wolfinger et al. (2021), such as the maximum travelling time to a test-centre of 60 minutes, the maximum of 24 hours to conduct a test after the suspected case became known and from the moment the specimen is taken to the result, respectively, as well as various parameters, were not changed for this computational study. Also, the maximum route length of a vehicle was kept at 12 hours representing the maximum shift length of the Austrian Red Cross employees (Wolfinger et al., 2021). As for the travelled distances and the time it takes to drive a certain route, the values used mirror real-world data in terms of distances and time (Wolfinger et al., 2021). To round off the input data for the LNS it should be mentioned that the travel cost in comparison with the fixed cost associated to using a mobile test-team is low, as per Wolfinger et al. (2021).

4. Computational results

The results of the computational study are presented per scenario. As part of the analysis, the results of the different scenarios within a federal state are compared. Furthermore, the differences and commonalities between the federal states of Upper Austria and Vienna are pointed out.

Only feasible solutions are considered in this analysis. The run with the best feasible solution of each problem instance is selected in a first step leading to a maximum of five problem instances per scenario and day under consideration. Which run is to be considered as the best run and is thus used for the analysis is based on the lowest total cost as minimizing the total cost is the CDTP's main objective. Average values of all problem instances being part of the analysis were determined for further handling per day before they were grouped into the previously introduced categories for analysis with 0 – 999, 1000 – 2999 and >2999 daily PCR tests. The resulting average values of all problem instances within the same category were used for the analysis.

However, there were two days for which none of the problem instances' runs was feasible for certain scenarios. Both days are part of Vienna's sample. For 7627 and 8124 daily tests no feasible run was detected with two available test-centres. For 8124 tests per day all runs with three test-centres also led to infeasible solutions. It can thus be concluded that from a certain number of potential cases to be clarified per day no feasible solution can be generated with the input data this master thesis works with. The results illustrate that this number lies between 6104 and 7627 for at least three test-centres and between 7627 and 8124 for more than three test-centres. Therefore, the problem instances of 7627 and 8124 tests in Vienna are not included in the analysis but looked at separately to guarantee the fairness of comparison. The detailed numbers of problem instances included in the analysis can be found in attachment III.

As for the analysis, the distribution of PCR tests conducted in test-centres and by mobile test-teams was taken a close look at. Moreover, values regarding the test-centres' utilisation and some tour characteristics were studied. Furthermore, the total cost and its development throughout the categories in the different scenarios was analysed. As the results for cost are not presented in monetary values, but in distances, the focus during the cost analysis lies on the comparison of results. Scenario 1, representing the current situation, has been taken as the basis of comparison. The cost changes of the other scenarios are therefore expressed in percentages based on the values of scenario 1 in tables 7 to 10.

The results revealed that in each run being part of the analysis all potential cases could be clarified within the time-to-test and time-to-result limits. As it is the same for all problem instances analysed, it is not mentioned in each part of the analysis. One more commonality which was found throughout all scenarios in both federal states is that the average duration of a tour is close to the allowed 12 hours.

4.1 Results for scenario 1

Comparing the results of scenario 1, in which 13 test-centres are available in Upper Austria and 3 in Vienna, it can be found that the distribution of tests being performed in test-centres and by mobile test-teams varies by 3.18 percentage points on average between both federal states. The higher value of potential cases being clarified through mobile test-teams is to be assigned to Upper Austria, as tables 5 and 6 reveal.

Upper Austria								
Category	Distrib. (%)		# Used		TC	Tours		
	TC	Vehic.	TC (13)	Vehic. (80)	Avg. util. (%)	Avg. cases (#)	Avg. length (km)	Avg. length (h)
0 - 999	61.45	38.55	2.36	9.49	55.73	23.93	148.77	11.92
1000 -2999	65.87	34.13	3.26	15.63	76.48	30.37	150.89	11.95
>2999	68.27	31.73	6.64	30.12	86.50	43.12	125.51	11.97
Average	64.55	35.45	3.68	16.45	69.97	30.65	143.94	11.94

Table 5: Average results for scenario 1 for Upper Austria

Vienna								
Category	Distrib. (%)		# Used		TC	Tours		
	TC	Vehic.	TC (3)	Vehic. (80)	Avg. util. (%)	Avg. cases (#)	Avg. length (km)	Avg. length (h)
0 - 999	69.84	30.16	1.00	9.80	50.07	24.81	103.93	11.96
1000 -2999	69.72	30.28	1.18	23.11	85.66	28.30	90.43	11.96
>2999	65.50	34.50	2.56	40.84	82.59	41.62	101.26	11.96
Average	67.73	32.27	1.82	30.81	82.33	34.42	96.27	11.96

Table 6: Average results for scenario 1 for Vienna

In Upper Austria, the share of potential cases being clarified through mobile test-teams increases with a decreasing number of daily tests. In the category with up to 999 test per day 8.55 percentage points more cases are covered by mobile test-teams than the minimum requirement of 30% dictates. In contrast, the percentage of tests being conducted by mobile test-teams in Vienna is close to the minimum requirement of 30% for the first two categories. It is striking that it increases to considerable 34.50 % in Vienna when more than 2999 tests must be conducted per day. This opposing development along with increasing numbers of daily tests can be explained by the different characteristics of a rural and urban setting. The lower the number of daily tests in Upper Austria, the lower the number of opened test-centres. This leads to the consequence that more persons who must undergo a test cannot reach a test-centre within 60 minutes and thus must be visited by a mobile test-team. The more detailed results, which are tabularly presented in attachment IV, illustrate that from 5521 daily tests upwards, the share of tests being conducted by mobile test-teams considerably exceeds the minimum requirement in Vienna. At the same time, the test-centre's capacities are not fully exploited. Having in mind that all three test-centres are located in one area of the city, as illustrated in figure 3, the increase of potential cases being clarified through mobile test-teams can be explained by the fact that citizens living in the outer areas of Vienna cannot reach a test-centre within an hour. The increased number of potential cases outside the reach of the test-centres are also mirrored in the average number of tests per tour. It increases from values around 30 for the problem instances with 3029 to 4286 tests per day to values around 50 for the problem instances with 5521 or more daily tests, as the detailed results in attachment IV show. At the same time, the average distance per tour increases by about 20km. The considerable increase of tests covered by a mobile test-team in a comparable time can be traced back to the higher absolute number of tests performed by mobile test-teams in combination with a larger number of vehicles in use, leading to the situation that each vehicle covers all cases in one area and does not have to drive long distances between the potentially infected persons.

As for the number of test-centres in use, it can be stated that it increases with higher numbers of daily tests in both federal states. The variance in Upper Austria is much larger (between 2.36 and 6.64) than in Vienna (between 1.00 and 2.56) though. Having in mind that 13 test-centres are available in Upper Austria whereas the number of available test-centres in Vienna amounts to 3 only, this difference was expected. Besides, the available test-centres vary in size. On average, each available test-centre in Vienna offers 5.67 parallelly operating test-stations, whereas the average value lies at 1.77 in Upper Austria. The range of opened test-centres in the rural area is especially large in the category covering more than 2999 daily tests (between 3 and 10). Thus, a high degree of flexibility in terms of number of test-centres to open seems to be indispensable in a rural setting. Moreover, it shows that no solution included in the analysis in the federal state of Upper Austria makes use of all 13 available test-centres.

Looking at the average utilisation of test-centres for both federal states, it needs to be mentioned that the offered capacity is not fully used. In the lowest category of daily tests, the average utilisation lies at about half the capacity only in Vienna and slightly higher (55.73%) in Upper Austria. With an increasing number of daily tests this value increases in Upper Austria, reaching an average utilisation rate of 86.50% in the category with more than 2999 daily tests. In Vienna, however, the average utilisation of test-centres is highest in the category of 1000 – 2999 tests per day. The different development of utilisation rates can be traced back to the number of test-stations per test-centre. As previously mentioned, each test-centre in Vienna houses on average 3.9 more test-stations than test-centres in Upper Austria do. Therefore, when an additional test-centre is opened, the test-centre capacity jumps up in Vienna, whereas it only slightly increases in Upper Austria when an additional test-centre is opened. Moreover, the decrease in the share of tests being conducted in test-centres from the second to the third category in Vienna is mirrored in the development of the average utilisation rate. Nevertheless, due to the fact that the population density is considerably higher in Vienna, the overall utilisation lies at 82.33% in the urban region whereas it reaches an average value of 69.97% in the rural region.

As for the vehicles, both federal states would be able to work with the currently available ones in the category with the lowest number of daily tests. For the category with 1000 - 2999 daily tests, the vehicles, which are in use in Upper Austria (15.63), slightly exceed the number of the currently 15 available vehicles (ORF, 2021b), whereas in Vienna, only about three quarters of the available 29 vehicles (ORF, 2021b) are in use (23.11). However, considerably more vehicles would be needed in both federal states with more than 2999 daily tests to get all potential cases tested within 24 hours after they become known and to evaluate the specimens in a laboratory within another 24 hours, when each day is analysed separately.

The tour characteristics develop similarly in both federal states. The average number of tests per tour increases with an increasing number of tests that need to be conducted per category. Nevertheless, more tests are performed per tour on average over the whole scenario in Vienna as more days fall into the category with the highest number of daily tests. Furthermore, the kilometres driven per tour decrease in the category with the highest number of tests per day in the rural setting. This is to be explained by the considerable increase in opened test-centres, enabling a greater share of potentially infected persons to reach a test-centre within 60 minutes. The remaining potential cases requiring a mobile test-team to come by are clustered in the regions further away from the test-centres, as previously seen in the category with more than 2999 daily tests in Vienna. In general, a mobile test-team in Upper Austria has, on average, a 49.52 % larger distance to travel than a mobile test-team in Vienna due to greater distances in rural areas.

As previously stated, the problem instances with 7627 daily tests in Vienna led to feasible solutions with 3 available test-centres. The detailed results can be found in attachment IV. These reveal that all available test-centres are operating in combination with an average of 78.6 vehicles. These values illustrate that the capacity limits are almost exploited. Therefore, the problem instances with 8124 daily tests did not lead to feasible solutions. What is striking is that more than half of all potentially infected persons (51 %) are tested by mobile test-teams although the average utilisation of test-centres lies at 78.52% only. As already pointed out above, the locations of test-centres in combination with the constraint that the travel time to a test-centre cannot exceed 60 minutes seem to lead to this result.

4.2 Results for scenario 2

In scenario 2, in which the number of available test-centres increases to 17 in Upper Austria and to 5 in Vienna, the results are more cost-efficient for both federal states than in scenario 1, as the results presented in tables 7 and 8 reveal.

Upper Austria

Category	Distrib. (%)		# Used		TC	Tours			Total cost
	TC	Vehic.	TC (17)	Vehic. (80)	Avg. util. (%)	Avg. cases (#)	Avg. length (km)	Avg. length (h)	% Change based on scenario 1
0 - 999	63.06	36.94	2.53	9.11	51.49	23.91	154.14	11.92	-0.52
1000 -2999	67.33	32.67	3.69	15.26	73.23	29.84	144.67	11.95	-0.76
>2999	69.38	30.62	7.20	29.32	86.91	42.72	134.16	11.97	-2.23
Average	65.99	34.01	4.03	15.97	67.17	30.36	146.23	11.94	-1.88

Table7: Average results for scenario 2 for Upper Austria

Vienna

Category	Distrib. (%)		# Used		TC	Tours			Total cost
	TC	Vehic.	TC (5)	Vehic. (80)	Avg. util. (%)	Avg. cases (#)	Avg. length (km)	Avg. length (h)	% Change based on scenario 1
0 - 999	69.84	30.16	1.00	9.60	66.76	25.41	107.90	11.96	-8.68
1000 -2999	69.75	30.25	1.02	23.02	91.80	28.47	90.74	11.97	-2.17
>2999	69.27	30.73	3.18	33.78	80.61	44.99	101.11	11.95	-11.22
Average	69.53	30.47	2.04	27.41	85.18	36.14	96.55	11.96	-9.45

Table 8: Average results for scenario 2 for Vienna

When the results of scenarios 1 and 2 are compared, it can be identified that both federal states open slightly more test-centres while using fewer mobile test-teams in scenario 2.

In Upper Austria, the cost advantage amounts to 1.88%, as the results presented in table 7 show, whereas in Vienna the results of scenario 2 are 9.45% more cost-efficient. The great cost decrease in Vienna can be explained by the cost decrease of more than 8% in the category with less than 1000 tests per day and the cost decrease of considerable 11.22% in the category with the highest number of daily tests. When the values of tables 6 and 8 are compared, it can be identified that the share of tests performed by mobile test-teams in the category with more than 2999 tests per day decreases in scenario 2 to 30.73%. Therefore, 7.06 less vehicles are in use in this category compared to the results in scenario 1, resulting in a great decrease of cost. At the same time, the higher number of available test-centres is made use of. The solutions of the problem instances with more than 5521 daily tests open at least four test-centres, as can be seen in the more detailed results presented in attachment IV. With opening a fourth (and fifth) test-centre, a test-centre is opening in the western part of the city, enabling more potentially infected persons to reach a test-centre within one hour. In return, the areas in which mobile test-teams must visit potentially infected persons are further reduced, which leads to an even greater number of tests which are performed per tour in the category with the highest number of daily tests in the urban setting (44.99) compared to the value in scenario 1 (41.62), enabling a more cost-efficient way of testing potentially infected persons. The cost associated with opening an additional 0.62 test-centres is lower than the cost advantage resulting from the reduced number of vehicles.

In the category of 1000 – 2999 daily tests in Vienna the cost slightly decreases (-2.17%) due to an increase in average utilisation of the opened test-centres of considerable 6.14 percentage points, while opening slightly less test-centres. Looking at the problem instances' solutions in more detail reveals that with 1176 tests per day, the effect of having the option of opening a test-centre housing three test-stations only does decrease the total cost as less capacity is left unused. On the other hand, having a greater range of solution possibilities by having more test-centres available also improves the solution of other problem instances within the same category without making use of the newly available test-centres. There are, nevertheless, also two problem instances, namely the ones with 2697 and 2795 daily tests, for which the solution with five available test-centres is worse. However, it needs to be mentioned that the runs with 3 available test-centres when having 2795 daily tests were able to perform about six times the number of iterations which the runs with 5 available test-centres were able to achieve within the same time. For the problem instances with 2697, the results of scenario 1 performed more than 3.5 times the number of iterations than those with 5 available test-centres.

The results of the first category in Vienna reveal a cost decrease of 8.68% compared to scenario 1, as previously seen. This development illustrates the impact the number of test-stations per test-centre can have on the total cost. While in scenario 1 the opened test-centre had four test-stations available, the one opened in scenario 2 operates three parallel test-stations. Testing the same number of potentially infected persons in scenarios 1 and 2 in the opened test-centre within this category points out how the average utilisation, which does considerably increase in scenario 2, positively influences the total cost.

In Upper Austria, scenario 2 also presents a more cost-efficient solution throughout all categories compared to scenario 1. The cost decrease in the two lowest categories, which lies below 1% each, can be traced back to the slightly lower number of vehicles in use. It should also be mentioned that the results of scenario 2 provide the lowest rate of potentially infected persons getting tested through the visit of a mobile test-team in the rural region. Although the average utilisation of test-centres decreases from scenario 1 to scenario 2 (-4.24 percentage points in the category with 0 – 999 daily tests, -3.25 percentage points in the category with 1000 – 2999 daily tests), the decrease of 0.38 (0 – 999 daily tests) and 0.37 (1000 – 2999 daily tests) vehicles still results in a decrease of total cost. This development underlines the considerably higher cost per test conducted through a mobile test-team compared to the cost involved when potentially infected persons undergo the PCR test at a test-centre. When looking at the results for the individual problem instances of the rural area, it can be identified that not once the higher number of available test-centres was made use of. In Upper Austria, the maximum number of opened test-centres amounts to 10, which is identical to the highest number of test-centres opened in scenario 1. The results for the highest category in Upper Austria show a higher decrease of total cost (2.23%). The cost advantage in this category is not only based on the 0.8 fewer vehicles in use, but also on the slightly higher test-centre utilisation rate (+0.41 percentage points).

As previously mentioned, the only feasible solutions for all problem instances in Vienna were achieved in scenario 2. The increased number of available test-centres is made use of for testing 7627 and 8124 potentially infected persons on one day. For each problem instance with 7627 and 8124 daily tests, as the table in attachment IV points out, there are 5 test-centres in use. Thanks to the higher number of test-centres available, 64.96% of 7627 and 61.32% of 8124 potential cases can be tested in test-centres. Thus, both values are in the range of the other problem instances with more than 2999 daily tests per day in Vienna in scenario 1. Comparing the results of the problem instances with 7627 daily tests to the ones seen in scenario 1, the increased number of available test-centres led to a decrease of 26.80 vehicles in use. Moreover, the share of potentially infected persons being tested by mobile test-teams decreases by 15.96 percentage points compared to the results of scenario 1. At the same time, the average utilisation of test-centres stays about the same. The cost decrease for the problem instances with 7627 daily tests amounts to considerable 21.76% in scenario 2, compared to scenario 1. It thus shows that especially for days with high numbers of tests, a large capacity of test-centres is of major importance to save cost.

4.3 Results for scenario 3

The results for scenario 3, in which the number of available test-centres is reduced to 10 in Upper Austria and to 2 in Vienna, illustrate the negative influence on the total cost when having fewer test-centres available. The average results of scenario 3 can be found in tables 9 and 10.

Upper Austria									
Category	Distrib. (%)		# Used		TC	Tours			Total cost
	TC	Vehic.	TC (10)	Vehic. (80)	Avg. util. (%)	Avg. cases (#)	Avg. length (km)	Avg. length (h)	% Change based on scenario 1
0 - 999	61.14	38.86	2.40	9.56	54.14	24.06	149.84	11.93	-0.56
1000 -2999	65.51	34.49	3.23	15.71	73.41	30.58	151.17	11.94	1.09
>2999	66.86	33.14	7.16	30.84	89.31	44.23	138.46	11.97	0.36
Average	63.96	36.04	3.81	16.68	68.94	31.04	147.57	11.94	0.43

Table 9: Average results for scenario 3 for Upper Austria

Vienna									
Category	Distrib. (%)		# Used		TC	Tours			Total cost
	TC	Vehic.	TC (2)	Vehic. (80)	Avg. util. (%)	Avg. cases (#)	Avg. length (km)	Avg. length (h)	% Change based on scenario 1
0 - 999	69.84	30.16	1.00	9.80	50.07	24.96	103.62	11.96	0.00
1000 -2999	69.82	30.18	1.02	23.18	84.22	28.16	90.24	11.96	-0.05
>2999	53.96	46.04	2.00	56.38	81.46	40.41	107.08	11.97	26.83
Average	62.31	37.69	1.48	38.20	81.11	33.79	98.92	11.97	21.53

Table 10: Average results for scenario 3 for Vienna

The development of results in Vienna is the most extreme one, when the cost are compared to those in scenario 1. The main difference is that the distribution of potential cases getting tested in test-centres decreases in the category with more than 2999 tests per day in scenario 3 (53.96%) since only 2 test-centres with a total of 11 test-stations are available. The minimum share of tests that need to be clarified through mobile test-teams is exceeded in the category with more than 2999 tests by considerable 16.04 percentage points. Hence, the logical consequence is that the number of vehicles in use increases to a great extent within this category in Vienna compared to scenario 1 (+15.54 vehicles). Studying the more detailed results for Vienna, it can be seen that the share of potential cases getting clarified by mobile test-teams does vary between the instances in the category with more than 2999 daily tests. In both other categories, the number of vehicles in use does not differ much compared to the values in scenario 1. The values for the category of up to 999 cases are even identical in terms of distribution of cases as well as test-centres and vehicles in use. Moreover, it is striking that with the higher share of potential cases getting clarified through mobile test-teams the average tour length in terms of kilometres also increases in the urban setting. The fact that the average utilisation of test-centres decreases in the problem instances with higher daily numbers of tests mirrors the situation which has already been explored in scenario 1. Both test-centres opened in scenario 3 in Vienna are located closely to one another. Therefore, although the capacity is not fully exploited yet, a greater share of tests is conducted by mobile test-teams to ensure that no potentially infected person travels for longer than one hour to a test-centre. The described development is also reflected in the cost increase of 26.83% in the category with more than 2999 daily tests in Vienna compared to the current situation. The results for the category of 1000 – 2999 daily tests in the urban setting should be more expensive and not more cost-efficient than the results in scenario 1. The slightly different development of results than expected can be traced back to the restricted runtime together with certain weaknesses of the solving method. Overall, having only two available test-centres in Vienna leads to a cost increase of more than 20% compared to the current situation.

As for the federal state of Upper Austria, representing a rural area, the results of scenario 3 do not appear to differ from the previous ones to a great extent at first glance. When looking at the average number of test-centres in use throughout all scenarios, it is not surprising that having only 10 test-centres available does not lead to considerably different results since none of the solutions used more than 10 test-centres, as previously described. Nevertheless, the overall results of scenario 3 are the least favourable ones. In the category of 1000 – 2999 tests per day it can be seen that the average utilisation of test-centres decreases by 3.07 percentage points in scenario 3 compared to the current situation. At the same time, the number of vehicles in use increases by 0.08. In total, these developments account for a cost increase of 1.09%. In the largest category, the cost increase in scenario 3 is minor compared to scenario 1 with 0.36%. The increase in cost is to be traced back to the fact that more cases are tested by mobile test-teams (+1.41 percentage points). Not even a whole vehicle more is used to perform all tests. However, each of the 30.84 vehicles drives an additional 12.95km on average per tour. The resulting additional cost cannot be compensated by the higher utilisation rate. Taking a look at the category with up to 999 daily tests in Upper Austria, a similar development as was seen in the category of 1000 – 2999 tests in Vienna can be identified. The cost decreases by 0.56% compared to scenario 1, although it would be expected to increase. When looking at the more detailed results, it can be found that the results for four out of the nine days falling into this category are more cost-efficient than the ones in the current situation. The results of the remaining five days developed as expected and are more expensive than the results in scenario 1.

5. Conclusion and answers to the research questions

To conclude, the fluctuating rate of PCR tests, which must be conducted as per official order, influences the number of test-centres as well as mobile test-teams required to minimize total cost, as revealed by the analysis. A general trend of opening more test-centres can be identified with an increasing number of daily tests, which was to be expected. The same trend can be determined for the number of operating mobile test-teams. As the course of the pandemic is comparable to waves, it might be advisable, according to the presented results, to adjust the number of test-centres and the ones of available vehicles when the rate of new infections' trend changes.

As the computational study's results indicate, the setting, whether it is rural or urban, does not have an impact on which scenario is the most cost-efficient one. For both federal states, scenario 2, representing an increased number of available test-centres, is the most cost-efficient one. In general, the higher number of available test-centres offers advantages as the range of solution is larger and it can thus lead to better results. Both additional test-centres made available in scenario 2 in Vienna were especially lucrative for the lowest category of daily tests, as they both were assumed to house three test-stations. Currently, the test-centre with the lowest number of test-stations operates four test-stations parallelly. The results of scenario 3 were the most cost-efficient in the category of 0 – 999 tests per day in the federal state of Upper Austria. Furthermore, the results show that the differences between the scenarios in the urban area are much greater than those in the rural area. Having in mind that there are in general more people living in Vienna than there are in Upper Austria and that the average number of test-stations does vary considerably between Upper Austria and Vienna, this development was to be expected.

The solutions of scenario 2 are not only the ones with the overall lowest cost for the federal state of Vienna, but it also is the only scenario for which feasible solutions for all problem instances being part of the sample of the urban region could be reached. The capacity provided by the lower numbers of test-centres in combination with 80 available vehicles did not suffice for the high numbers of potential cases needing clarification. Since the model applied is restricted to one day, problem instances with too high numbers of daily tests exceeding the total test capacity lead to infeasible solutions.

Upper Austria opens on average in all scenarios and all categories under consideration an additional 2.06 test-centres compared to Vienna. At the same time, the range of opened test-centres is considerably higher in the rural setting. On the contrary, the average utilisation of test-centres is 14.19 percentage points higher in Vienna compared to Upper Austria. Moreover, the average number of vehicles in use is of 15.77 greater in the urban area, while conducting an additional 4.1 tests per tour. Furthermore, the average tour in Vienna is 48.66 km shorter than in Upper Austria. These differences picture the varying conditions rural and urban settings must work with.

5.1 Reflection of results

It should be mentioned that the generalisation of the presented results is limited as the share of random decisions being made in the LNS is high. To begin, the number of problem instances generated for each day being part of the sample was set to five, leading to 25 runs per day having in mind that five runs were performed per problem instance. Each of the five runs performed per problem instance led to different results. Comparing the generated results showed that although no exact same results were achieved for two runs of the same problem instance, a trend could be determined, which in turn can be used to make decisions on how many test-centres should be made available to minimize total cost.

However, if the runtime limits were set differently, chances are great to receive varying results. The fixed runtime limits per category ensured that the results are comparable to a certain extent. When looking at the number of iterations that were performed per run though, a very large span can be identified. Not only when comparing the number of iterations between the different categories, but also within a category the number of performed iterations varies considerably.

Moreover, it should be mentioned that the results for scenario 3 in the category of up to 999 tests per day in Upper Austria and the results for scenario 3 in the category of 1000 – 2999 daily tests in Vienna should be more expensive than those of the other two scenarios as they have the worst conditions of finding solutions having in mind that scenario 3 offers a part of the test-centres which are available in the other scenarios. It might be worthwhile introducing certain fixed cost for each test-centre which is not opened as the location needs to be reserved. To do so, it would be necessary to work with monetary values to mirror the rental cost.

One more noteworthy aspect is that the categories being part of the sample vary noticeably in size. In Vienna, for instance, a single day falls in the category of 0 – 999 daily tests while 11 days with more than 2999 daily tests are included in the sample. For Upper Austria, the number of days per category are more evenly distributed with a range of 6 (>2999 daily tests) to 9 (< 999 daily tests). Having only one day with five problem instances which are used for the analysis limits the significance of the results.

Besides, the model applied in this master thesis does neither include values of the past nor of the future, which led to the infeasible solutions in scenarios 1 and 3 in the federal state of Vienna for the largest problem instances. In real world, if a certain number of potential cases could not be tested on one day, these are transferred to the next day. Therefore, it would be interesting to develop a dynamic model, as already mentioned by Wolfinger et al. (2021), which does include this possibility. As the analysis revealed, the number of test-stations in a test-centre is decisive for the cost as these are based on the number of test-stations. It would be interesting, especially for the urban setting, to exchange the fixed number of test-stations allocated to a test-centre by a range of numbers of available test-stations in the dynamic model. In the rural setting, the average utilisation of test-centres was between 51.49% and 55.75% in the lowest category. Since the cases are spread broadly, more than one test-centre had to be opened. To further decrease cost, it could be worthwhile looking into the opening hours of test-centres in rural regions to increase the average utilisation, especially when the daily numbers of PCR tests are low.

Besides, it should be mentioned that the computations are based on the assumption that the moment of when a person turns into a suspected case, and the according coordinates are known in advance when planning the tours, as pointed out by Wolfinger et al. (2021). Of course, these conditions cannot be fulfilled in real world.

For future studies, it would be interesting as well to set monetary values for fixed cost of vehicles and test-stations/ test-centres, which can be used for all problem instances to further improve the comparability of results.

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7. Attachment

Attachment I: Daily number of PCR tests conducted as per official order in the months under analysis.

Day of the month	June 2020 (low numbers of new infections)		November 2020 (high numbers of new infections)		January 2021 (medium number of new infections)	
	Vienna	Upper Austria	Vienna	Upper Austria	Vienna	Upper Austria
1	2115	484	7972	3571	3885	2907
2	2079	272	4700	6052	2287	1179
3	2645	700	5974	3596	2513	4524
4	2965	901	6172	4782	357	1171
5	1954	941	6401	3836	4138	1503
6	2376	742	5589	3920	9717	2003
7	2115	478	7035	5052	2795	1267
8	2942	333	4737	3599	4919	1583
9	1840	514	6062	6435	5521	1605
10	2025	529	6637	3075	14900	1314
11	2115	661	7148	4552	906	1134
12	3450	316	7627	4369	4488	1626
13	1172	409	7408	4648	2956	1310
14	1041	188	7247	3641	3786	1295
15	850	328	8124	1257	2988	1330
16	1695	436	4616	3324	2481	758
17	3902	620	7459	4273	1478	692
18	1691	662	7617	3642	3118	1089
19	3029	532	8194	3687	2762	1455
20	2497	416	8256	3811	3614	1219
21	967	286	8093	4138	3376	1300
22	803	322	4854	6408	2352	1199
23	3417	433	5940	2024	2697	677
24	2287	786	6857	2553	1586	647
25	1847	660	9472	3141	2708	963
26	2089	838	10344	3293	3333	1009
27	2386	670	6829	2744	2902	1174
28	1658	396	8868	14637	3161	1129
29	1176	527	4286	968	2956	1134
30	2323	695	2468	1790	2740	597
31	/	/	/	/	2449	843

Attachment II: Numbers of daily PCR test conducted as per official order forming the sample

Upper Austria	Vienna
316	803
433	1176
484	1478
529	1840
532	2079
662	2323
758	2449
843	2645
901	2697
1171	2795
1219	3029
1257	3161
1267	4138
1300	4286
1605	5521
2024	5940
3075	5589
3324	5974
3571	6401
4648	7627
6052	8124

Jun.20
Nov.21
Jan. 2021

Attachment III: Feasible solutions included in analysis

Upper Austria

Month	Category	# Cases	Scenario 1	Scenario 2	Scenario 3
June 2020	0 - 999	316	5	5	5
		433	5	5	5
		484	5	5	5
		529	5	5	5
		532	5	5	5
		662	5	5	5
		901	5	5	5
November 2020	1000 - 2999	1257	5	5	5
		2024	5	5	5
	>2999	3075	5	5	5
		3324	5	5	5
		3571	5	5	5
		4648	5	5	5
		6052	5	5	5
January 2021	0 - 999	758	5	5	5
		843	5	5	5
	1000 - 2999	1171	5	5	5
		1219	5	5	5
		1267	5	5	5
		1300	5	5	5
		1605	5	5	5

Vienna

Month	Category	# Cases	Scenario 1	Scenario 2	Scenario 3
June 2020	0 - 999	803	5	5	5
	1000 - 2999	1176	5	5	5
		1840	5	5	5
		2079	5	5	5
		2323	5	5	5
		2645	5	5	5
	>2999	3029	5	5	5
November 2020	>2999	4286	5	5	5
		5589	5	5	5
		5940	5	5	5
		5974	5	5	5
		6401	5	5	5
		7627	5	5	0
		8124	0	5	0
January 2021	1000 - 2999	1478	5	5	5
		2449	5	5	5
		2697	5	5	5
		2795	5	5	5
	>2999	3161	5	5	5
		4138	5	5	5
		5521	5	5	5

Attachment IV: Detailed computational results

		Upper Austria							
	# Daily PCR tests	Distrib. (%)		# Used		TC	Tours		
		TC	Vehic.	TC (10 - 17)	Vehic. (80)	Avg. Util. (5)	Avg. Cases (#)	Avg. length (km)	Avg. length (h)
Scenario 1 (13 test-centres)	316	62.03	37.97	2.20	6.20	32.50	19.62	165.25	11.88
	433	55.89	44.11	1.60	7.60	59.29	25.36	167.93	11.93
	484	60.58	39.42	2.20	8.60	51.65	22.09	137.00	11.94
	529	57.47	42.53	1.80	9.80	63.28	22.92	154.23	11.93
	532	57.82	42.18	2.00	9.20	57.71	24.43	152.80	11.95
	662	62.60	37.40	2.80	10.20	55.60	24.37	145.04	11.90
	758	64.09	35.91	3.00	10.80	54.56	25.41	150.49	11.92
	843	67.21	32.79	2.60	10.80	62.53	25.64	135.84	11.91
	901	65.42	34.58	3.00	12.20	64.42	25.56	130.35	11.94
	Avg. 0 - 999	61.45	38.55	2.36	9.49	55.73	23.93	148.77	11.92
	1171	66.85	33.15	3.20	14.00	65.49	27.81	143.90	11.94
	1219	64.70	35.30	3.40	14.80	77.54	29.28	148.01	11.95
	1257	63.55	36.45	3.00	15.60	79.58	29.43	148.42	11.94
	1267	65.37	34.63	3.00	15.00	73.01	29.42	144.44	11.94
	1300	63.29	36.71	3.20	15.80	78.07	30.14	156.77	11.95
	1605	69.15	30.85	3.40	15.60	74.33	31.92	152.89	11.96
	2024	68.20	31.80	3.60	18.60	87.31	34.60	161.79	11.96
	Avg. 1000 -2999	65.87	34.13	3.26	15.63	76.48	30.37	150.89	11.95
	3075	67.16	32.84	6.00	24.80	85.84	40.78	152.40	11.97
	3324	68.45	31.55	5.40	24.80	81.37	42.54	125.26	11.97
	3571	69.00	31.00	6.20	27.20	86.33	40.81	119.30	11.97
	4648	67.41	32.59	7.20	34.00	88.95	44.73	111.37	11.97
	6052	69.35	30.65	8.40	39.80	90.01	46.75	119.22	11.98
	Avg.>2999	68.27	31.73	6.64	30.12	86.50	43.12	125.51	11.97
	Avg. Scenario 1	64.55	35.45	3.68	16.45	69.97	30.65	143.94	11.94
Scenario 2 (17 test-centres)	316	62.22	37.78	2.40	6.00	30.50	20.20	162.38	11.89
	433	57.04	42.96	1.80	7.40	56.85	25.29	173.78	11.94
	484	63.84	36.16	2.60	8.20	43.48	21.50	151.96	11.91
	529	60.53	39.47	2.00	9.20	51.75	22.79	154.69	11.91
	532	59.74	40.26	2.00	9.20	59.53	23.23	139.50	11.93
	662	64.11	35.89	3.00	9.60	53.70	24.90	161.19	11.94
	758	64.35	35.65	2.80	10.60	51.32	25.71	157.55	11.93
	843	68.45	31.55	2.60	10.60	56.97	25.15	138.45	11.93
	901	67.30	32.70	3.60	11.20	59.33	26.40	147.77	11.93
	Avg. 0 - 999	63.06	36.94	2.53	9.11	51.49	23.91	154.14	11.92
	1171	68.80	31.20	3.80	13.40	64.39	27.37	139.48	11.94
	1219	66.06	33.94	3.80	14.40	70.63	28.88	138.73	11.95
	1257	63.22	36.78	3.00	15.80	77.58	29.40	147.29	11.93
	1267	67.55	32.45	3.40	14.40	69.86	28.76	139.00	11.94
	1300	66.94	33.06	4.00	15.00	71.72	28.65	152.22	11.95
	1605	69.06	30.94	3.40	15.40	77.88	32.44	156.59	11.95
	2024	69.72	30.28	4.40	18.40	80.54	33.36	139.41	11.96
	Avg. 1000 -2999	67.33	32.67	3.69	15.26	73.23	29.84	144.67	11.95
	3075	69.27	30.73	6.40	23.80	81.91	39.78	149.82	11.97
	3324	68.64	31.36	6.00	25.20	88.80	41.56	141.16	11.97
	3571	69.61	30.39	6.60	26.80	82.48	40.72	139.97	11.97
	4648	69.38	30.62	8.00	32.00	89.19	44.68	124.88	11.97
	6052	70.01	29.99	9.00	38.80	92.18	46.86	114.96	11.98
	Avg. >2999	69.38	30.62	7.20	29.32	86.91	42.72	134.16	11.97
	Avg. scenario 2	65.99	34.01	4.03	15.97	67.17	30.36	146.23	11.94
Scenario 3 (10 test-centres)	316	60.63	39.37	2.00	6.40	34.21	19.74	165.25	11.91
	433	57.23	42.77	2.00	7.60	48.18	24.50	162.79	11.93
	484	62.35	37.65	2.40	8.60	43.98	21.20	131.53	11.92
	529	60.72	39.28	2.20	9.40	53.31	22.17	145.89	11.93
	532	57.78	42.22	2.00	9.60	52.69	23.47	135.22	11.93
	662	59.27	40.73	2.60	10.40	57.26	26.02	155.74	11.93
	758	64.83	35.17	3.00	10.40	53.98	25.73	152.84	11.93
	843	64.27	35.73	2.40	11.20	73.33	27.00	156.30	11.92
	901	63.20	36.80	3.00	12.40	70.34	26.73	142.98	11.94
	Avg. 0 - 999	61.14	38.86	2.40	9.56	54.14	24.06	149.84	11.93
	1171	65.14	34.86	3.40	14.40	71.02	28.31	134.26	11.94
	1219	62.12	37.88	2.80	15.40	74.29	30.11	154.26	11.93
	1257	62.72	37.28	2.80	15.80	75.03	29.86	152.15	11.94
	1267	66.74	33.26	3.00	14.40	66.65	29.51	155.33	11.95
	1300	65.94	34.06	3.40	15.40	72.08	28.73	147.19	11.95
	1605	69.36	30.64	3.40	15.20	74.16	32.64	162.39	11.95
	2024	66.57	33.43	3.80	19.40	80.64	34.93	152.59	11.96
	Avg. 1000 -2999	65.51	34.49	3.23	15.71	73.41	30.58	151.17	11.94
	3075	66.07	33.93	5.60	26.00	88.58	40.17	148.84	11.97
	3324	67.04	32.96	6.00	24.80	88.94	44.25	136.13	11.97
	3571	68.82	31.18	6.40	26.20	85.50	42.65	138.67	11.97
	4648	66.83	33.17	8.00	33.80	87.56	45.83	137.26	11.98
	6052	65.51	34.49	9.80	43.40	95.94	48.25	131.38	11.97
	Avg. >2999	66.86	33.14	7.16	30.84	89.31	44.23	138.46	11.97
	Avg.scenario 3	63.96	36.04	3.81	16.68	68.94	31.04	147.57	11.94
	Avg.Upper Austria	64.83	35.17	3.84	16.37	68.69	30.68	145.91	11.94

Vienna

	# Daily PCR tests	Distrib. (%)		# Used		TC	Tours		
		TC	Vehic.	TC (2 - 5)	Vehic. (80)	Avg. Util. (5)	Avg. Cases (#)	Avg. length (km)	Avg. length (h)
Scenario 1 (3 test-centres)	803	69.84	30.16	1.00	9.80	50.07	24.81	103.93	11.96
	Avg. 0 - 999	69.84	30.16	1.00	9.80	50.07	24.81	103.93	11.96
	1176	69.39	30.61	1.00	13.40	72.86	27.15	98.67	11.96
	1478	69.13	30.87	1.00	17.20	91.23	26.68	93.05	11.96
	1840	69.81	30.19	1.00	20.00	76.46	27.82	92.45	11.96
	2079	70.26	29.74	1.00	22.20	86.94	27.92	88.98	11.96
	2323	70.77	29.23	1.00	23.40	97.86	29.23	90.60	11.96
	2449	69.30	30.70	1.20	26.20	90.76	28.90	88.81	11.96
	2645	69.77	30.23	1.20	28.80	89.38	27.83	82.67	11.96
	2697	69.61	30.39	1.40	28.40	86.23	29.01	86.40	11.97
	2795	69.46	30.54	1.80	28.40	79.22	30.12	92.26	11.97
	Avg. 1000 -2999	69.72	30.28	1.18	23.11	85.66	28.30	90.43	11.96
	3029	69.89	30.11	2.00	29.40	79.65	31.05	93.69	11.98
	3161	69.85	30.15	2.00	31.00	82.34	30.77	91.84	11.97
	4138	68.90	31.10	2.00	41.80	98.44	30.91	91.03	11.97
	4286	69.91	30.09	2.00	41.80	97.86	30.98	88.90	11.97
	5521	65.73	34.27	3.00	36.40	76.61	51.99	108.88	11.95
	5589	64.72	35.28	3.00	38.40	76.41	51.36	112.57	11.96
	5940	61.53	38.47	3.00	46.00	77.09	49.69	112.70	11.95
	5974	61.49	38.51	3.00	46.60	77.44	49.37	106.21	11.95
	6401	57.44	42.56	3.00	56.20	77.50	48.48	105.50	11.95
	Avg.>2999	65.50	34.50	2.56	40.84	82.59	41.62	101.26	11.96
	Avg. scenario 1	67.73	32.27	1.82	30.81	82.33	34.42	96.27	11.96
Scenario 2 (5 test-centres)	803	69.84	30.16	1.00	9.60	66.76	25.41	107.90	11.96
	Avg. 0 - 999	69.84	30.16	1.00	9.60	66.76	25.41	107.90	11.96
	1176	69.39	30.61	1.00	13.20	92.09	27.64	102.33	11.96
	1478	69.13	30.87	1.00	16.80	91.23	27.30	96.71	11.97
	1840	69.81	30.19	1.00	19.40	76.46	28.68	95.37	11.97
	2079	70.26	29.74	1.00	21.80	86.94	28.41	91.30	11.96
	2323	70.77	29.23	1.00	22.60	97.86	30.21	94.85	11.97
	2449	69.58	30.42	1.20	25.00	92.64	29.83	92.18	11.97
	2645	69.77	30.23	1.00	28.40	94.15	28.21	81.78	11.97
	2697	69.61	30.39	1.00	29.40	95.79	27.98	82.34	11.96
	2795	69.46	30.54	1.00	30.60	99.05	27.98	79.76	11.97
	Average 1000 -2999	69.75	30.25	1.02	23.02	91.80	28.47	90.74	11.97
	3029	69.89	30.11	2.00	27.60	82.36	33.06	105.26	11.97
	3161	69.85	30.15	2.00	28.40	84.90	33.59	106.50	11.97
	4138	68.35	31.65	2.00	41.60	96.12	31.55	91.14	11.97
	4286	69.91	30.09	2.60	40.20	85.20	32.21	93.92	11.97
	5521	69.49	30.51	4.00	30.40	73.56	55.42	101.32	11.94
	5589	70.13	29.87	4.00	30.20	74.70	55.28	96.22	11.94
	5940	69.60	30.40	4.00	33.00	75.47	54.72	102.17	11.93
	5974	69.48	30.52	4.00	33.00	76.35	55.29	104.98	11.93
	6401	66.73	33.27	4.00	39.60	76.83	53.79	108.50	11.93
	Avg. >2999	69.27	30.73	3.18	33.78	80.61	44.99	101.11	11.95
	Avg.scenario 2	69.53	30.47	2.04	27.41	85.18	36.14	96.55	11.96
Scenario 3 (2 test-centres)	803	69.84	30.16	1.00	9.80	50.07	24.96	103.62	11.96
	Avg. 0 - 999	69.84	30.16	1.00	9.80	50.07	24.96	103.62	11.96
	1176	69.39	30.61	1.00	13.40	72.86	27.05	99.50	11.96
	1478	69.13	30.87	1.00	17.20	91.23	26.64	90.75	11.96
	1840	69.81	30.19	1.00	19.00	65.54	29.28	101.62	11.96
	2079	70.26	29.74	1.00	22.20	74.52	27.88	89.60	11.96
	2323	70.77	29.23	1.00	23.20	83.88	29.36	89.59	11.96
	2449	69.97	30.03	1.00	26.20	87.43	28.09	86.17	11.97
	2645	69.77	30.23	1.00	28.40	94.15	28.18	86.88	11.96
	2697	69.61	30.39	1.00	29.20	95.79	28.19	80.72	11.96
	2795	69.64	30.36	1.20	29.80	92.59	28.79	87.31	11.96
	Avg.1000 -2999	69.82	30.18	1.02	23.18	84.22	28.16	90.24	11.96
	3029	69.89	30.11	2.00	27.20	72.18	33.55	113.31	11.98
	3161	69.85	30.15	2.00	28.60	75.34	33.34	110.96	11.98
	4138	70.28	29.72	2.00	38.00	95.62	32.43	108.09	11.98
	4286	69.91	30.09	2.00	39.00	97.86	33.12	108.67	11.98
	5521	43.83	56.17	2.00	68.60	78.57	45.21	99.65	11.97
	5589	43.30	56.70	2.00	71.40	78.57	44.38	98.33	11.96
	5940	40.69	59.31	2.00	77.00	78.50	45.75	102.83	11.97
	5974	40.48	59.52	2.00	77.80	78.52	45.70	102.15	11.97
	6401	37.44	62.56	2.00	79.80	77.95	50.18	119.77	11.97
	Avg. >2999	53.96	46.04	2.00	56.38	81.46	40.41	107.08	11.97
	Avg. scenario 3	62.31	37.69	1.48	38.20	81.11	33.79	98.92	11.97
	Avg. Vienna	66.52	33.48	1.78	32.14	82.88	34.78	97.25	11.96

Vienna

	# Daily PCR tests	Distrib. (%)		# Used		TC	Tours		
		TC	Vehic.	TC (2 - 5)	Vehic. (80)	Avg. Util. (5)	Avg. Cases (#)	Avg. length (km)	Avg. length (h)
Scenario 1 (3 test-centres)	7627	49.00	51.00	3.00	78.60	78.52	49.49	122.45	11.97
Scenario 2 (5 test-centres)	7627	64.96	35.04	5.00	51.80	77.38	51.60	113.76	11.95
	8124	61.32	38.68	5.00	62.80	77.72	50.04	117.49	11.95

Attachment V: Deutsches Abstract

Eine umfangreiche Teststrategie stellt einen wichtigen Bestandteil für die Bekämpfung der COVID-19 Pandemie dar. Im Rahmen dieser Teststrategie werden alle Personen, die Symptome aufzeigen oder Kontakt zu einer infizierten Person hatten, zeitnah mit Hilfe eines Polymerase-Kettenreaktion -Tests (PCR Test) auf das Coronavirus getestet. Die PCR Tests werden entweder in Testzentren, zu denen potenziell infizierte Personen selbst anreisen, oder von mobilen Testteams durchgeführt, bevor sie in einem Labor ausgewertet werden.

Ziel dieser Szenarioanalyse ist es, Erkenntnisse darüber zu erlangen, wie unterschiedliche Anzahlen von verfügbaren Testzentren bei einer gleichbleibenden Anzahl von verfügbaren mobilen Testteams die Gesamtkosten für den Betrieb von Testzentren und das Routing von mobilen Testteams beeinflussen.

Die Grundlage der durchgeführten Szenarioanalyse bildet das Contagious Disease Testing Problem (CDTP), welches mit Hilfe einer Large Neighbourhood Search Metaheuristik gelöst wird. Der Fokus dieser Masterarbeit liegt auf den Berechnungen von drei Szenarien mit unterschiedlichen Anzahlen an zur Verfügung stehenden Testzentren. Jedes Szenario wird dazu auf drei Phasen der Pandemie angewandt, um die hohe Fluktuation an behördlich angeordneten PCR Tests zu berücksichtigen. Außerdem wurden die Berechnungen für die Österreichischen Bundesländer Oberösterreich und Wien durchgeführt, um etwaige Unterschiede zwischen ländlichen und städtischen Regionen aufzuzeigen.