ETH zürich

Multi-Criteria Decision Analysis

A Site Selection Problem in the Canton of Zurich

Hospital Planning for the Canton of Zurich

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Inhalt

1 Problem Definition

The canton of Zurich has very high health costs. One of the canton's problems is that there are too many hospitals (Hehli, 2018). The canton wants to reduce the number of hospitals but the decision which one to remove is a very difficult political question. The consulting company PWC has developed a care model for a virtual future hospital landscape in “a thought journey into the care landscape of the day after tomorrow” (PWC, 2017: p. 18-21). It assumes a massive decline in the number of hospital beds required and calculates a bed density of 2.4 beds per 1000 inhabitants (today 2.7). For the Greater Zurich Region, for example, they estimate that just five hospitals, some of them very large, would be sufficient to supply the population and guarantee optimum productivity. Christian Schär, president of the “Verband Zürcher Krankenhäuser” talks in an interview about a future need for hospital beds reduced by a quarter. This is mainly due to a shift from stationary to ambulant hospital treatment (Anderegg, 2018). There are repeated discussions in the Canton of Zurich about shutting down smaller hospitals such as the Affoltern Hospital in the current year. Reducing the number of hospitals is a very emotional topic in population but also for the local politicians and therefore closure plans are often coming with great local resistance (Anderegg, 2019).

This analysis should be a decision base for the future hospital planning of the Canton of Zurich. The aims are to show which criterias make a good hospital location, which locations in the canton are particularly suitable for a hospital (MADM approach) and thus contribute to the decision as to which hospitals could be considered for closure in the future (MODM approach). In doing so, the aim is to reduce the number of hospital beds by a quarter.

For this study, 26 acute hospitals from the Canton of Zurich are considered, which are listed in Table 1. They have a total of 4460 beds and are spread over the whole Canton of Zurich.

Table 1: Hospitals of the Canton of Zurich

Nr.	Name	Betten	**Nr.**	Name	Betten
1	Bezirksspital Uster	208	**14**	See-Spital Kilchberg (Sanitas)	106
2	GZO Spital Wetzikon	156	**15**	Spital Bülach	200
3	Kantonsspital Winterthur	445	**16**	Spital Dielsdorf (Adus Medica)	15
4	Kinderspital Zürich	170	**17**	Spital Limmattal	181
5	Klinik Bethanien	96	**18**	Spital Männedorf	129
6	Klinik Hirslanden	335	**19**	Spital Zollikerberg	174
7	Klinik im Park	133	**20**	Stadtspital Triemli	396
8	Klinik Lindberg	68	**21**	Uniklinik Balgrist	84
9	Klinik Pyramide am See	20	**22**	Universitätsspital Zürich	941
10	Klinik Susenberg	13	**23**	Waidspital	213
11	Paracelsus Spital Richterswil	31	**24**	Spital Affoltern	73
12	Schulthess Klinik	137	**25**	Klinik Lengg	20
13	See-Spital Horgen (Spital Zimmerberg)	106	**26**	Limmatklinik	10

2 Evaluation Criteria

For the analysis, the seven criteria “Central Area”, “Population Catchment Area”, “Land Price”, “Accessibility of Public Transport”, “Highway Access”, “Main Street Access” and “Air Quality” were selected. The following chapter describes the evaluation criteria. The Score Maps of each Evaluation Criteria is shown in the appendix 7.1.

2.1 Central Area (c_area)

In the Canton of Zurich (2018), twelve central areas are listed in the cantonal guiding plan. The central areas are visualized in Figure 1. These centers are to be preferred in the planning of public buildings and facilities and therefore also for hospitals. This criterion also takes into account a regional distribution of the hospitals. The decision variables “Central Area” is introduced as a binary variable with score 1 for central areas and value 0 for the rest.

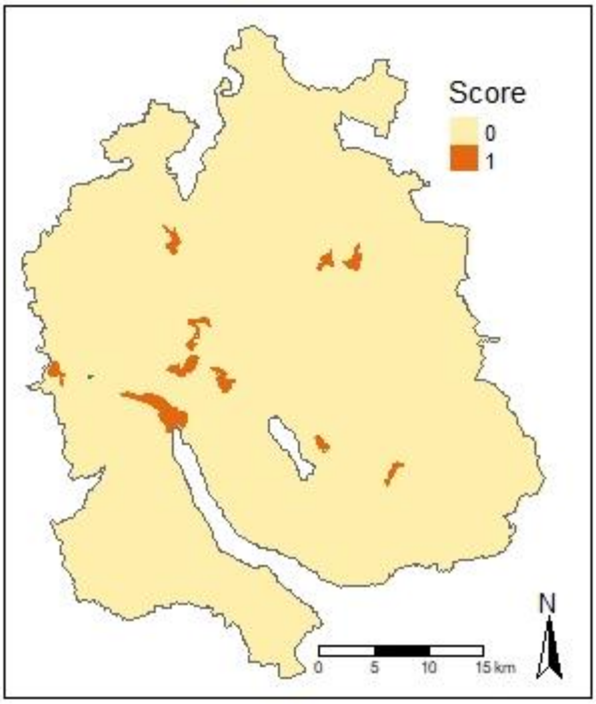

Figure 1: Score Map of the Central Area

2.2 Population Catchment Area (p_catch)

The population catchment area of a hospital is of particular importance. It describes the number of potential customers who would visit a hospital. A study conducted by PWC (2017, p. 19-21) in which they sought an optimal location distribution of Swiss hospitals determines the average driving distance of 12km to the next hospital, which leads to 98% coverage of population of the canton of Zurich to reach a hospital within 30 minutes. In this case, the catchment area of a pixel is calculated by focal statistics with a round moving window with a radius of 121 pixels. This represents 12.1 km.

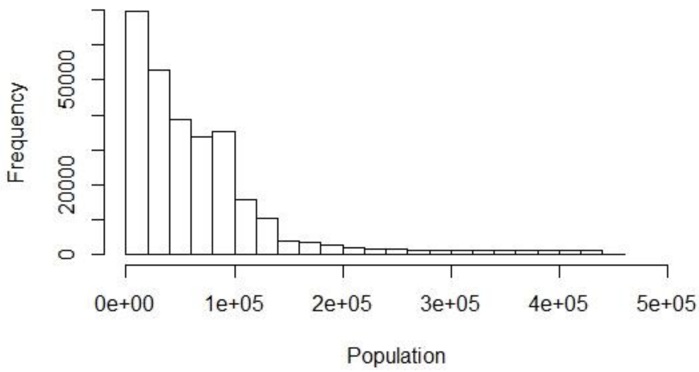

Figure 2: Histogram of population catchment after focal statistics

An analysis of the calculated data shows that most pixels have a catchment area of 0 to 150,000 inhabitants. For the standardization the value 1 is assigned for all pixels over 150’000 inhabitants and between 150'000 and zero the value decreases linearly. The value of 150’00 inhabitants seams realistic because this is more than the population of Winterthur, the second large city of the Canton.

2.3 Land Price (price)

The land price plays an important role in hospital planning. On the one hand, a low-cost land price lowers the costs of a hospital, on the other hand, a higher added value can be achieved on areas with a high land price, e.g. by living.

The "Land Price" variable is introduced as a continuous variable. As basic data for the land price, a selection of residential properties including price and area is available. A price per square meter is calculated for each property. This data is interpolated across the room using ordinary kriging.

For the standardization, it must be considered that the very expensive areas get a value close to zero with a small difference, because they are not usable for locating a hospital. The difference between the very low prices, which are mostly located in non-settlement areas or in rural areas, should also be small. The difference between the values should be in the settlement area. Basically, the cheaper the land, the more suitable it is. This phenomenon is represented as follows by an arc tangent function:

$$y = -\frac{1}{pi} * \arctan(0.2 * (x - 18.88) + 0.5$$

The value of 18.88 is representing the median of all square meter prices. This mean value is assigned to score 0.5. The rather steep distribution of the arc tangent function seen in Figure 3: Histogram of housing price data Figure 4 is represented by the constant 0.2. It is chosen in such a way because the distribution of the scores in kriging is quite narrow (see Figure 3).

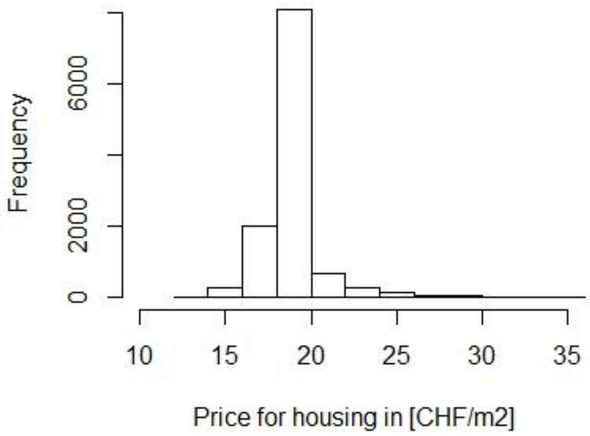

Figure 3: Histogram of housing price data

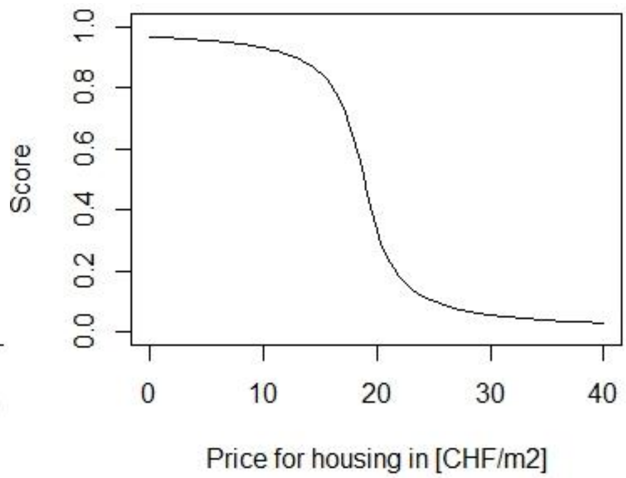

Figure 4: Utility function for the housing price

2.4 Accessibility of Public Transport (pt)

The Federal Office for Spatial Development describes the accessibility of public transport in Switzerland by "ÖV-Güteklassen". This is a categorization of the areas corresponding to the quality of public transport offer. Good public transport access is important for a hospital in order to reduce the number of car trips. In standardization, the four categories A-D are classified according to their quality. This decision variable is discrete. Category A ("very good accessibility") gets value 1, category B ("good accessibility") gets value 0.75, category B ("medium

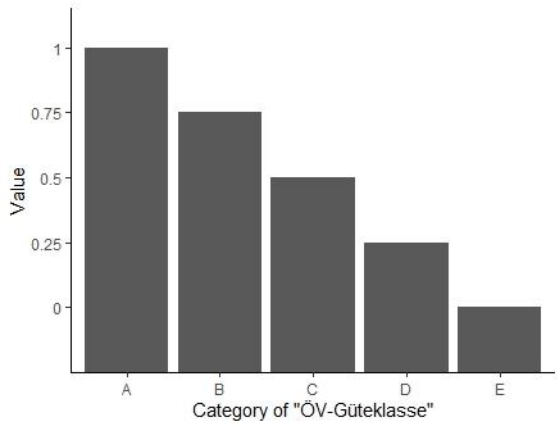

Figure 5: Utility function for accessibility of public transport

accessibility") gets value 0.5 and category D ("low accessibility") gets value 0.25. The rest gets zero.

2.5 Highway Access (h_street)

For a hospital, the access by road is of great importance, especially via the highways. The ambulance must reach the site as quickly as possible, which happens best on these roads.

The "Highway Access" variable is introduced as a continuous one. For the calculation of this criterion, the distance to the next motorway entrance is therefore considered. A location within 300 meters is assigned a value of 1, followed by a linear decrease in suitability. Areas with a distance of more than 5 kilometers are assigned the value 0. The standartization is visualized in **Fehler! Verweisquelle konnte nicht gefunden werden.**.

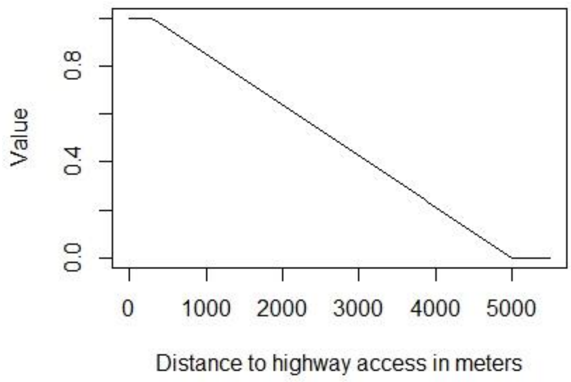

Figure 7: Utility function highway access

2.6 Main Street Access (m_street)

Not only the highway access but also the main street access is important for a hospital location. A main road is wide and therefore easily to drive through for the ambulance. For this reason, a hospital should be located as close as possible to a main road, such that the vehicle does not have to travel for a long time on side roads to reach it.

This variable is introduced as a continuous variable. It is standardized with a linear function starting from zero distance (score 1) down to 1km (score 0). For locations more than one kilometer away from the next main street, the score is 0.

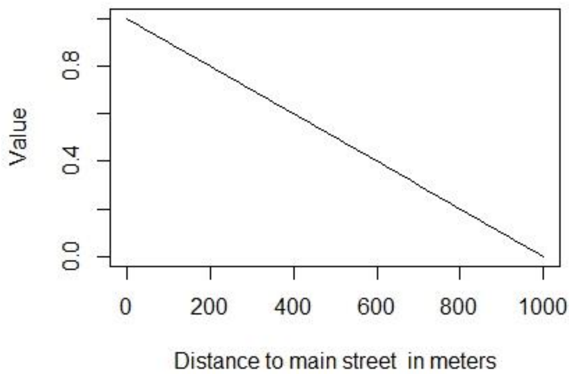

Figure 8: Utility function for the distance to main roads

2.7 Air Quality (NO2)

In order to create a good environment for the patients of a hospital, the air quality of the environment plays an important role. A good air quality allows certain patients to take a walk outside and it is possible to open the window to get fresh air.

A TIFF file with raster data of the NO2 emissions is used to calculate the air quality. The "air quality" is introduced as a continuous variable and it is standardized with a linear function from the lowest value 0 ng/m^3 (value 1) to the highest value of the dataset 21741 ng/m^3 (value 0). The utility function is visualized in Figure 8.

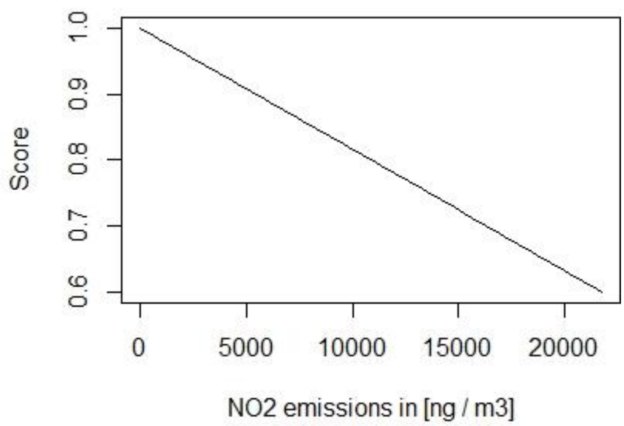

Figure 9: Utility function for NO2 emissions

3 Site Selection Methodology

3.1 Criterion Weighting

The chosen criterias are of varying importance for the decision. The weights of the different criterias were set using the pairwise comparison method. In a first step, the pairwise comparison matrix is created by a rating of the relative preference between each two criteria. The scale for the pairwise comparison was between 1 (“equal importance”) and 9 (“extreme importance”). The set scores are in the matrix shown in Table 2.

Table 2: Pairwise comparison of criteria

	h_street	**no2**	**pt**	**m_street**	**c_area**	**price**	**p_catch**
h_street	1	6	3	3	7	0.5	1
no2	1/6	1	1/4	1/6	0.5	1/6	1/6
pt	1/3	4	1	3	5	0.25	2
m_street	1/3	6	1/3	1	4	0.2	1/4
c_area	1/7	2	0.2	1/4	1	1/8	1/6
price	2	6	4	5	8	1	2
p_catch	1	6	½	4	6	1/2	1

This table is the basis for the computation of the criterion weights. The consistency ratio of 0.079 proves that the original pairwise comparison matrix indicates a reasonable level of consistency (< 0.1). Out of this matrix, the weights are calculated (shown in Table 3).

Table 3: Calculated weights

h_street	**no2**	**pt**	**m_street**	**c_area**	**price**	**p_catch**
0.20	0.03	0.15	0.09	0.04	0.32	0.17

3.2 Simple additive weighting method

The multi-attribute decision problem to find out where the best location for a hospital is in the Canton of Zurich is solved by the simple additive weighting method. This method calculates for each alternative (A_i) a total score by multiplying the calculated weights with each of the standardized values of each attribute at location i and summing them up over all attributes as shown in the following formula.

$$A_i = 0.20 * h_{street_i} + 0.03 * no2_i + 0.15 * pt_i + 0.09 * m_{street_i} + 0.04 * c_{area_i}$$
$$+0.32 * price_i + 0.17 * p\_catch_i$$

3.3 Multi objectives decision rules

To make the decision which hospitals to remove in order to get an optimal number of hospitals or hospital beds we use a MODM approach. To test different types of optimizations, three approaches were calculated with different objective functions. The constraint for all approaches is that the total number of beds in the canton must be reduced by a quarter of today (see chapter 1). Approach 1 maximizes the product of the calculated score value and the number of beds in each hospital. Approach 2 maximizes only the scores of the hospital. The decision variable for both scenarios is a binary variable (the hospital stays, or it is removed). Finally, approach 3 takes the beds as decision variable and maximizes the score of each hospital.

Table 4: Objective function and constraints of MODM

	Approach 1	**Approach 2**	**Approach 3**
objective	$f_1(x) = \max\left\{\sum_{i=1}^{26} A_i \cdot bed_i \cdot x_i\right\}$	$f_2(x) = \max\left\{\sum_{i=1}^{26} A_i \cdot x_i\right\}$	$f_3(x) = \max\left\{\sum_{i=1}^{26} A_i \cdot x_i\right\}$
constraints	$\sum_{i=1}^{26} bed_i \cdot x_i \leq \sum_{i=1}^{26} bed_i \cdot 0.75$	$\sum_{i=1}^{26} bed_i \cdot x_i \leq \sum_{i=1}^{26} bed_i \cdot 0.75$	$\sum_{i=1}^{26} x_i \leq \sum_{i=1}^{26} bed_i \cdot 0.75$ $x_i \leq betten_i \; i \in \mathrm{N}$
	$x_i \in \{0,1\}$	$x_i \in \{0,1\}$	

4 Results

4.1 Results of the MADM Approach

The results of the analysis are described in the following chapter. Figure 9 shows the distribution of the calculated score for the usability of the location for a hospital in the Canton of Zurich. It shows that the areas with a value above 0.6 are spread over the whole canton, but mainly along the transport axes and the densely populated areas.

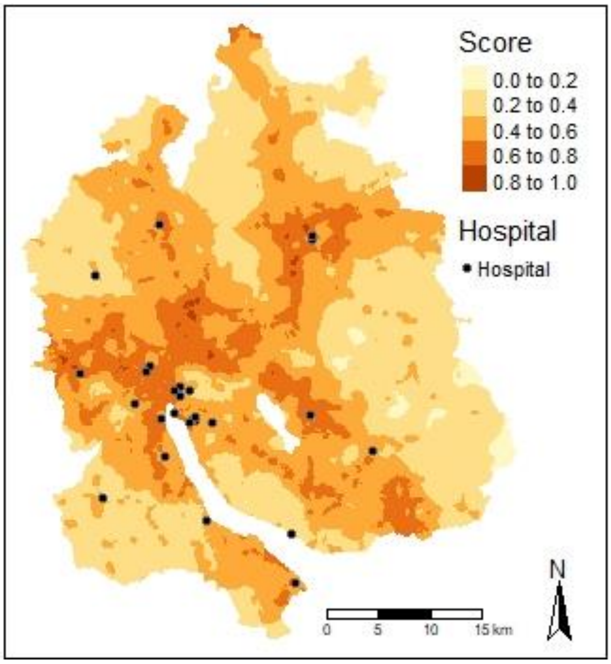

Figure 10: Score of hospital suitability in the Canton of Zurich

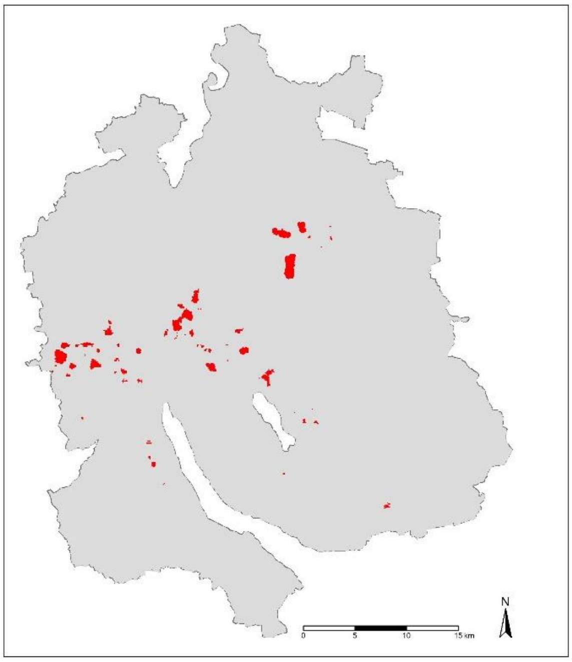

Figure 11: Locations with higher scores than the best hospital

The histogram in Figure 12 shows the distribution of the score values. It shows that most of the values are between 0.2 and 0.8 and that they're roughly normally distributed.

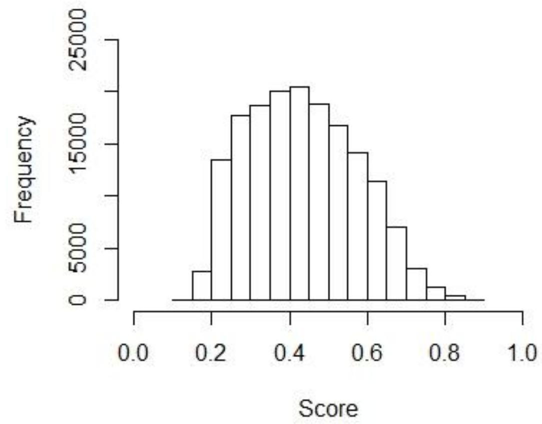

Figure 12: Histogram of the score values

In Figure 13 we can see the score for each hospital in the Canton of Zurich. The Kantonsspital Winterthur is the best located hospital of the Canton with a score of 0.74. On the second and third position are the Klinik Susenberg with a score of 0.69 and the Limmatklinik with 0.68. All these hospitals are located in a central region, have good public transport and highway accessibility and are not in a high-price area. The worst located hospitals with a score of only 0.33 is the Spital Dielsdorf. On the second last position is the Spital Männedorf with a score of 0.35. Spital Affoltern which is one of the hospitals that the canton would like to close is with a score of 0.43 at the third least position.

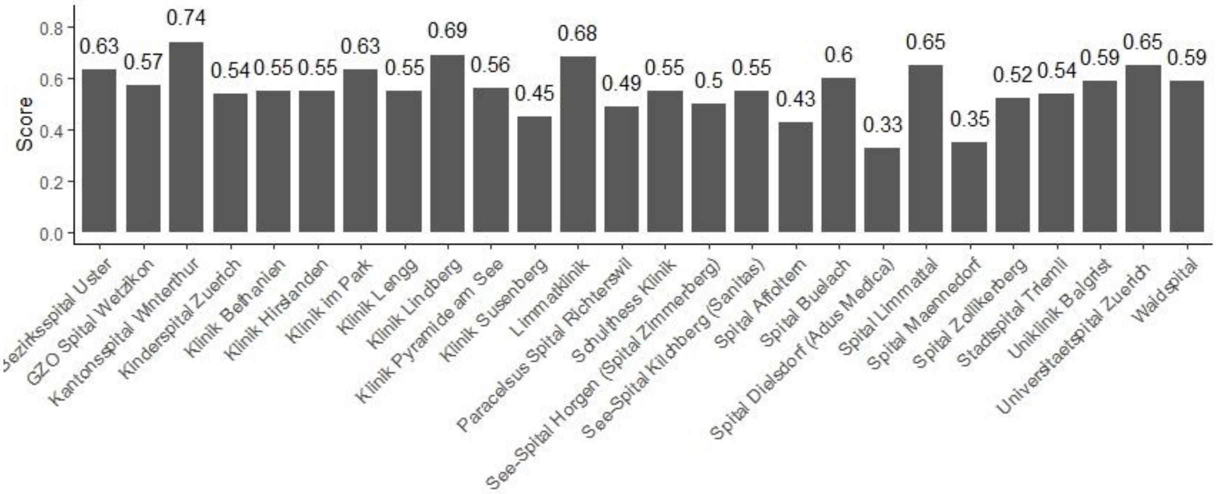

Figure 13: Score Value of Hospitals

There are some areas that are more suitable for a hospital such as the best classified hospital in the Canton of Zurich. These areas are shown in Figure 11 and should be considered if a new hospital is built in the Canton of Zurich.

4.2 Results of the MODM Approach

The calculated score is the basis for the MODM. This is intended to show which hospitals will have to be closed if the number of hospital beds is reduced by a quarter. The three approaches defined in chapter 3.3 give different solutions, shown in the overall results in appendix 7.2 Table 5.

With the first approach the overall score is maximized. As a result, the algorithm automatically minimizes the number of hospitals, because two badly scored hospitals have even a higher score than one with a score somewhere in the middle. With this approach the renowned Universitätsspital Zürich and Spital Zollikerberg are closed. Universitätsspital Zürich is the biggest hospital in the Canton with 941 beds.

With the second approach, the overall score times the number of beds is maximized. This leads to a closure of ten hospitals in total. The closure affects two larger hospitals in the region, the Triemlispital and the Kinderspital Zürich because they have a very poor score. But most of the hospitals are smaller ones.

The third approach shows similar results as in the second approach. The only difference is that 10 beds of the Limmatklinik will remain in approach three.

5 Discussion of results and recommendations

The standardization and weighting of the criterias produces meaningful results. With the Arcus Tangent function, it is important to note that the values 1 and 0 cannot be achieved. However, this does not lead to major changes. A sensitivity analysis, in which the individual criterias were weighted 0.1 points higher, showed that the criterion "central area" has a particularly strong effect on the overall score. This is because the variable can only have binary values. The result can deviate by up to 8% due to this change (appendix 7.3 Table 6). For single hospitals with extreme scores such as Universitätsspital Zürich with a very high land price and the Spital Kilchberg with a very bad air quality (directly at the highway) the sensitivity analysis shows also high sensitivity (7% and 4%).

Normally, when a hospital closes, it is not demolished but converted and used differently. Therefore, in further analysis the focus could be more on the potential of these areas for new uses other than hospitals. Other variables such as view (e.g. for residential use), size of the site or facilities (e.g. for old people's homes) could be considered.

The first approach in linear programming is not convincing. It rather randomly closes two hospitals in order to achieve the desired number of beds. The second and third approaches give more realistic results. However, the third approach fails because one hospital retains exactly 11 beds and closes the rest. This seems unrealistic. In a further calculation, it would have to be checked whether the mean value of the score could be optimized. This would mean that only those hospitals that achieve the best score would be retained. However, this is not possible by linear programming.

In further analyses, the regional distribution and the different specializations of the hospitals could also be taken into account. This could lead to a more profound decision on the hospital future of the Canton of Zurich.

6 Literatur

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PWC (2017): *Schweizer Spitäler: So gesund waren die Finanzen 2017.* Vergleich der wichtigsten Kennzahlen von Schweizern Spitälern. Siebte Ausgabe.

7 Appendix

7.1 Maps of the Evaluation Criteria

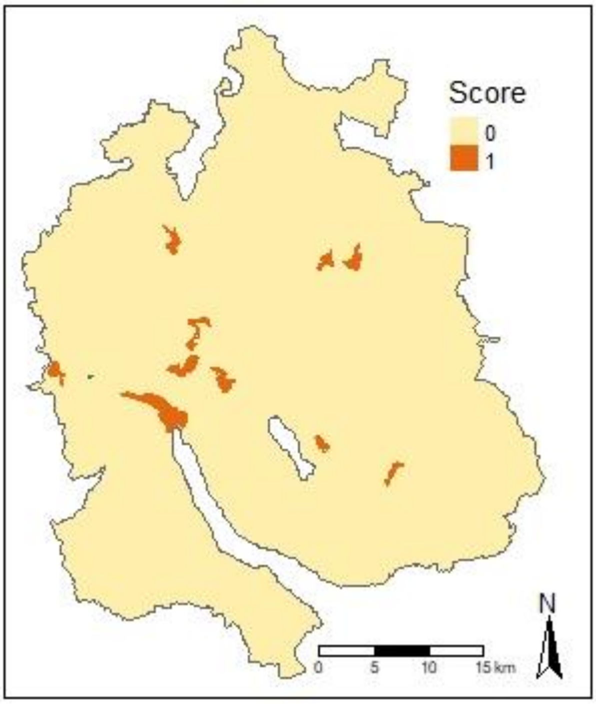

Figure 14: Score Map of Population Catchment Area

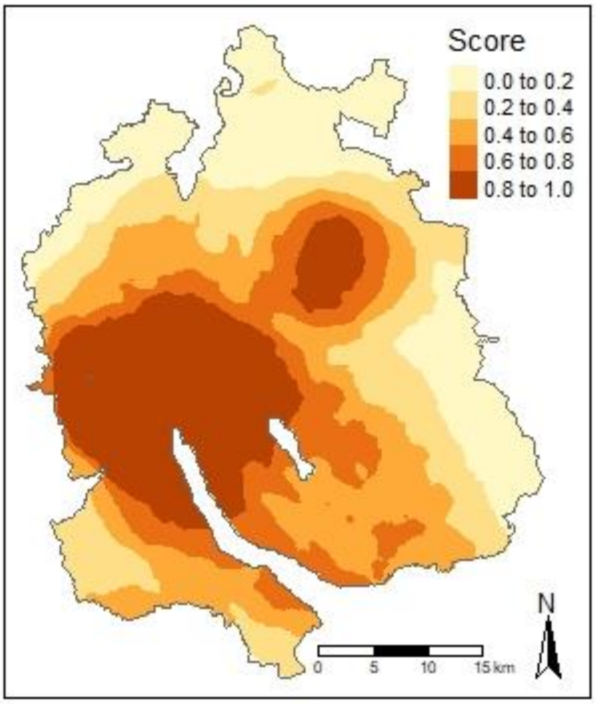

Figure 15: Score Map of Central Area

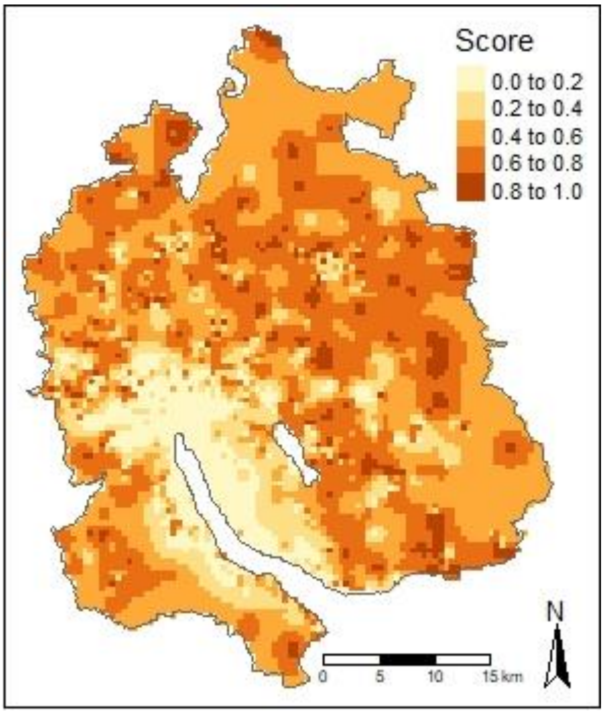

Figure 16: Score Map of Land Price

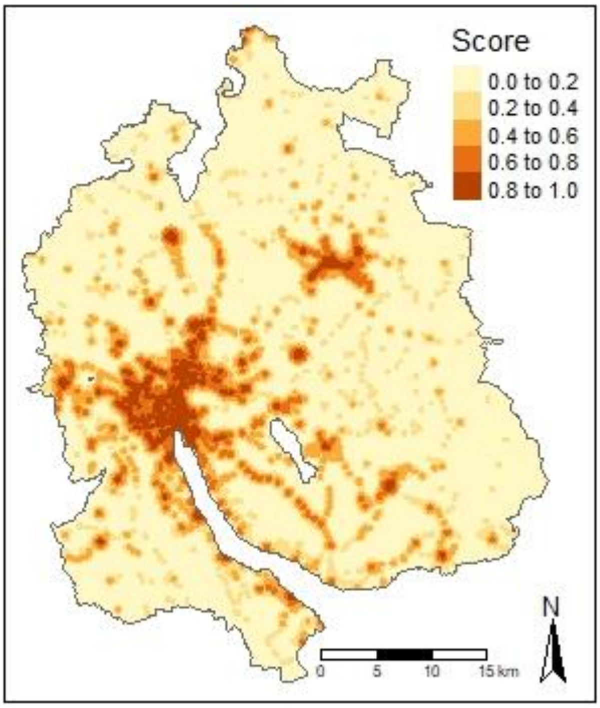

Figure 17: Score Map of PT Accessibility

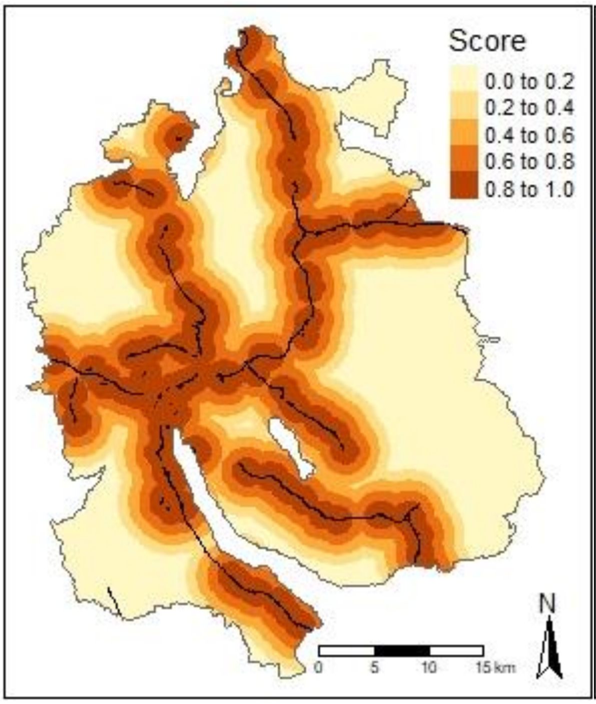

Figure 18: Score Map of Highway Access

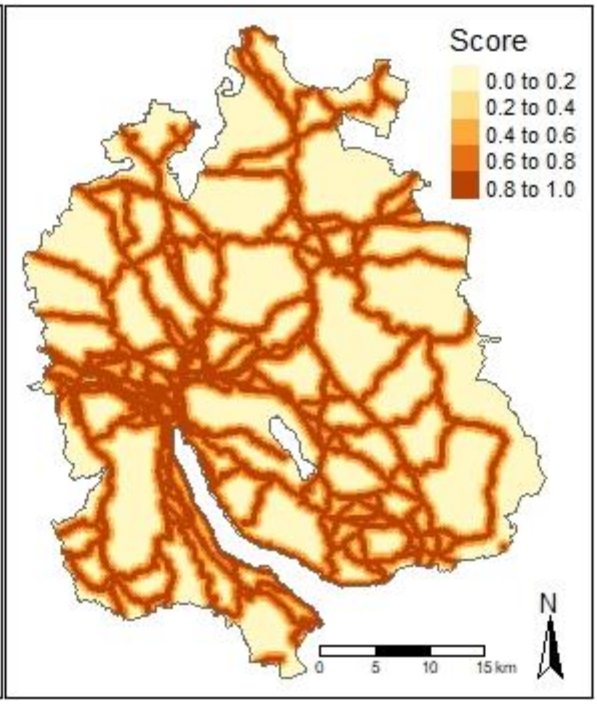

Figure 19: Score Map of Main Street Access

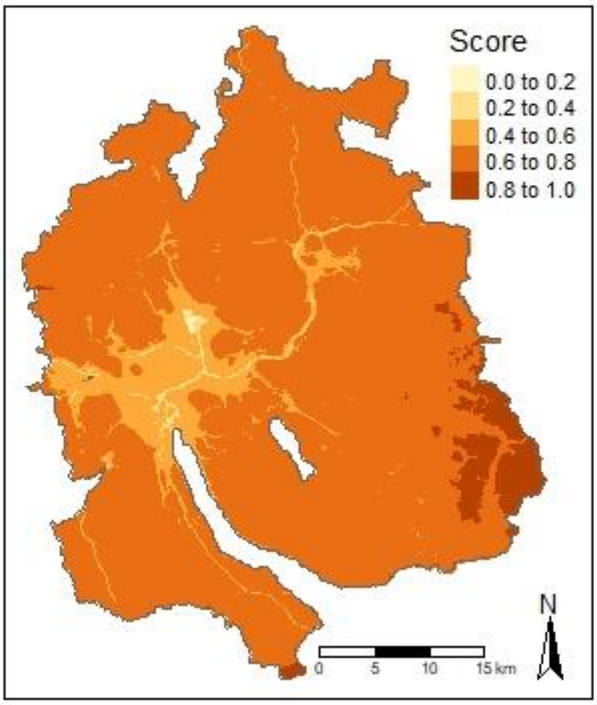

Figure 20: Score Map of Air Quality

7.2 Overall Results

Table 5: Overall Results

Name	Bezirksspital Uster	GZO Spital Wetzikon	Kantonsspital Winterthur	Kinderspital Zuerich	Klinik Bethanien	Klinik Hirslanden	Klinik im Park	Klinik Lindberg	Klinik Pyramide am See	Klinik Susenberg	Spital Richterswil	Schulthess Klinik	See-Spital Horgen	See-Spital Kilchberg	Spital Buelach	Spital Dielsdorf	Spital Limmattal	Spital Maennedorf	Spital Zollikerberg	Stadtspital Triemli	Uniklinik Balgrist	Universitaetspital Zuerich	Waidspital	Spital Affoltern	Klinik Lengg	Limmatklinik
Beds	208	156	445	170	96	335	133	68	20	13	31	137	106	106	200	15	181	129	174	396	84	941	213	73	20	10
Score	0.78	0.63	0.82	0.55	0.57	0.65	0.73	0.74	0.59	0.50	0.68	0.66	0.67	0.67	0.78	0.53	0.77	0.58	0.75	0.65	0.67	0.65	0.61	0.52	0.65	0.81
A 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1
A 2	1	1	1	0	1	1	1	1	1	0	0	1	0	1	1	0	1	0	0	0	1	1	1	0	1	0
A 3	208	156	445	0	96	335	133	68	20	0	0	137	0	98	200	0	181	0	0	0	84	941	213	0	20	10

7.3 Sensitivity analysis

A sensitivity analysis was performed to check how much a change in the weighting of the individual variables would change the overall result. The weighting was increased by 0.1 points for each variable individually, while it was reduced by 1/6 for the others. The results of the analysis are shown in Table 6.

Table 6: Sensitivity analysis

	highway access	no2	public transport	main roads	center	housing price	population catchment
Bezirksspital Uster	0%	1%	3%	3%	-8%	1%	0%
GZO Spital Wetzikon	2%	0%	3%	3%	-6%	3%	0%
Kantonsspital Winterthur	-3%	2%	1%	1%	2%	-1%	1%
Kinderspital Zürich	0%	2%	2%	2%	-7%	-5%	5%
Klinik Bethanien	0%	5%	-3%	-3%	-6%	-4%	5%
Klinik Hirslanden	0%	-1%	2%	2%	-7%	-1%	4%
Klinik im Park	-1%	1%	4%	4%	-8%	-3%	4%
Klinik Lindberg	1%	-1%	0%	0%	-7%	2%	4%
Klinik Pyramide am See	-1%	2%	5%	5%	-7%	-4%	5%
Klinik Susenberg	1%	4%	-5%	-5%	-5%	-3%	6%
Spital Richterswil	2%	-3%	3%	3%	-6%	2%	0%
Schulthess Klinik	0%	-1%	1%	1%	-7%	0%	4%
See-Spital Horgen (Spital Zimmerberg)	0%	2%	5%	5%	-7%	1%	0%
See-Spital Kilchberg (Sanitas)	0%	-4%	3%	3%	-7%	-1%	5%
Spital Bülach	0%	4%	2%	2%	-8%	1%	-2%
Spital Dielsdorf (Adus Medica)	3%	-2%	4%	4%	-5%	4%	1%
Spital Limmattal	-1%	-1%	0%	0%	-7%	2%	5%
Spital Männedorf	2%	0%	5%	5%	-6%	0%	2%
Spital Zollikerberg	1%	1%	2%	2%	-7%	0%	4%
Stadtspital Triemli	-1%	2%	2%	2%	-7%	-1%	5%
Uniklinik Balgrist	-1%	1%	4%	4%	-8%	-2%	4%
Universitätsspital Zürich	-3%	2%	1%	1%	2%	-7%	2%
Waidspital	-1%	1%	3%	3%	-7%	-4%	4%
Spital Affoltern	3%	-2%	4%	4%	-5%	5%	0%
Klinik Lengg	0%	-1%	0%	0%	-7%	0%	5%
Limmatklinik	-5%	2%	1%	1%	2%	-3%	2%