Web Processing - Standardised GIS Analyses for Cable Route Planning

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The least cost paths for a power line route from a power station is computed to a power station further inland. Down sampling and clipping as studied as techniques to speed-up the computation. The path from clipped cost raster often matches the original path. The speed-up of the clipping can not be known before hand.

CCS Concepts: • **Computing methodologies** → **Modeling and simulation**; • **General and reference** → Estimation.

Additional Key Words and Phrases: GIS, least cost path

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1 INTRODUCTION

The German power system adds a lot of renewable energy sources in the north, because wind energy reaches highest efficiency with high wind speeds. At the same time old power plants e.g. nuclear, hard coal and lignite are going out off service [1]. These older power plants were mainly situated in southern and central Germany. The power sink, which is industrial and private demand does not shift northwards. Therefore, the renewable energies have to be transported from north to south which increases the congestion in the power grid. The amount of offshore wind power, that the German energy system can use, can be greatly increased by adding new power lines [2].

But for building power lines, finding the shortest path is not sufficient. Additional parameters also have to be taken into consideration. As the steepness of a road or the soil, play an important role for the building cost of a road or pipeline [3]. For planing the additional routes for a power grid, further aspects as legal regulations and acceptance by the local population have to be taken in consideration. Also technical aspects, as the effects on the grid stability are further points take into consideration [4].

Due to the increasing need for renewable energy wind offshore wind turbines supply 5.5 % annual percentage in 2020 of the German energy mix [5].

Other methods as the multi-criteria decision analysis (MCDA) consider further aspects as stakeholder, experts, public and decision maker [6] (see section 5).

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For planning a possible route for a power line the least cost path algorithm is applied. The least cost path algorithm is a Dijkstra algorithm [7] applied on a raster map. The vertices of the graph are the pixel centers, that are connected to the eight neighboring pixel centers via the edges. This enables to find routes on graphs that are not predefined like road notworks. The weights of the edges are the local costs to travel from one pixel center to the neighboring pixel center. The costs might be physical costs, as the local slope, but also can be composed on other factors as the acceptance rate for the land usage of a given class. The least cost path algorithm consists of at least two sequential steps. 1) The first step is to aggregate the costs of traveling from the starting point to a given set of end points. This step generates the aggregated cost raster of traveling from the starting point to any point of the cost raster. 2) In the next step the back tracking, the route of the actual least cost path is calculated. For each ending point the path via the lowest cost neighbor is taken until arriving at the starting point.

Some implementations switch the role of start and ending points, so that either many starting points and one end point, or one end point and many endpoints can be used. In some implementation there is a extra step between 1) and 2) that calculates cost-weight direction raster, that encodes the direction of the shortest path to the starting point as integer values.

2 METHODS

We retrieve a set of different spacial data-sets from public sources as a basis to create the cost raster. Field of study are the counties of Cuxhaven and Osterholz in the state of Lower Saxony, Germany. Areas protected by different European and National conservation laws are provided by the German Environment Agency as Web Feature Service (wfs) [8].

The nationwide land coverage (ATKIS) with a scale of 1:250000 are provided by the Federal Agency for Cartography and Geodesy [9]. The nationwide power grid (tags: 'power': line) has been retrieved via OpenStreetMap [10]. Local data as houses at Level of Detail 1 are offered by the State Office for Geoinformation and Land Surveying of Lower Saxony [11]. In addition, local planning geodata for the land usage are taken from 'Metropolplaner' (Planing data Lower Saxony & Bremen) [12].

PyWPS [13] is used to provide the least cost path algorithm as a Web Processing Service (wps) in combination with flask [14]. As client Birdy [15] connects to the wps, sending the cost raster and receiving the resulting least cost path. The initial implementation of the least cost path algorithm is based on the implementation for the QGIS-Plugin 'Least Cost Path' [16] in version 1.0.

The different layers from the different entities are optionally filtered, buffered and then rasterized. Filtering the layers of the files for special attributes enables to further differentiate. For examples makes it possible to differentiate between heath and uncultivated land in the land coverage. Adding a buffer can be used either used to convert a line objects as power grids and streets into a polygon with the correct physical width, or to add minimum distance from an existing of planed area to the new power grid. Each of theses rasterized layers are given a weight, or cost that expresses the cost of using land covered by this layer. The costs of all layers is aggregated with the maximum function. Thus, an area covered by multiple layers is uniformly used with the highest costs. Any place in the study area, that is not covered by any layer and thus does not have a weight yet, is given the default cost.

The costs have been grouped into different levels (see table 1) starting from *preferential* areas with very low costs, via *no restrictions*, which is the default, used when no other layers are covering the local area, to *restricted*, *strongly restricted* and *prohibited* areas with high costs. These higher costs resemble the degree how much a place of this cost should be avoided, while routing the path. The ratio of the higher costs to the lower costs directly translates into the additional diversion in pixels the algorithm is willing to go, for avoiding an area of this high costs. Thus, as *prohibited* areas describe a legal obligation, not to use these areas or only to the utmost minimum, the weight that resembles the costs for these types of areas, has to be especially high.

All these layers are provided as vectors. While the least cost algorithm use raster data. The rasterization transforms a vector into a raster. The rasterization can be executed in two different ways. In both ways, the rasterization can be imaged, as the old vector is layered over the new raster grid with the new given resolution and the new affine transformation and the coordinate reference system of the vector. Both rasterization techniques differ in the selection of the pixel, that describe the original polygon. The pixels can be selected , if either the center of that pixel is overlaid by the geo-object, or any part of the pixel is overlaid. The version with any part overlaid is called all touched True. The version where a overlaid pixel center is require is called all touched False. All touched False is considered the default (see figure 1).

Table 1. Used levels of costs, the applied numerical equivalent and example layer this cost have been used for.

Cost Level	Cost	Example
Prohibited	500	Conversation areas as National Parks, Buildings
strongly Restricted	10	Conversation areas as Bird Reserve
Restricted	5	Protected Landscape Area, Industrial Areas, motorway, railway
No Restriction	0.5	Default
Preferential	0.1	Power Grid, Motorway and Railway Buffers

The completed list of layers and their processing, can be found in **Supplement S1**.

All three steps of the generation of the least cost path: generation of the cost raster, aggregation and back tracking is shown with an example for a starting cost raster of 50 m resolution and a rasterization with all touched False (see 2).

The chosen implementation applies early stopping. Therefore, the costs for points that are not needed to try to connect to the end point are not aggregated. After an aggregated cost for every end

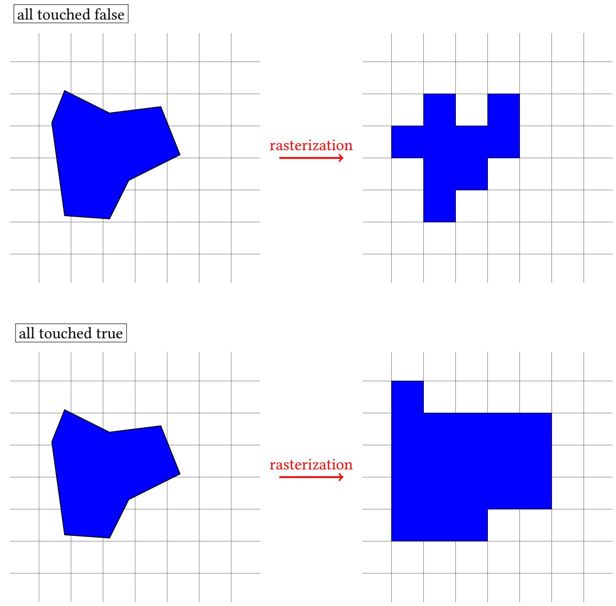
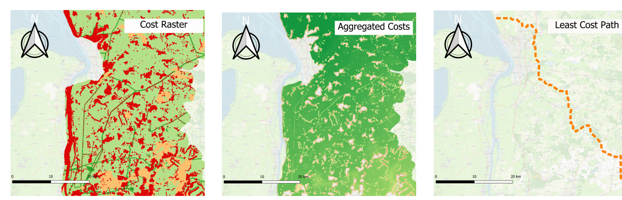


Fig. 1. Graphical example for rastering a vector (left blue), to a raster (right blue) with either all-touched False (above), or all touched True (below).



(a) Cost Raster. (b) Aggregated Cost Raster. (c) Least Cost Path.

Fig. 2. Figures of Cost raster and the resulting aggregated Costs and the least cost path for a resolution of 50 m.

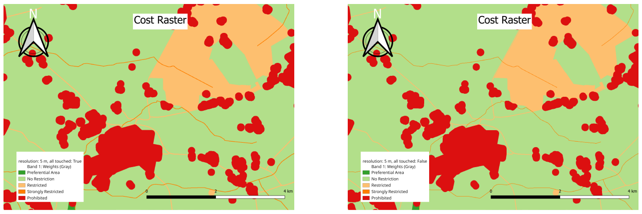
point has been found, the aggregation stops and the back tracking starts. Because the end point ends at a power transformer, which is a building type, the paths ends at in a *Prohibited* Area. Therefore, areas even farther away from the starting point have been explored first.

3 RESULTS

In this chapter we want to show the different cost raster, that were created from the very same set of layers, but computed for different resolutions. From this different raster the cost paths are calculated and compared. In the last step the raster with lower resolution were used to calculate in a way, that they shall result in similar paths as if the paths were computed from a high resolution raster.

3.1 Cost Raster

The cost raster contains all the costs as weights for the geographic region of the study area. The regions outside the study area are



(a) All touched: True. (b) All touched: False.

Fig. 3. Figures of the cost raster. Contrasting the for different values in all touched at a resolution of 5 m.

(a) All touched: True. (b) All touched: False.

Fig. 4. Figures of the cost raster. Contrasting the for different values in all touched at a resolution of 100 m.

given, a no-data value and will not be use for the calculation of the least cost path. It is decided to use the maximum value, for any place in the raster, that is covered by several rules at the same time. When the resolution that is use for the rasterization is smaller than the object size, than the effect of the rasterization with all touched True or False is limited. For all touched True any part of the pixel that is covered by the object, will attribute that whole pixel to the object. Thus, the object appears to be halve a pixel size larger in all directs. As can be seen in figure 3 that shows a detailed view of the costs for village of Beverstedt. Due to the maximum aggregation of the costs, the average cost of the raster of all touched true will be over estimated. All touched false will be a better description of the real size of the object.

In contrast when the resolution the is much less, than the size of the object the described behavior changes. On one hand, while the area, of the pixel is increased for all touched True, also the area for which the cost is overestimated increases. On the other hand while the pixel size for all touched False increases, not only the over estimated area increases for that pixel as describes for all touched true, but in addition the object is less probable situated in the center of the pixel. The consequence of the pixel is, that will decreasing resolution that object is not included in the rasterziation. Hence, hence for all touched false lower resolution leads ot a loss of information. Because the default is relative small compared the over effect is a underestimation of the costs. The figure 4 shows for the resolution of 100 m, that while larger are still included in the map they appear to be much larger. On the contrary smaller objects might not be included. Objects that are small on in one dimension as streets will be included in a stochastic manner. Described by the likely of that a object of that sized overlaps with the pixel center. Thus, with having larger areas and more objects, with higher costs, all touched True rasterization might more likely lead to longer roots and more likely in blocking the direct spatial path.

3.2 Least Cost Paths

For each resolution the costs paths were estimated for the rasterization with setting all_touched False and all_touched True.

The hypothetical path starts at a transformer about 6 km north the container terminal Bremerhaven and then end at a transformer in the south east of the Osterholz county.

The distance of both paths is calculated with the mean minimum distance. For every vertex P_i in the path L_1 the minimum between the vertex and the path L_2 is computed and afterwards the minimum distances are averaged (see equation 1).

$$d_{mean} = \frac{1}{|L_1|} \sum_{i=1}^{n} d_{min}(p_i, L_2) \Big| p_i \in L_1 \quad (1)$$

This equation is used, to measure the extent of similarity between the paths.

$$d_{max} = max(\sum_{i=1}^{n} d_{min}(p_i, L_2)) \Big| p_i \in L_1 \quad (2)$$

Hence, the mean minimum euclidean distance between the two paths can used to compute the similarity. As different table 2 shows the distance between the two paths decreases with increasing resolution. In addition, this tendency is depicted in figure 5 for the calculated cost paths of 5 m and 100 m resolutions.

In contrast the largest distance between the paths (see equation 2) will be used, to estimate the minimum distance to the areas that still should be examined to grantee a, that at least cost path found in this limited space is still likely to be optimal.

At the same time the differences in the aggregated costs stay almost constant. When normalize the aggregated costs by the resolution. On one hand it can be seen, that the all_touched False under estimate the costs and that this tendency scales linear with the resolution. On the other hand, the all_touched True least cost over estimates the aggregated costs on a linear scale of the resolution. Therefore, the difference for the normalized least cost paths is reduced on scale by the resolution.

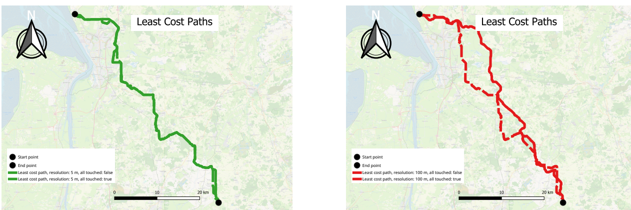
Comparing the all_touched True rasterization and all_touched False for the same resolution in contrast with the paths of all_touched False rasterization at the different resolutions the later paths are more similar. The mean average distance between the 100 m resolution run and the 5 m resolution run is 257.97 m.

The similarity of all all_touched False runs is higher than, the similar between the all_touched False and all_touched True runs with the same resolution, except for the highest resolution.

Hence, in an overall perspective paths of the all_touched False runs stay in a similar region, while paths of the all_touched True coverage strongly to the paths all_touched False runs. This behaviour is depicted in figure 6. On a more detailed level, it can be seen, that also the Paths of all_touched converges the all_touched True path. But the extent is smaller. The length of the the paths only differs to a maximum of about 10 %. The least path distance for higher

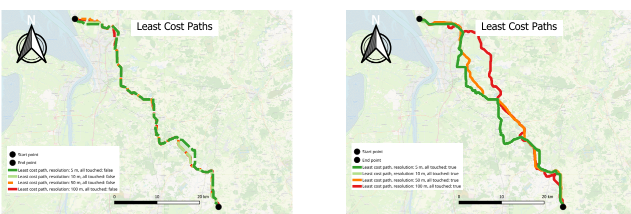
Table 2. Least cost paths as length for the different resolution (res) of the raster, including the mean minimum distance and the maximum minimum distance and the aggregated (agg.) costs. From the agg. costs the differences of the agg. costs and the corrected (corr) agg. by resolution are given.

res /m	$l_{al=f}/m$	$l_{al=t}/m$	d_{mean} /m	d_{max}/m	agg. $cost_{al=f}$	agg. $cost_{al=t}$	Δ costs	corr agg. $costs_{al=f}$	corr agg. $costs_{al=t}$
5	76136.27	78002.00	126.04	1065.00	18665.923	19616.756	-850.00	93329.60	97584.77
10	75430.10	77936.57	277.92	1590.00	8931.245	9731.175	-799.95	89312.45	97311.75
25	75422.85	78422.85	313.75	1621.15	3354.869	3872.656	-517.78	83871.73	96816.40
50	76135.02	70619,95	1140.01	4950.00	1409.023	2300.073	-891.05	70451.15	115003.65
100	76283.80	74120.73	1946.41	6016.64	640.516	1572.268	-931.70	64051.60	167226.80



(a) resolution of 5 m. (b) resolution of 100 m.

Fig. 5. Figures of the least cost paths. Contrasting the paths for different resolutions. Paths computed from all touched false raster are indicated by dashed lines. Results from all touched True are indicuated by continuous lines. Higher resolutions are indicated by the color green, lower resolutions by the color red. Using OpenStreetMaps as base map.



(a) all touched false. (b) all touched true.

Fig. 6. Figures of the least cost paths. Contrasting the changes of the least cost paths for the different results, depending on the parameter all_touched. Paths computed from all touched false raster are indicated by dashed lines. Results from all touched True are indicuated by continuous lines. Higher resolutions are indicated by the color green, lower resolutions by the color red. Using OpenStreetMaps as base map.

resolutions can be lower, because new paths, between regions that are forbidden in higher resolution can open. On the other side the length of the paths can increase, because with higher resolution more vertices will be used.

The zonal stat (see table 3) for a buffer of 100 m (5 m) around the path has been used, to estimate the percentage of which costs levels are around the path. When using all_touched True rasterization with higher resolution the tendency is to use a higher percentage of the *Preferential Level* and less the*NoRestriction* Level. The ratio of the 100 m buffered least cost path, strongly shifted to Levels lower costs.

There is no strong tendency for the all_touched False least cost paths.

3.3 Execution time

In theory, the execution time should increase with the square of the resolution, because higher resolutions result in a higher number of pixels and thus data points the aggregated costs needs to be calculated for. A full logarithmic fit for several repetitions of the execution shows, that the execution time scales with power of 2.1997 ± 0.007 of the inverse resolution. With the caveat of a low number of samples this can equally be success fully be fitted to a second degree polynomial of the inverse resolution with a r^2 for the test set of 0.99 and a the squared inverse of the resolution with a r^2 for the test set of 0.99. Hence, the order of magnitude

The total execution time consists of two parts. The aggregation of the costs and the back tracking of the least cost to find the path.

3.4 Faster Processing of the Cost Path Algorithm

The final least costs paths should between the least cost paths of the lower resolution, with a tendency to be nearer to the paths resulted by the all touched false rasterization. The first step is to optimize the calculation speed is, only to calculated the least cost paths for this smaller area. Another method, is to improve the prediction of the medium resolution itself and thus reduce the need for a computation in higher resolution.

3.4.1 Compare least cost paths, for overlay of both rasterizations. As all touched true rasterization overestimates and all touched true underestimates the real costs. A weighted mean will describe the real costs more precise. As present work indicates, that the weight should favor the all touched false raster. The best weight should be the percentage of the pixel, which is covered by the object, but this can not be computed in this work. Thus, the best weight has to be searched. An alternative might be to compute the cost raster in higher resolution, but than to reproject the to a smaller resolution with a using a (linear) interpolation of the of the weights.

While the aggregated thus can be speed up. The time needed for the back tracking stays unchanged.

The optimal ratio of overlaying all touched false and all touched true cost raster for 10 m resolution is estimated via the resulting least cost path. The mean distance of least cost paths for different ratio has been estimated to the path from the all touched false raster of the next higher (5 m) resolution. Table 4 shows, that distance decreases with the higher ratio from 1:1, 2:1, 4:1 and than increases with higher ratio 8:1, 16:1 and so on. In addition, the distances to the original paths from the all touched false and all touched true

Table 3. ratio (r) of Category percentages of each least cost path for a buff of 100 m (5 m) around the least cost path.

res /m	all touched	$r_{Preferential}\%$		$r_{NoRestriction}\%$		$r_{Restricted}\%$		$r_{stronglyRestricted}\%$		$r_{Prohibited}\%$	
5	False	4.7	(5.4)	58.7	(58.9)	8.8	(8.4)	0.7	(0.7)	27.1	(26.7)
10	False	19.6	(33.5)	68.5	(64.5)	1.0	(0.8)	0.8	(0.3)	10.1	(0.9)
25	False	19.2	(34.2)	68.9	(64.9)	1.0	(0.2)	0.7	(0.1)	9.7	(0.6)
50	False	20.4	(33.2)	68.0	(66.2)	0.9	(0.1)	0.7	(0.0)	10.1	(0.5)
100	False	21.1	(30.7)	69.1	(68.8)	1.1	(0.0)	0.7	(0.0)	7.9	(0.4)
5	True	18.9	(28.5)	67.3	(66.4)	1.3	(1.6)	1.0	(0.5)	11.5	(3.0)
10	True	18.9	(33.7)	66.6	(63.4)	1.6	(1.4)	1.4	(0.6)	11.5	(1.0)
25	True	18.7	(31.9)	65.5	(65.5)	2.0	(1.3)	2.5	(0.7)	11.4	(0.6)
50	True	9.1	(13.0)	75.7	(83.0)	3.9	(2.0)	4.2	(1.6)	7.1	(0.4)
100	True	7.0	(10.1)	73.8	(81.9)	5.5	(3.9)	8.5	(3.6)	5.2	(0.4)

raster change with the applied ratio of the overlayed raster. So that, a lower ratio increases the similarity to the path of the all touched true raster, the similarity to the paths from the all touched false raster increases with the ratio.

Table 4. Length of the path computed from the overlaying of all touched false and true raster and the mean distance of the paths to the paths calculated from the all touched false 5 m resolution and all touched false and true raster of 10 m resolution.

r	$d_{5\ al=f}$ /m	$d_{10\ al=f}$ /m	$d_{10\ al=t}$ /m
1:1	119.6	285.50	47.21
2:1	97.11	263.51	74.19
4:1	40.13	206.38	100.16
8:1	41.73	169.02	137.34
16:1	56.69	153.32	152.71
32:1	56.69	145.56	162.09
64:1	163.48	10.61	272.36

3.4.2 Compare least cost paths, for down sampled cost paths. As an alternative to the super position of the all touched true and false raster for the same resolution, the all touched false raster was down sampled to 10 m, 25 m, 50 m and 100 m with bi-linear interpolation. With this method smaller structures still can be seen in the cost raster, although the resolution is reduced. The distances of the paths that are computed from the bi-linear down sampled 5 m resolution raster (all touched false) is from table 5 shows, that a low distance to path of the 5 m resolution raster was only obtained when down sampling to a resolution not to low. Only when down sampling to a resolution of 10 m, is the computed path considerable close to the path from the higher resolution raster. Is holds true, but to a much reduced extend to the path computed from the raster, that was down sampled to a resolution of 25 m. The opposite is true for the lower resolution raster which is more similar to paths computed from the all touched true cost raster. For every path from a down sampled raster is more similar to a path computed from an all touched true raster, than an all touched false raster, although the all touched false raster of the 5 m resolution was used for down sampling.

Table 5. Length of the path computed from the bi-linear down sampled raster and the mean distance of the paths from the down sampled raster to the paths calculated from the all touched true and all touched false raster of the same resolution as the down sampled raster.

res /m	l /m	$d_{5\ m}$ /m	$d_{al=f}$ /m	$d_{al=t}$ /m
10	75980.62	59.34	219.35	143.63
25	70205.27	385.79	558.12	432.77
50	69217.86	730.82	693.42	255.70
100	66667.87	1681.3	1605.63	400.55

3.4.3 Restrict search to a buffered around the least cost paths. Construct a polygon form the two lines. Buffer the polygon with twice the max minimum path distance.

This enabled the possibility to run a 2.5 m resolution cost raster and clip it to the extent of the polygon. This clipped 2.5 m raster for all touched true did only slightly change the path. While the all touched False raster, leads to a totally new segment at the end of the path. Due to the small resolution, that a small path with the extent of about 2.5 m width became passable. This small path is a power line next to road between which build a cone in a protected landscape area. The street and the protected landscape area are both restricted areas, while the power line is preferential. This showing, that the way the cost raster is created in the first place can play a vital role, in the end result. So that a nuance, can cause a detour. When this behavior occurs, the polygon can not grantee to include the least cost path. Therefore this polygon should be overlayed with a polygon around the shortest path.

3.4.4 Examine the proposed solutions. To broaden the view and verify the current result, four different routes should be found with the presented strategies applied. Two paths form the starting point to two new points in the south east of the investigated area and two paths from the north, north east of the investigates area to the ending point.

For three of the four routes the least cost path computation from the clipped raster, was able to compute the expected result. For the forth path, the least cost path from the 5 m resolution raster was out side of the buffer around the least cost path from the 50 m resolution raster. The speed up from the clipping of the higher resolution raster depends on the amount of pixels that, have been clipped. Bi-linear down sampling the of the high resolution raster to a medium resolution, did not result in any benefits compared to an original medium resolution raster. The resolution corrected aggregated costs of the least cost path from the down sampled raster are higher, than those, from the higher 5 m resolution raster and the medium 10 m resolution raster. In addition, is the distance, from this path to the path from the high resolution raster much higher, than the distance of path from the original 10 m resolution raster to the path from the 5 m resolution raster (see table 6).

interpretation. Why result from down sampling so different? Don't know.

Table 6. Length of the path, the resolution corrected costs and the mean distance to the path created from the 5 m resolution all touched false raster for the four control routes, for the reference path of constructed from the 5 m and 10 m raster and the down 5 m to 10 m down sampled raster and the 5 m clipped raster.

Route	Method	$length/m$	$costs_{al=f}$	d_{mean} /m
P1-E	5 m	107889.58	208547.79	
	Clipped	107889.58	208547.79	0.0
	Down	96754.20	212910.95	628.05
	10 m	107232.94	203010.15	103.49
P2-E	5 m	103706.41	155567.86	
	Clipped	103706.41	155567.86	0.00
	Down	92403.29	158238.58	639.88
	10 m	104249.94	149899.72	177.68
S-P3	5 m	102187.09	34503.81	
	Clipped	90377.39	37926.14	4465.37
	Down	94125.55	37574.93	742.41
	10 m	102461.58	32445.96	81.18
S-P4	5 m	96449.22	33865.53	
	Clipped	96449.22	33865.53	0.00
	Down	87861.12	36462.72	796.40
	10 m	96739.47	31899.31	83.46

4 DISCUSSION

As shown, the need for computation time increases with the power of two with the resolution. Similarly, the usage of main memory increases. Which in tern limits the processable data points and resolution. On the error only scales linear with the resolution. Hence, there is a diminishing return of smaller errors, compared to compute time and resources used.

Therefore, this worked tries a) to reduce the needed to compute power and b) decrease the deviation for a given resolution.

For b), two methods have been used to increase the similarity of the paths computed from medium resolution raster, to the path of the highest resolution raster. These methods can be used as surrogates for the more complex calculation of the least cost path with the higher resolution. In the first method a bi-linear down sampling of the higher resolution raster has been applied and in the second method, the all touched false and true raster where averaged in different ratios, to compute the optimum mixed raster, for the used costs. While the second method of using an averaged raster, a higher similarity to the path from the highest resolution raster, the down sampling method is more simple and does not need to be optimized for the given costs. Hence, it is easier and widely applicable.

For a), to reduce the computational complexity, the calculation of the medium resolution raster has been applied, to reduce the search space of the aggregation. While this method reduces the calculation time and usage of main memory, the backtracking part stays unchanged.

As the original least cost path QGIS plug-in the used algorithm stops the least aggregation of the costs after the final end point has been found. This early stopping might result in suboptimal paths around the end points for some edge cases, where the connection via another neighbor might be more optimal.

The set of rules that are used create the cost raster, includes a rule for creating a buffer around buildings which is set to the level *prohibited* areas. The resolution of the medium level raster needs to be high enough to crudely show every detail, Hence at least in the magnitude of the minimum object size plus twice its buffer, in this example in the range of at least 25 m or 10 m to include the streets in all touched false raster. Other details as rivers and houses, ae already includes in lower resolution raster, because of the buffering. Although the overall result can change, due super position of objects and there buffer. Nevertheless, does higher resolution resemble, the geography more precise, but in addition show paths that are too small, to be taken. On the other hand, as the run from the starting point to the end point at a resolution of 2.5 m shows, new ways, that could not be reached before, do hint inconsistencies of the rules that construct the cost raster.

Object and there buffer might leave a path that, is smaller than 10 m resolution. So a second rule to find a good resolution, that it should be in the magnitude of the size of the structure to be build. While the used data set for buildings, also includes power poles, the area of the level *preferential* power grid, includes isles of high costs. In further works, these should be excluded.

In this work, the effect of computation costs and deviation of the results, is examined for a very limited set of points. Also, only the costs of finding the least cost path from one starting point, to a single end point has been considered. When, multiple endpoints are used, the computation cost for the aggregated cost raster has only to computed once. On the other hand the effect early stopping is not as dramatic, because the algorithm would only stop early for the last end point with the highest cost. When calculating several paths from one raster, the benefits of chapter 3.4 is reduced. Especially, the pre-calculation on lower resolution raster and buffering of the resulting paths as a restricted search area decreases in its effectivity. As the number of paths rises, fewer of points in higher resolution cost raster will be deselected for the final estimation of the least cost path. The least cost algorithm does only select the most cost-effective path. Therefore, paths of similar, but slightly worse cost are stay unknown. An end-user might be interested in selecting a path from a set of possible paths of similar aggregated costs and apply an adapted set evaluation criteria. This can be achieved a by adapting the backtracking, to get an array of paths or by applying perturbation on the costs.

In this work, the single cost raster layers aggregated with the maximum function. Another possible aggregation function is the sum. Each aggregation function can be justified, by a different interpretation of the costs and its scale. The reasoning of selection the maximum function is, limiting the maximum costs. When the *prohibited* level is used as the highest level. Then higher levels are *prohibited* within the concept. This an area even more *prohibited*, when it is included in two different rules of the level? On the other side, This aggregation is unable to differentiate between these nuances, as the sum function is. This way, one can differential between, different sublevels. One consequence is, that a small mediation between high and low single cost raster, in the final cost raster is possible.

The fact, that all touched False raster lead to more similar results compared to high resolution raster, is due to the fact, that the default level is relatively low. In cause the default level would rise, the effect probably would flip for low resolution raster. For high resolution raster, this effect would still hold true, because the fact, that the raster pixel center is used for sampling, reflects the original geometry better.

The fact that the differences in the costs between the paths from the all touched false to the all touched true rasters stay almost constant over the different resolution is probably due to the fact that, the costs per resolution stays in narrow range of costs. This effect of the similar aggregated costs per resolution could also be seen in the testing paths, even when the paths changed strongly with the change of resolution or algorithm applied. Which might be a hint for an evenly spatial distribution of the costs.

The all touched true cost raster show every detail, but the sampling with all touched true increases the size of the features. The fact that the aggregated costs per resolution for all touched true rasters overestimates the costs when computing the path from a low resolution raster, might be due to the fact, that the values of the costs are un-evenly distributed, but that the high costs are much more frequent differ and the costs are exponential scaled exponentially.

5 RELATED WORKS

Older models are e.g. are optimizing the well fare, economic modeling is not sufficient for planning modern routes, as the aspect of environmental sustainability, security of supply and the public acceptance more and more play an important role [17] in modern planning.

In contrast to a GIS analysis, these further factors can be studied done with a multi-criteria decision analysis (MCDA) [6].

Stakeholder as decision maker can be included and combined with an expert system [6].

The uncertainties connected with MCDA data uncertainties, preferential uncertainties and model uncertainties are examined by a with a sensitivity analysis [6] or simulation [18]. Both inter and intra criteria preferential uncertainties [19] can be considered.

The different models of the power system, that are used in the expert system span from not modeling the grid at all to models that includes Kirchhoffs laws [6]. The calculation of a power system is complex, as changing one edge will change the flow in all parts of grid and the actual grid data are confidential [6]. Some models include not only the grid of a nation alone, but consider neighboring states or the overall European power system [20].

6 CONCLUSION

The cost of computation of the least cost path scales with the square of the resolution. The difference between the aggregated costs of the paths per resolution computed from the all touched false raster and the all touched true raster only shows a linear decrease. Hence, the gain in precision per compute time decreases. The presented methods tried to circumvent this bottleneck. When using the researched strategies, on medium resolution raster, the computation for high resolution results might successfully be reduced, without compromising the run time for worse distances to the least cost path from the high resolution raster. The paths might change very strongly even with small changes in total costs. Hence to develop an alternative backtracking algorithm that, that generates a set of possible paths within a corridor of costs might be a good strategy, to offer alternative routes and show variations between these routes at the same time. An alternative method for future methods, would be to specify a range of costs and compute the aggregation of the costs and superimpose these aggregations and compute the path by backtracking from the superimposed cost raster. This in turn increases the computation time again.

In an actual search for least cost path a survey might be used as method to estimate the costs. When the sample size of the survey is large enough, the weights might take local differences relative acceptance into consideration.

Only changes in the algorithm have been applied in the search for a speed-up. There a still other methods as just-in-time compilation.

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