

# Examination of catchment areas for public transport

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## ***1. Abstract***

The paper presents an approach to examine catchment areas for stops in high quality public transport systems based on the street network in the examined area. This is achieved by implementing the Service Area function from the ArcGIS extension Network Analyst. The approach is compared to a more simple approach using only the Euclidean distance from the examined stop and the paper describes the differences in detail-level of the results. Furthermore, the paper describes how the Service Area approach can be used to examine increments in the catchment areas by adding extra entrances to stations or by making changes in the street network around the station. The paper also discusses the degree of realism in used GIS networks and how it can affect the size of the catchment areas. It is concluded that the Service Area approach improves the detail-level and accuracy in catchment area analyses. These improvements are well suited for examinations of changes in station entrances and/or street network.

*Keywords:* Catchment area, Service area, Detour factor, Street network, Accessibility, Station, Public transport

## ***2. Introduction***

High quality public transport systems like rail and light rail have fewer stops than public transport systems of lower quality e.g. bus. Because of the fewer stops it is important that the stops are located as good as possible. This means that the stops should be located in areas with a high potential of travellers in order to offer the best possible service for the public. Furthermore, this will secure that as many passengers as possible will use the public transport system. Areas with a high potential of travellers are areas with dense housing and many workplaces but also shopping areas, sport facilities and areas with entertainment (e.g. cinemas and amusement parks) can have a high potential of travellers.

Public transport systems mostly attract travellers from areas just around the stops [3] – not many passengers are willing to travel a long distance by foot, bike or car to get to the public

transport system [4]. Therefore, the amount of travellers in the public transport system is more or less proportional to the amount of people living and working just around the stops in the so-called catchment area.

The potential of travellers in the catchment area can be examined using simple GIS overlay analyses based on circular buffers around the stops (cf. section 3). However, this approach does not take into account that it is rarely possible to travel as the crow flies in urbanized area with many physical obstacles and barriers. By using a method that searches a street network (referred to as the Service Area approach) it is possible to calculate travel routes to and from stops and thereby improve the accuracy compared to the simple buffers (cf. section 4). The two approaches to determine catchment areas are then compared (cf. section 5).

As the stops are the passenger's gateway to the public transport system it is important that it is easy to get to and from the stop. For some transport systems such as railways, the stop can have a certain geographical extent (e.g. most of the stations of the Copenhagen suburban railway are about 200 meters long). By adding entrances in both ends of the platform, the accessibility to the station can be improved and the catchment area thereby increased (cf. section 6).

It is not only the number of entrances to a given station which determines the size of the catchment area; also the streets surrounding the stop are an important aspect. By using Service Areas instead of simple circular buffers around the stops it is possible to analyze how the layout of the streets influences on the size of the catchment area. Furthermore, it is possible to analyze how changes in the layout of the streets can improve accessibilities to stops (cf. section 6)

Making catchment areas by searching a street network requires a high degree of realism meaning a high level of detail in the used GIS network in order to get reasonable catchment areas. Furthermore, some features in networks can have a rather inappropriate influence on network search e.g. double digitized roads. Generally it is important that the GIS network used in the Service Area calculation represent the routes of the feeder traffic to and from stops as well as possible (cf. section 7).

### ***3. Circular buffer approach***

The simplest way to analyze the potential number of travellers for a stop is to consider the Euclidean distance from the stop. Given a stop's location and detailed information on the stops neighbourhood, like a land-use map or a map with buildings, it is possible to examine the area within a certain distance of the stop. When using GIS this can be achieved in two simple (geoprocessing) steps:

1. Making a circular buffer around the station
2. Intersecting the buffer with the maps describing the neighbourhood

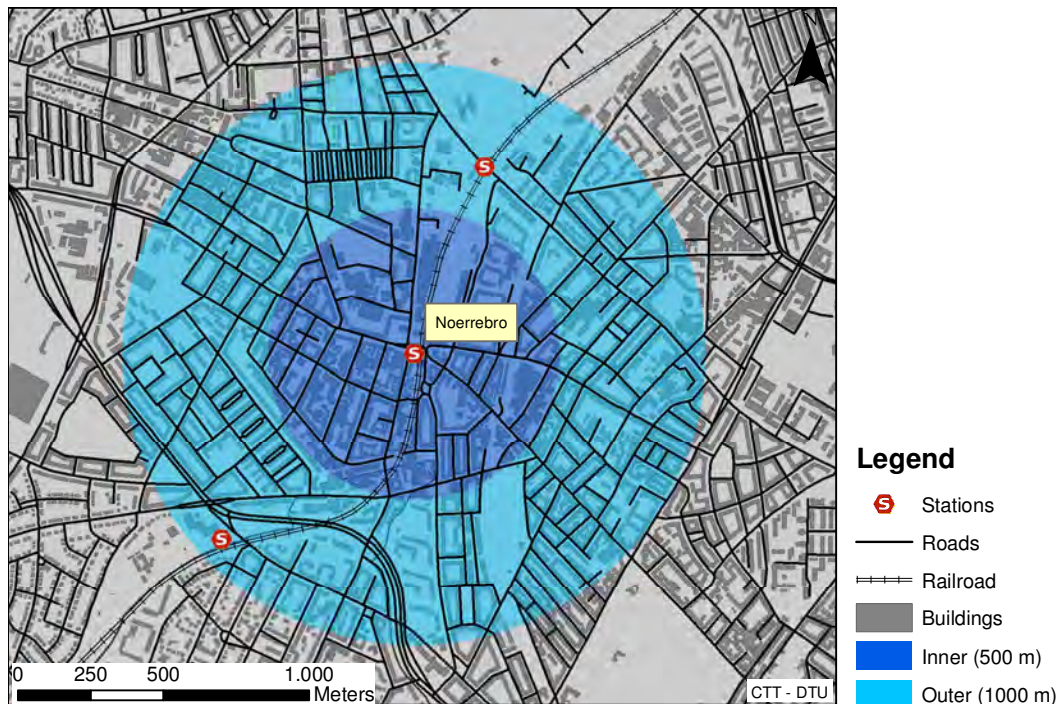
Afterwards different land-use areas or buildings within the buffer can be examined and if data on e.g. population and workplace density is available it is possible to calculate a measure for the potential number of travellers<sup>1</sup>.

At Centre for Traffic and Transport (CTT) at the Technical University of Denmark (DTU) this simple approach has been used the last couple of years to examine and optimize stop locations along new railway and light rail lines (e.g. [1]). Often the level of detail in the method has been increased by dividing the catchment area into different rings depending on distance to the station (e.g. [1]). By applying weights for each ring it is possible to take into account that the expected share of potential travellers will drop when the distance to the stop is increased.

Figure 1 shows the calculated catchment area for Noerrebro Station in Copenhagen. The catchment area is divided into an inner and outer ring, often characterized as primary and secondary catchment area and the distances are (in this case) set to 500 and 1,000 meters (as [5] suggest).

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<sup>1</sup> Population and workplaces can be used to determine the potential number of travellers as they are a large and regular cause for transportation e.g. [7]. But also other relevant causes for transportation can be used in analyses of potential travellers [8]. Information can be obtained through sources like the Danish HSK, CVR, BBR or CPR.



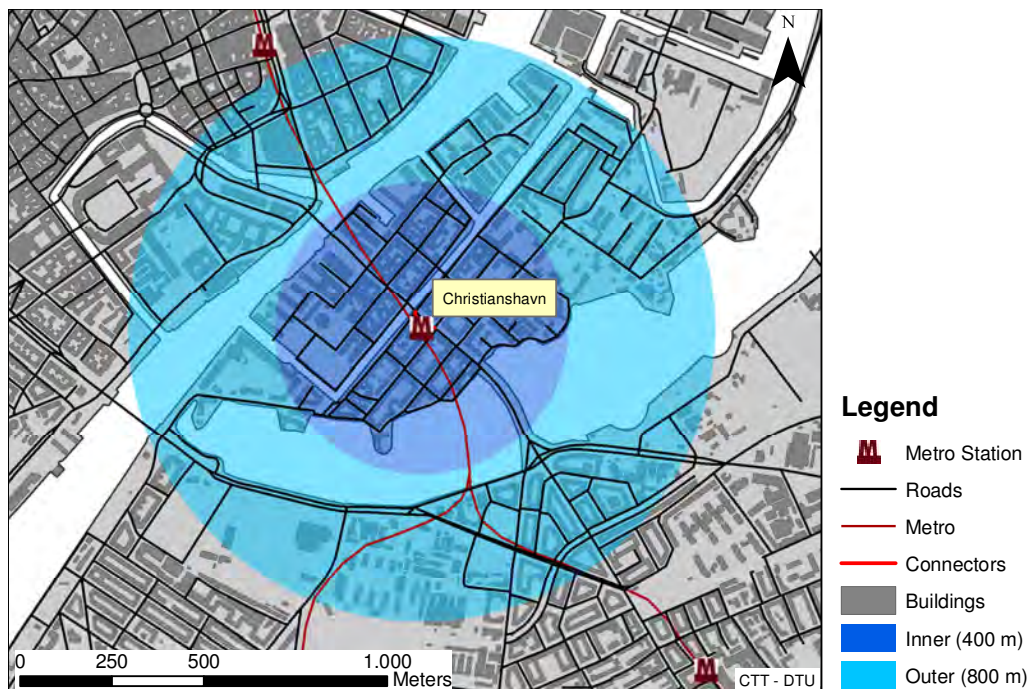
**Figure 1 – Catchment area determined by circular buffer approach for Noerrebro Station in Copenhagen**

The number of rings and the distances for each ring varies on the type of project and the accepted detail level for the results. Overall the catchment area should cover the distance, it seems reasonable to walk or cycle to get access to the public transport system. This distance depends on the type of transport system. A high quality transport system like regional trains will normally have larger catchment areas than lower quality systems like light rail. The expected shares of potential travellers in each ring can then be determined based on market share investigations.

### **3.1. Weakness of the circular buffer approach**

Even though the circular buffer approach is a fairly good way of examining the catchment areas for stops it has a weakness. The method does not take the stops geographical surroundings into account. In most cases the actual walking distance from a certain location to a stop is somewhat longer than the direct Euclidean distance. The reasons for this can be found in both natural barriers like rivers, but also manmade obstacles like buildings, canals and rail tracks. This disadvantage in the approach is often handled by applying a detour factor that reduces the buffer distance and in this way compensates for the fact that people have to walk longer in the actual street network. However, in cases where the length of the detours varies a lot within the stop surroundings, this solution is not very precise. Furthermore areas which are separated completely from the stop by e.g. rivers can still be considered as part of the stops catchment area.

Figure 2 shows the catchment area for Christianshavn Metro Station in Copenhagen examined by the circular buffer approach. Some parts of the catchment area are partly isolated from the station by the harbour, the canals and the lakes in the district. The actual distance from these parts to the metro station is longer than the assumed distance that people are willing to travel. Hence, these parts should not be regarded as part of the catchment area.



**Figure 2 – Catchment area determined by circular buffer approach for Christianshavn Metro Station in Copenhagen**

#### **4. Service Area approach**

Using Network Analyst Service Area function for ArcGIS<sup>2</sup> it is possible to apply a more accurate method to determine the catchment areas for stops than with the circular buffer approach (cf. section 3). In most cases, the road and path network in a city will give a good approximation of the actual walking distance between two locations. The Service Area approach makes it possible to create buffers (or service areas) based on the street network. The Service Area function calculates buffers by determining a point in each branch of the network based on the impedance of each link and interpolating these branch points.

The Service Area approach requires a network dataset. This dataset must be based on a detailed road map describing the streets and paths around the stop. Furthermore, it is necessary to connect the stops to the street network (if the stops are not located directly in the network nodes). This is done by creating connector links between the stop and the surrounding road network. Figure 3 shows how the suburban train station Oesterport in

<sup>2</sup> Other GIS software have similar functions

Copenhagen is connected to the surrounding road network in the calculations. To make the results as accurate as possible the connectors should resemble the actual station entrances. This is achieved by digitizing the connectors to the points in the road network where actual entrances are. Finally it is necessary to specify the impedance in the network dataset. In this paper the length on each road link is used but in other cases this could be the walking time instead. For the connectors the impedance is set to 0. In this way the buffers are calculated as the chosen distance from each entrance.

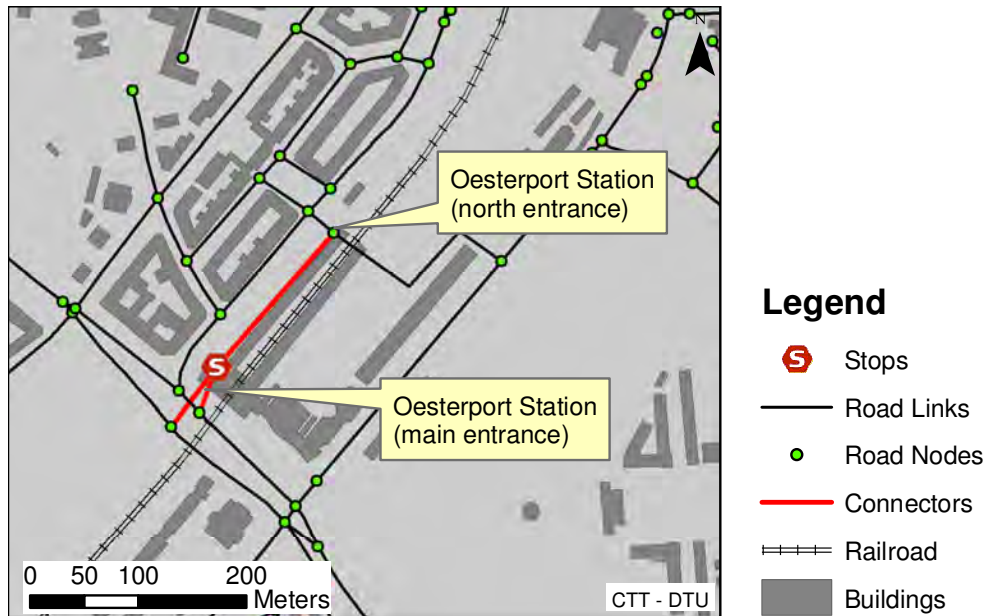


Figure 3 – The digitalizing of entrances for Oesterport Station in Copenhagen

When the network dataset is build the catchment area can be calculated. In figure 4 is illustrated how a simple ArcGIS geoprocessing model can be set up to perform the calculations.

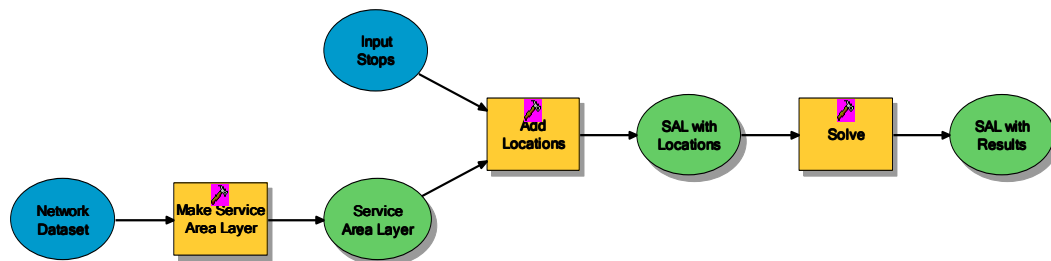
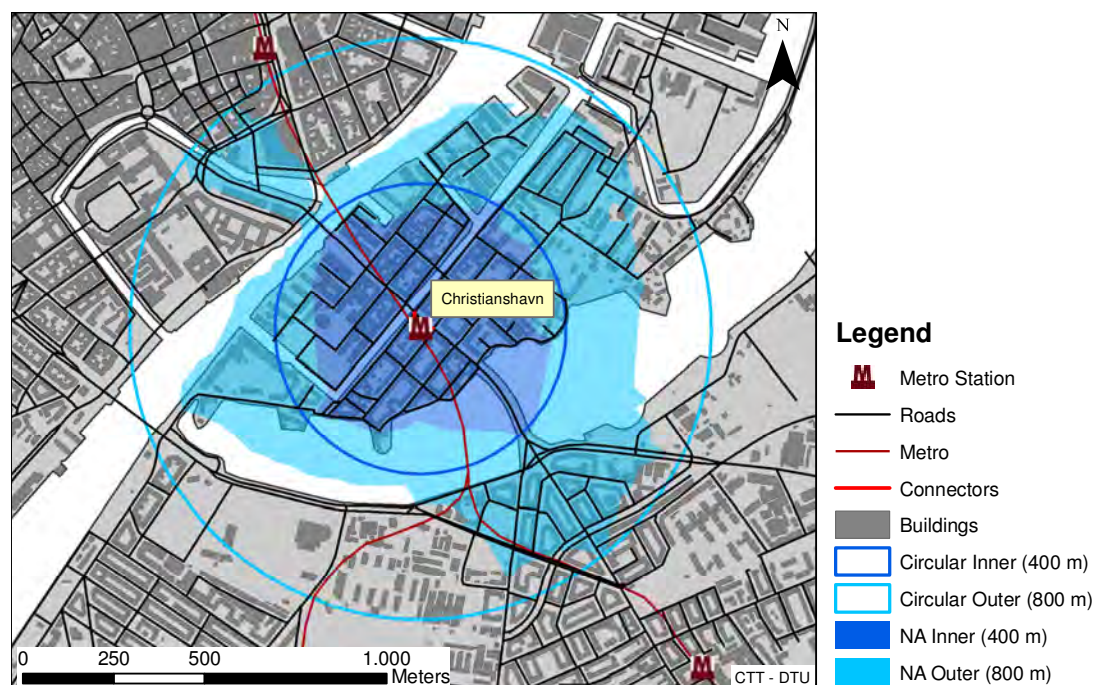


Figure 4 – ArcGIS Service Area Geoprocessing model to calculate catchment areas around stops

Figure 5 shows the catchment area for Christianshavn Metro Station calculated with the Service Area approach. Like for the circular buffers shown in figure 2 it is chosen to divide the catchment area into an inner and outer buffer. The shape of the calculated buffers now corresponds to the road network around them. Furthermore, it can be seen that some of the

areas which in the circular buffer approach was considered within the catchment area are excluded in the Service Area approach. This is due to the limited possibilities for crossing the lakes and canals and corresponds with the fact that people in these excluded areas do not have good access to Christianshavn station.



**Figure 5 – Catchment area determined by Service Area approach for Christianshavn Metro Station in Copenhagen**

## 5. Comparison of the two approaches

As described above the results of the two approaches differs somewhat. The circular buffer approach (cf. section 3) considers all locations within the chosen distance from the stop to be within the catchment area. The Service Area approach (cf. section 4) will exclude some of these locations due to the geographical surroundings and the detours people have to walk in the actual street network. This means that the circular buffer approach consistently overestimates the size of catchment area and thereby often also the potential number of travellers. When using the circular buffer approach this is sometimes handled by applying a detour factor on the buffer distance. The detour factor is depending on the layout of the streets and geographical barriers in the stops surroundings. Since this can vary a lot from stop to stop and from city to city it is very doubtful that one detour factor can be applied to improve the accuracy of the circular buffer approach in general.

To examine the variation of the detour factor, table 1 shows catchment areas calculated for some selected stations in the Copenhagen area with both the circular buffer approach and the Service Area approach. The proportion between the size of the catchment area calculated by the circular buffer approach and the Service Area approach is also shown in table 1.

<b>Station</b>	<b>Area</b> (600m Circular Buffer)	<b>Area</b> (600m Service Area Buffer)	<b>Proportion</b>
Bispebjerg (S-tog)	1,130,970 m <sup>2</sup>	419,879 m <sup>2</sup>	0.37
Charlottenlund (S-tog)	1,130,970 m <sup>2</sup>	728,505 m <sup>2</sup>	0.64
Christianshavn (Metro)	1,130,970 m <sup>2</sup>	663,117 m <sup>2</sup>	0.59
Dybboelsbro(S-tog)	1,130,970 m <sup>2</sup>	596,301 m <sup>2</sup>	0.53
Hellerup (S-tog)	1,130,970 m <sup>2</sup>	855,473 m <sup>2</sup>	0.76
Jaegersborg (S-tog)	1,130,970 m <sup>2</sup>	652,961 m <sup>2</sup>	0.58
Nordhavn (S-tog)*	1,226,513 m <sup>2</sup>	671,198 m <sup>2</sup>	0.53
Noerrebro (S-tog)	1,130,970 m <sup>2</sup>	842,050 m <sup>2</sup>	0.74
Oesterport (S-tog)*	1,327,989 m <sup>2</sup>	709,205 m <sup>2</sup>	0.54
Sjæloer (S-tog)	1,130,970 m <sup>2</sup>	715,351 m <sup>2</sup>	0.63
Svanemoellen (S-tog)	1,130,970 m <sup>2</sup>	703,817 m <sup>2</sup>	0.62
Sydhavn (S-tog)	1,130,970 m <sup>2</sup>	654,828 m <sup>2</sup>	0.58

(\*) Station has more than one entrance

**Table 1 – Proportions between the sizes of the catchment area calculated with the circular buffer approach and Service Area approach for a number of stations in the Copenhagen area.**

Table 1 show that the proportion between the circular buffer approach and the Service Area approach vary a lot from 0.37 to 0.75. This variation indicates that it is not possible to apply one general detour factor to improve the circular buffer approach (also [6] shows this tendency). Instead a method like the Service Area approach where the actual geographical surroundings are included in the calculations is preferable.

## **6. Increasing the catchment area**

As the catchment area is the area from where (most of) the passengers have origin or destination, it is important for the bus or train operators to have as large a catchment area as possible. The Copenhagen suburban rail operator (DSB S-tog) has found out that the primary catchment area is a 600 meter circular buffer from the stations entrance [2] ([9] works with a catchment area between 400 and 800 meters).

### **6.1. Additional entrances to stations**

Many of the stations at the Copenhagen suburban rail network only have one entrance to the station (in one end of the platform). By establishing an extra entrance in the other end of the platform – about 200 meters away – an additional 20% is added to the primary catchment area if using a 600 meter circular buffer approach [2], cf. figure 6.



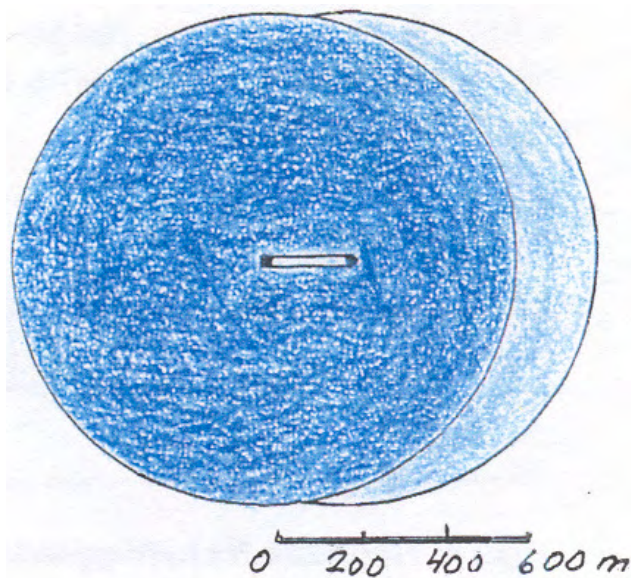


Figure 6 – Catchment area of one versus two entrances to the station [2]

Additional entrances to stations can extend the calculated catchment area for both circular buffers and buffers calculated by the Service Area approach. Figure 7 shows the extension of the catchment area for Herlev Station when adding an extra entrance. The catchment area is calculated for both circular buffers and Service Areas.

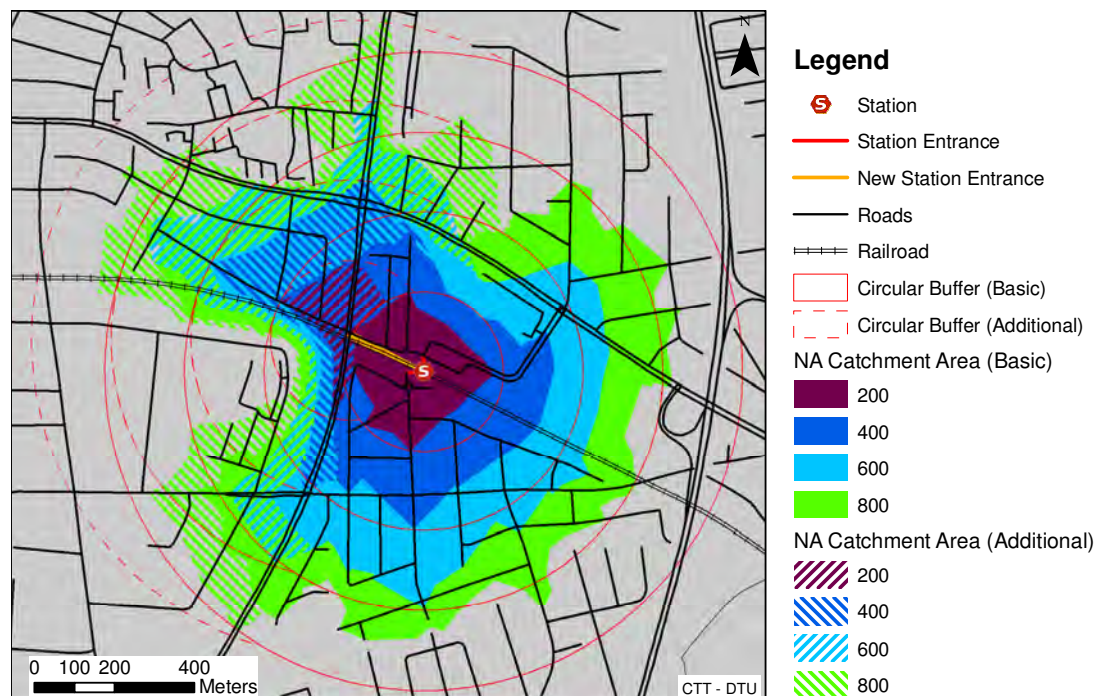


Figure 7 – Change in catchment area when an additional entrance is established at Herlev Station

Figure 7 shows that the catchment area at Herlev Station is extended when an additional entrance is established. In this case the catchment area at Herlev Station is extended by 25% when calculating the catchment area as a 600 meter distance by the Service Area approach.

The 25% extension of the 600 meter catchment area is larger than the 20% extension as the circular buffer situation described (cf. figure 6). The larger extension (in this case) is due to the layout of the street network but in other situations the extension might be smaller than 20% due to another layout of the street network. Increments in catchment areas when establishing an extra entrance to a station are always fixed using the circular buffer approach, while it varies depending on the layout of the streets in the stations surroundings when using the Service Area approach.

The difference of the Service Area buffers when adding an extra entrance to Herlev station is illustrated in figure 8.

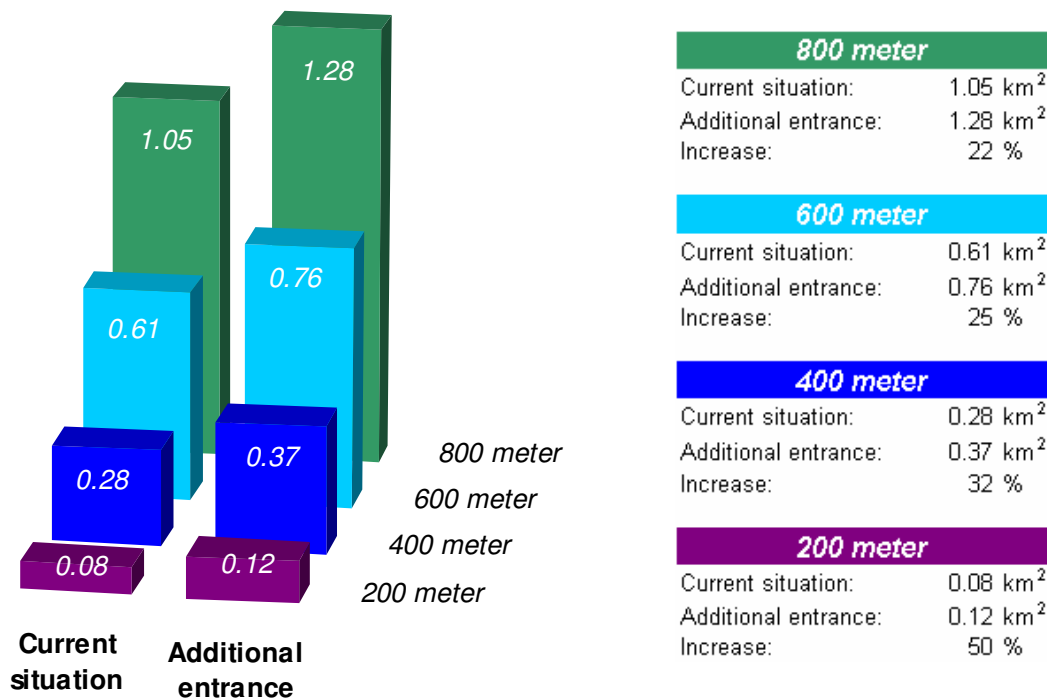
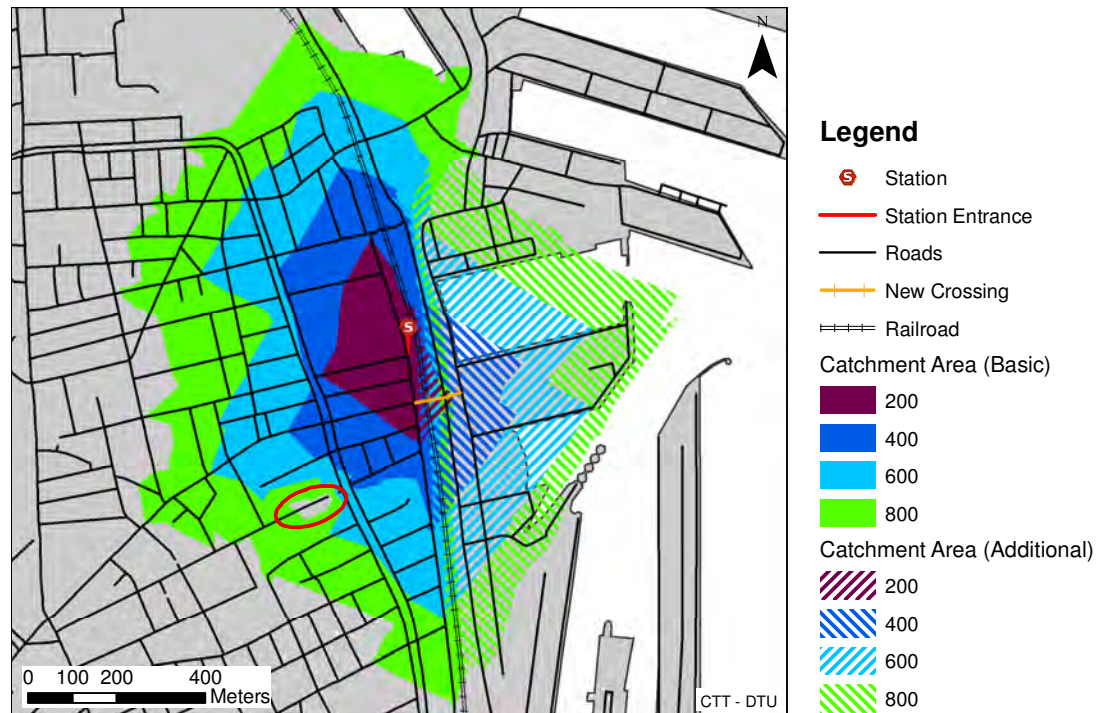


Figure 8 – Change in size of the catchment area when an additional entrance is established at Herlev Station. Calculated by the Service Area approach

## 6.2. Improving the general accessibility to stops

The catchment area can not only be extended by establishing extra entrances to the stops – it is also possible to extend the catchment area by improving the general accessibility to the stop. This can be achieved by changes in the layout of the streets surrounding the stop. Improving the actual street network can result in shorter and thereby faster access to the stop if e.g. a bridge or a tunnel is established to cross a barrier like a railway or a river/stream.

Figure 9 shows the effect of the catchment area calculated with the Service Area approach with and without the combined bridge and tunnel across the railway at Nordhavn Station<sup>3</sup>.



**Figure 9 – Catchment area calculated by the Service Area approach with and without a tunnel/bridge to cross the tracks at Nordhavn Station**

Figure 9 shows that the catchment area at Nordhavn Station is much larger with the combined tunnel and bridge across the railway at Nordhavn Station<sup>4</sup>. Besides the catchment area extension it is also shown that there might be gaps inside the catchment area which are not included in the catchment area hence the layout of the street network results in a long way to the station; perhaps due to missing links in the network cf. the red circle on figure 9.

Increments of catchment areas by improvements of the street network in a stops surroundings are possible to examine through the Service Area approach while the circular buffer approach will not show any changes in the catchment area.

## 7. Street Network

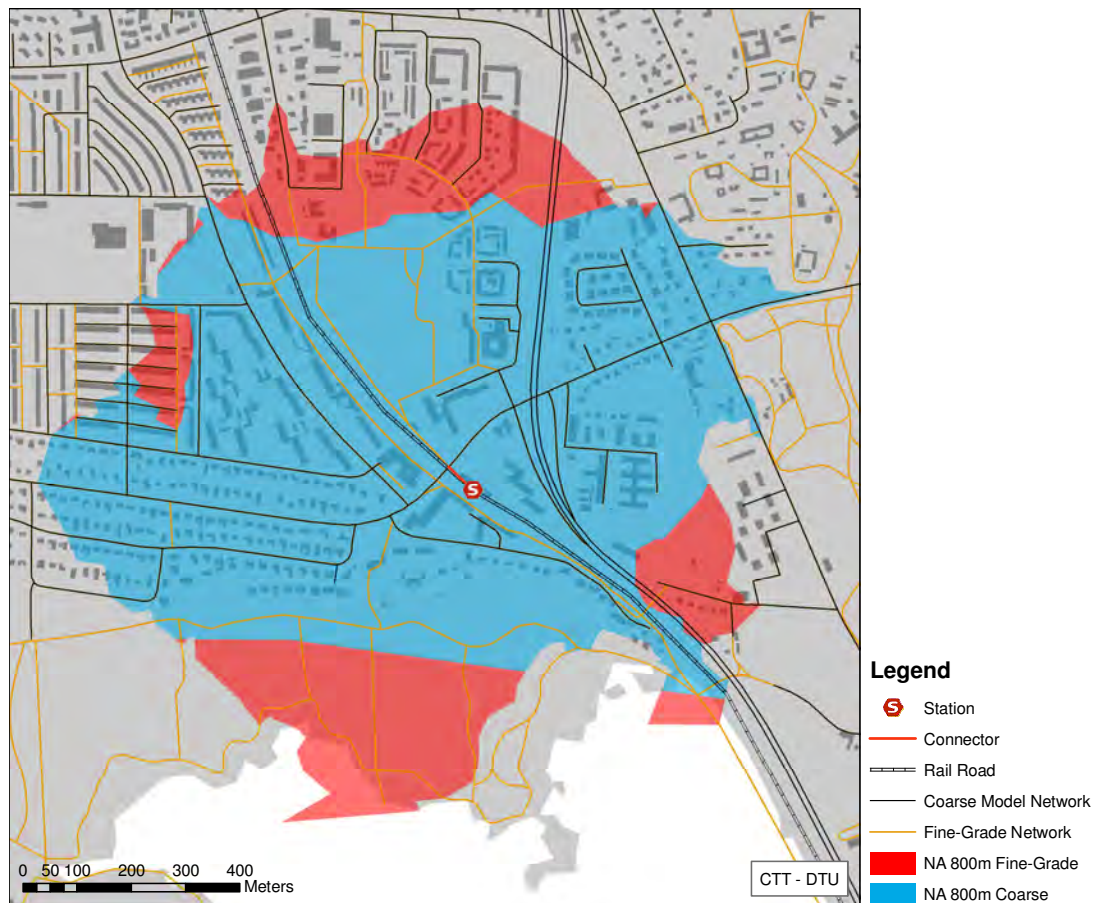
Giving that the Service Area is calculated by route searches in the implemented street network, the realism of the result is dependent on the quality of the used GIS network and how well the network represents the actual routes of the feeder traffic to and from the station.

<sup>3</sup> This combined tunnel and bridge exists today but it has been temporarily removed in the past due to reconstructions of tracks and roads in the area

<sup>4</sup> Impedance of stairs is left out of consideration

## 7.1. Degree of detail

GIS networks can have limitations. For example are minor local streets often excluded in traffic model networks because they are not needed for regional modeling. Furthermore, walk and bicycling are usually the predominantly mode of transportation between the station and the catchment area (e.g. [2] and [9]) and the feeder traffic is, therefore, not only limited to the street network as the motorized traffic. Walking and cycling paths can be used for the feeder purpose as well as the traditional street network. This means that the result of the Service Area network search is very much dependent on the degree of detail in the network and it is recommended that all local streets, walking and cycling paths are included in the used network<sup>5</sup>.



**Figure 10 – A more detailed network increases the catchment area at Sorgenfri station**

A more detailed network is not only more realistic it can also increase the catchment area as seen in figure 10 at Sorgenfri station. Here local streets and larger paths are implemented in the network<sup>6</sup> and the catchment area calculated by the Service Area approach increases when using this fine-grade network compared to the catchment area when using a traditional model

<sup>5</sup> This also means that major roads such as motorways should be excluded in the network search because they do not support conditions for soft road users

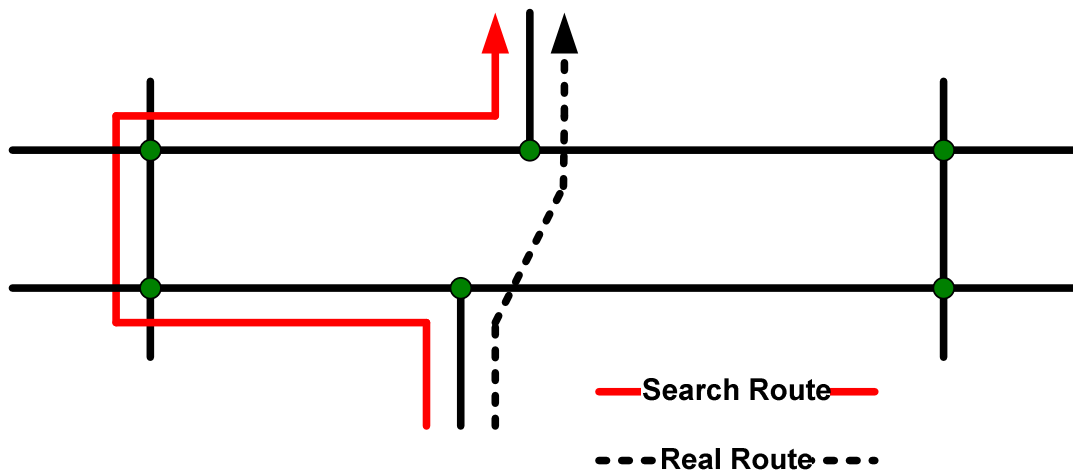
<sup>6</sup> The detailed network is based on the Krak KDV-map of Denmark

street network. In the northern part, the catchment area increases because minor local streets are implemented and in the southern part it increases because paths are included in the network. When calculating potential travellers the increase in the southern part of Sorgenfri station catchment area will have a very little influence (if any) because the increased area is a forest with very few regular potential travellers; thus increments of catchment areas are most relevant in urban areas as in the northern part of the catchment area at Sorgenfri station. However, the case could be that there was an urban area behind the forest and in such a case the additional catchment area could be relevant.

Detailed networks have high importance for the size and the realism of the Service Area calculated catchment area. But one should keep in mind that networks generally are not fully covering the actual routes of the feeder traffic. Travellers often avoid detours by creating their own small paths and sometimes such short cuts can make important connections that do not exist in even very detailed networks. Those connections can have a significant influence on the realism and size of the catchment area. As in many other aspects the best way to obtain the needed information of the network is by observations. Observing the catchment area can reveal those small short cut paths and it is then afterwards possible to implement them in the used GIS network.

## **7.2. Double digitized roads**

Another issue by using Service Area street network search is the double digitized roads. In GIS networks, roads can be double digitized with a link for each direction of traffic. It is rarely used on ordinary two-lane roads because the lanes are not separated and modeling links can be bi-directional. However, in street networks double digitized roads are often used for roads with four lanes or more. Primarily when the directional lanes are physically separated; for example by a central grass verge which is the case on many four-lane roads. This can be a problem in the Service Area street network search. If a four-lane street has a central grass verge it can be used as an island for crossing pedestrians or cyclist. This means that soft road users can cross the street in a straight line. When using the Service Area approach, the searched route has to follow the network. Therefore, the crossing of double digitized streets has to be done through crossing links; possibly forcing the search route on a practical detour as sketch in figure 11.



**Figure 11 – Service Area network search dilemma on double digitized roads**

In such cases the outcome will be a smaller catchment area than the actual catchment area.

However, it is important with knowledge of the implemented double digitized roads. Many four-lane streets are indeed separated by a central grass verge offering good crossing possibilities for the soft road users. For example this is the case on Strandboulevarden close to Nordhavn station. But some four-lane roads actually have the directional lanes separated by a central fence or crash barrier making soft road user crossing almost impossible<sup>7</sup>.

If the network is connected so that crossing of double digitized roads is possible; the catchment area calculated by the Service Area approach might increase as seen on figure 12. Strandboulevarden near Nordhavn station has a central grass verge and is relatively easy to cross for soft road users.

<sup>7</sup> Note also that on some double digitized roads traffic can be so massive that soft road user crossings are preferable at signalized intersections or pedestrian crosswalks; hence it might be realistic that the network search is forced through existing road links for crossing

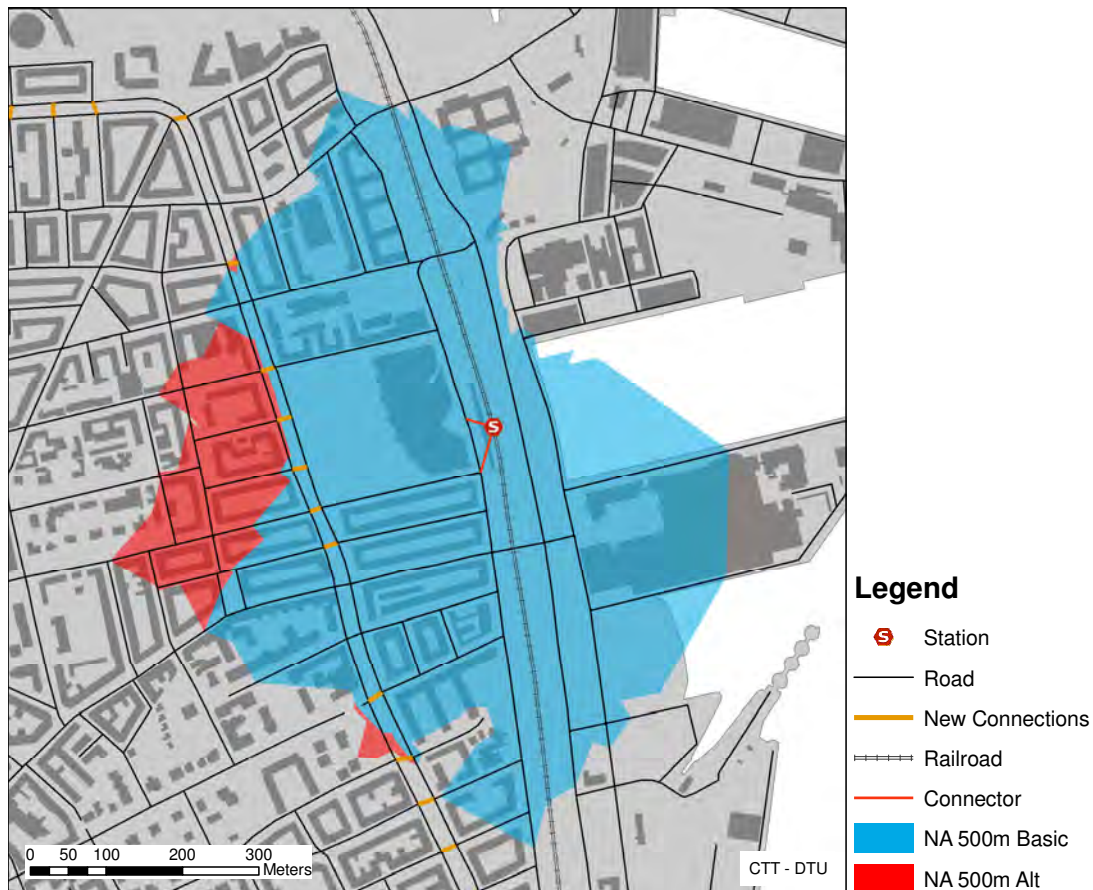


Figure 12 – Crossings of a double digitized road increases the catchment area at Nordhavn station

## 8. Conclusions

For some years GIS-analyses have been used in the planning process when new stops on e.g. railway lines had to be placed. Using GIS-analyses to place new stops made it possible to place the stops near as many households and workplaces as possible. However, the catchment area of households and workplaces has been calculated as the direct Euclidean buffer distance. Since travel in urbanized areas often is obstructed by physical obstacles and barriers, using a direct Euclidean distance will over estimate the size of the catchment area and thereby the number of potential travellers. This has traditionally been corrected (if at all) by a detour factor reducing the radius of the circular catchment area (catchment areas are sometimes also corrected manually if some kind of barrier has an influence that can not be ignored).

The paper has shown that the detour factor can vary significantly from stop to stop in Copenhagen. Therefore, the traditional circular buffer approach is inaccurate. Fortunately the Service Area approach can calculate the catchment area by travel distance in a street network instead of the Euclidean distance. Using the Service Area approach can improve the accuracy in catchment area calculation if a detailed network is available.

Just like the circular buffer approach the Service Area approach can also calculate the extension of the catchment area by adding an additional entrance to a station. However, the extension in percent using the circular buffer approach and the Service Area approach is not necessarily the same. This is because the layout of the street network is included in the calculations. If it is difficult to get to and from the new station entrance, the catchment area will only be slightly extended using the Service Area approach. On the other hand, if the accessibility to the station is much better at the new station entrance than the old entrance, the proportion of the extension of the catchment area might be larger using the Service Area approach than using the circular buffer approach.

As the Service Area approach uses the street network to calculate the catchment area, it is possible to analyse the improved/worsened accessibility to the stop when changes in the street network is made. The paper has shown that it is possible to extend the catchment area (using the Service Area approach) by making it easier to cross barriers.

The paper has shown that using detailed GIS networks can have an increasing influence on the catchment areas when using the Service Area network search. The more the used network represents the actual routes of the feeder traffic to and from the station the more realistic is the method and when using the Service Area approach for catchment areas it is, therefore, important with a detailed GIS network.

The overall conclusion of this paper is that the accuracy of calculating catchment areas can be improved by using the Service Area approach instead of circular buffers. Furthermore, the Service Area approach makes it possible to examine changes in size of the catchment area when changing the street network – an analysis which was not possible using the circular buffer approach.

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