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MASTER'S THESIS

Spatial Resolution of Transport Analysis Zones and Quality of Traffic Assignment: Comparing the Limit of Disaggregation in Different Study Areas

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Adnan Raees

Abstract

In Macroscopic travel demand modeling, the spatial resolution of a transport analysis zone has greater influence on traffic assignment results and model performance. Traffic assignment in macroscopic models designates trips from spatial zones to transport network via centroid connectors. The initial contact on the network is generally the closest point to centroid and then continues through the least resistance path towards destination zone. Consideration of coarser zones will lead many trips to be connected to the network at wrong points and as a result assigned to the wrong paths.

Disaggregation of transport analysis zones should therefore, improve the quality of traffic assignment results. However, as the transport network does not grow as the transport analysis zones get finer, a limit is expected, beyond which further disaggregation of zone´s spatial resolution will not result in significant improvement to the assignment results. The objective of this thesis is to assess and compare the transferability of the limit of disaggregation of zones across different study areas by using the gradual rasterization process. Each study area will be divided into multiple zone systems at different levels of spatial resolution and the limit of disaggregation will be defined by comparing the traffic assignment results from different zone systems, and then compared across different study areas. For this purpose, PTV VISUM and ArcGIS will be used for computation of network volumes and number of intrazonal trips and will then be analyzed and compared across different study areas to find an appropriate resolution of a zone system.

Declaration

I hereby declare that this thesis is the outcome of my own efforts and has not been published anywhere else before and not used in any other examination. Also, to mention that the materials and methods used and quoted in this thesis has been properly referenced and acknowledged.

Place and dated: Munich, 28.02.2018 Signature: ________________

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1. Introduction

1.1 Background

In this contemporary world, the disaggregation of cities and regions carries immense materiality in terms of urban and transportation planning, and regional analysis. Regional boundaries play a great deal in policy making and transportation planning. The distinguishing of cities and regions is clearly a complex system and to represent this system requires complex mathematical and computer modeling with the help of which effective and productive analysis and planning can be carried out (Wilson A. G., 2000).

For the purpose of transport modelling and to have a systematic study of mobility and transport, the main step involved is the disaggregation of study area into Transport Analysis Zones (TAZs) (McNally, 2007). These TAZs carry spatial properties of the respective study area and has greater impact on the results of transport planning models (Board, 1981).

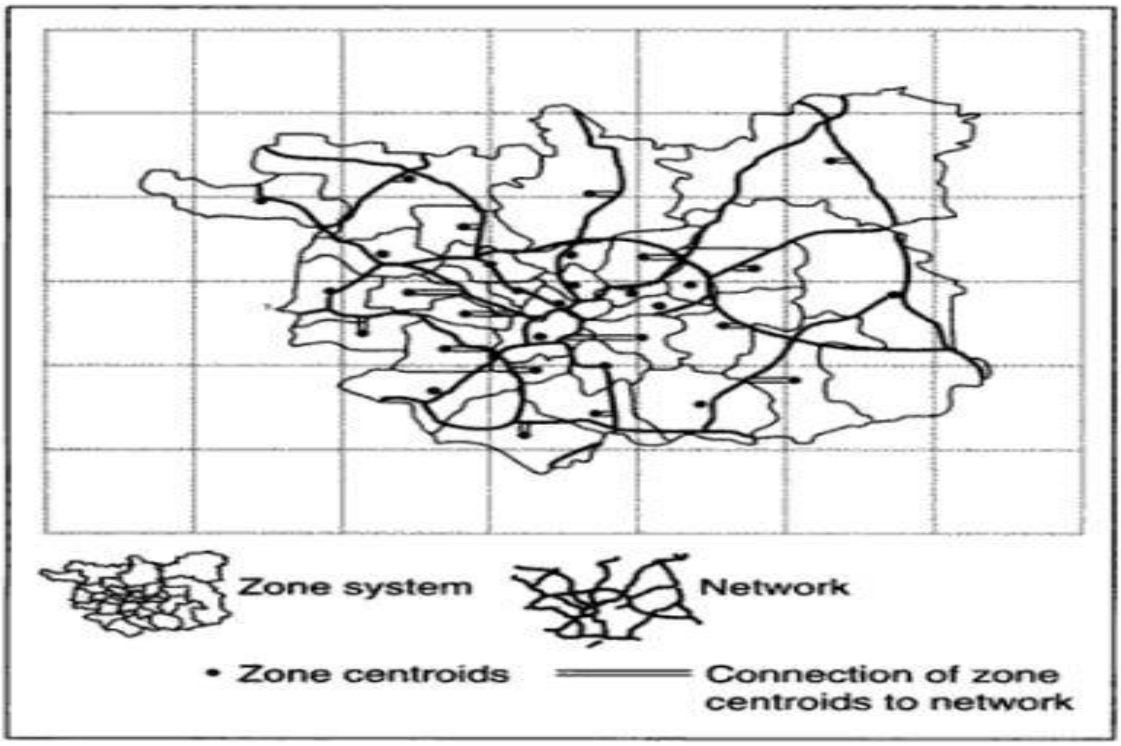

Figure 1: A Zone System with Nodes and Networks

Source: (Wilson A. G., 2000, p. 17)

The spatial resolution of transport analysis zones is a key component in the augmentation of any transport model. The size and number of distributed zones has greater influence on the efficiency of modelling procedure, effecting the accuracy and computational easiness of the transport model (Molly & Moeckel, 2017). The size of the zones has a direct repercussion on the traffic volumes, on the links of the network. Traffic assignment assigns the trips from the centroid of the zones to the nearest network link. So, if the size of the zone is scatological, it will assign the trips to the network at a misguided path and position. Finer the zones, it will find the shortest connecter to assign the trips on the network but then there will be a restraint of the disaggregation of zones, after which there will be no effect on the results of traffic assignment. In a report by Woods & Stover (1967), the traffic assignment on the network in a small-zone system differed approximately by 10 percent when set side by side to the medium sized zone systems. The relative disparity was greater with the large size zone systems. However, there was a downturn of intrazonal trips in larger zone systems.

1.2 Problem Statement

Ever since the distribution of the regions have begun, very little interest has been taken on the size of distribution of the region as a geographical entity, though the geographical entity carries within itself the definition and nature of the spatial object (Chapman, 1977). The segments in a zoning system represents defined entities that can be treated for observation and measurement of different spatial complications. In spatial analysis, the data collected for the objects of study forms the definition of spatial objects which can be capitalized to measure their characteristics. The barriers over exemplifying the suitable size of a zone system hold big methodological difficulties such as the 'modifiable areal unit problem (Openshaw, The Modifiable Areal Unit Problem, Concepts and Techniques in Modern Geography 38, 1984).

To conquer these spatial barriers, the compulsion to consult the geographic information systems (GIS) can play a great role. A unification of spatial elements such as raster and vector representations in geographic information systems would possibly conduct in conformity with spatial disaggregate models reducing the shortcomings of zone systems. According to Spiekermann & Wegener (2000), the applicability of spatial interpolation techniques can help in disaggregation of zones into raster representation which will lead to calculation of micro-scale indicators such as accessibility. Similarly, the vector spatial elements of transport networks that are accumulated from transport models can lead to efficient network algorithms such as minimal route search, mode and path choice and traffic assignment.

The clarification of a convenient zonal system for transportation modelling is the key to overthrow the spatial analytical problems that the transport modelers are facing, and a criterion should be set to define an appropriate resolution of zones in a zonal system.

1.3 Research Objectives

The objective of this research work is:

- To practice the gradual rasterization process across different study areas to form different zone systems which will be later modelled and analyzed and to improve the programming script of gradual rasterization process.
- To assign traffic on the zone systems created by gradual rasterization process and to compute network volumes on the network.
- To compare the network volumes on the links, number of zones and intrazonal trips within a zone because of different zone systems for every study area and correlation in between these study areas.
- To analyze a criterion to define an appropriate spatial resolution of Transport Analysis Zones (TAZ) depending on the comparison of quality of traffic assignment and number of raster cells across different study areas.

1.4 Research Methodology

Research is a systematic academic activity to gain the unfamiliar knowledge from the known and the process of solving a research process in a systematic way is known as Research Methodology (Kothari, 2004). Research methodology contains several significant steps which are mandatory to accomplish the desired research objectives, similarly a general but specific and systematic approach is chosen to achieve the desired goals of this thesis. A general synopsis of the methodological process to conduct this research is given in the below diagram:

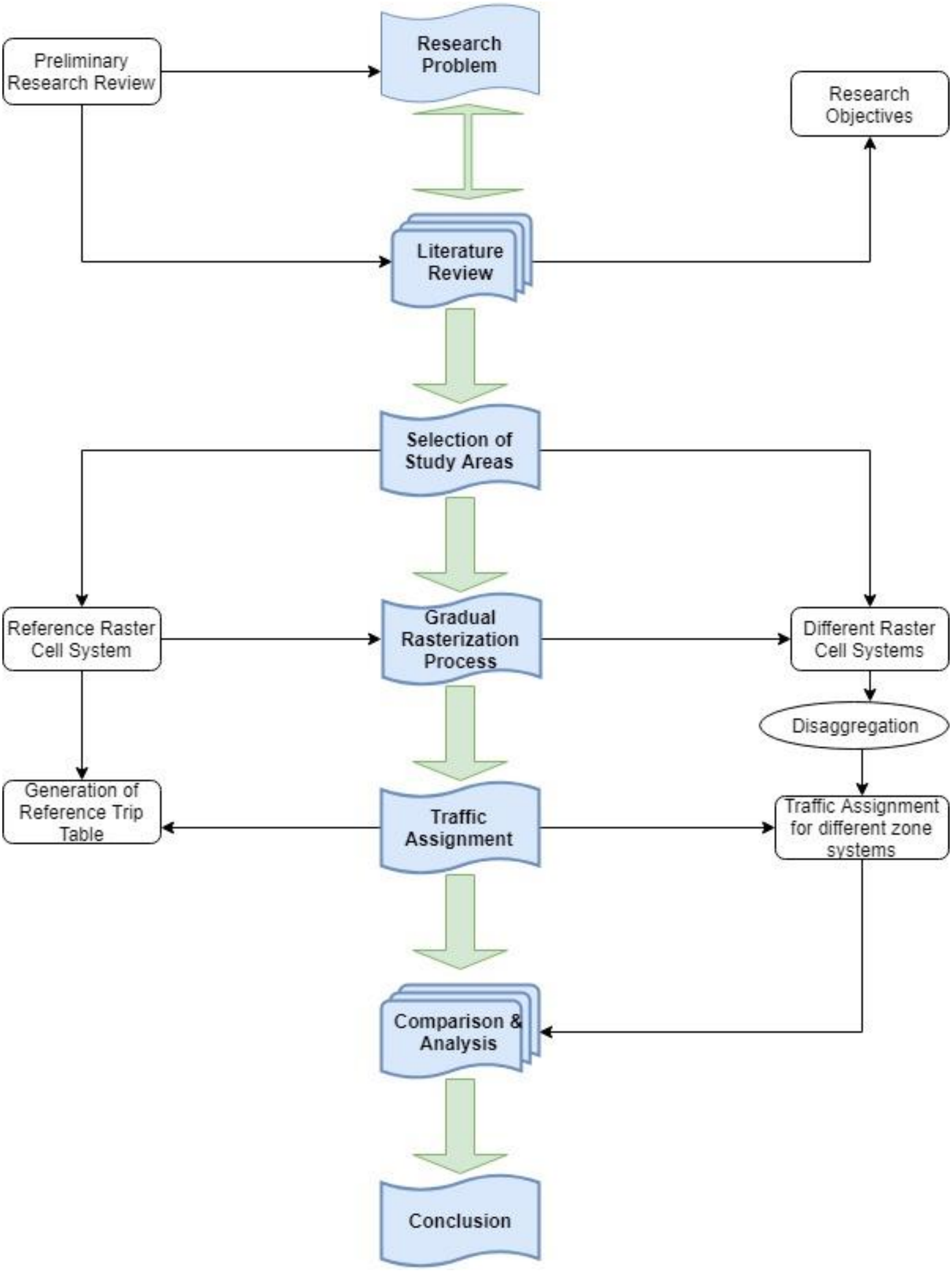

Figure 2: Research Design

Source: Author´s own

2. Literature Review

Literature Review renders a guideline for selecting appropriate elements, indicators, strategies, measures and questions to help identify research gaps and different assessments in refining the target and research objectives. For this research work, different articles related to spatial planning and previous work and methodologies were consulted and reviewed. A general brief overview of the previous work done on this research theme has been explained in this section.

2.1 Different Methods for Zone System´s Generation

Different approaches have been adopted to compose an applicable zone system which can diminish the computational complexity and other problems relating to spatial modelling. Tracking back to the progression of transport modelling, the propagation of zone systems has always been an important process due to its complication and multiplicity.

Batty (1974) who was a lecturer of geography at the University of Reading, exercised the apprehension of social entropy to develop spatial zone system. Spatial entropy refers to the diffusion of spatial information over an area which cannot be further maximized. The interrelationship of entropy-maximizing procedures and statistical analysis by Wilson A. G. (1970) were availed to develop a new modelling technique which partitioned the spatial systems irrespective of the zone shapes as stated by Batty (1974, p. 16) that “the effect of zone size or shape is subsumed within the logic of this model.” Using this apprehension of maximum entropy, the algorithm resulted in irregular shaped zones as demonstrated in the figure 3 on the next page.

However, the relevance of configuration in spatial modelling cannot be ignored as the centroids are an essential part of zones which are further connected to the transport network to generate trip production and attraction for traffic assignment. If the shape of the zones will not be consistent then it is burdensome to define the centroid of a zone and will ultimately connect the network at untrue paths which will greatly influence the traffic assignment. Therefore, the size and shape both are critical for spatial modelling of an area.

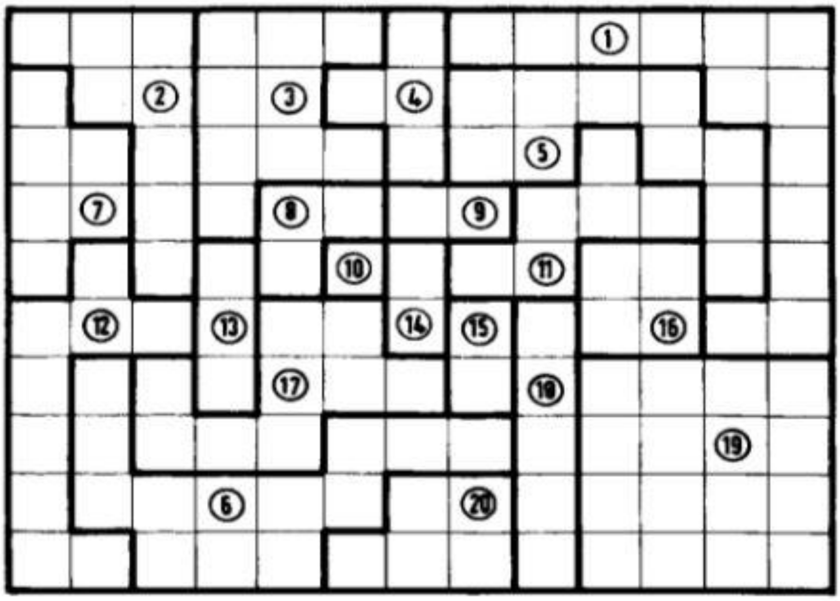

Figure 3: Results of Maximum Entropy Spatial Systems Algorithm

Source: (Batty M. , 1974, p. 26)

With the advancement of computerized era, GIS software was utilized by Openshaw & Rao (1995) to design zoning systems with the help of census data. The approach employed for this scheme was a reversed problem-solving technique known as Automatic Zoning Procedure (AZP) (Openshaw, 1977). This procedure involved the aggregation of spatial data of larger areas into smaller ones so that smaller zones follows the best fit statistical measures. As AZP are general purposed, to constitute an optimal zonal system, Openshaw & Rao (1995) flourished applicable functions such as equality zoning in GIS software to get best achievable results but this lead to the Modifiable Area Unit Problem (MAUP) (Openshaw, 1984) in spatial analysis.

This obstacle of Modifiable Area Unit was addressed by Viegas, Martinez, & Silva (2009). It occurs when the spatial data is arbitrary and has no geographic existence so ultimately the spatial units will also be abstract. MAUP is composed of scaling effects due to spatial data aggregation and zoning effects resulting due to spatial partitioning according to Wong & Amrhein (1996). For this specific motive, Viegas, Martinez, & Silva (2009) developed a GIS-based application to define valid and reliable zones that has geographic existence. It was theorized that intrazonal trips are not connected to the transport network and all trips are generated from centroid of zones. The survey data of trip production and attraction was availed to propagate grid areas of different dimensions and forms and were inspected. From the analysis, it was concluded that cell size carries critical implication on intrazonal trips.

Another Automatic Zoning approach turned to account by Cockings, Harfoot, Martin, & Hornby (2011) is the maintenance of already existing zoning system in a way that the zones which fit the criteria are retained and the zones which are not according to zoning design criteria are modified and optimized. Because starting the delineation of a zoning system from scratch is a lengthy and complex process. For sustainment of existing zone systems, the concept of split and merge was applied. A threshold was set to optimize the already existing zones based on population data. The areas where the population was beyond threshold limit were split into further units and the areas where the threshold did not meet were merged. As shown in figure 4 that the threshold of the zone system was set at 250 maximum and the minimal limit at 100 so the zones which did not meet these standards were split and merged subsequently.

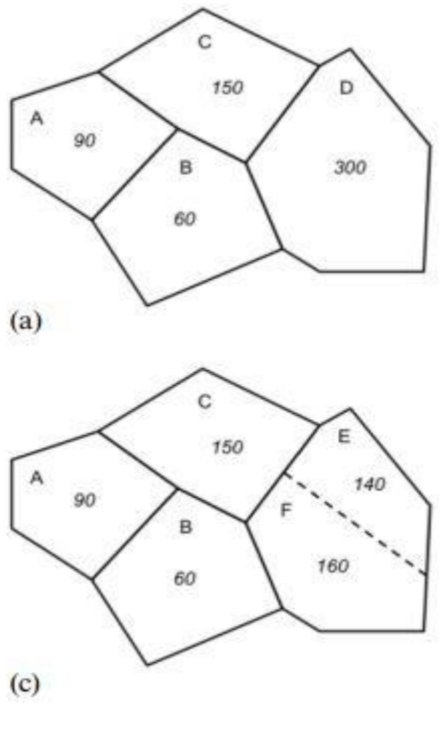

Figure 4: Split and Merge

Source: (Cockings, Harfoot, Martin, & Hornby, 2011, p. 2402)

Moreover, Lovelace, Ballas , & Watson (2014) modelled commuter patterns and has concluded that the higher spatial resolution will disdain the potential to model small-scale interventions such as commute of pedestrians and bikes. But at the same time, the finer spatial resolution will aid in modelling the commuter patterns with greater improvements, on the other hand will increment the computational entanglement of the model. Hagen-Zanker & Jin (2012) have alternative to discrete zone systems to rectify the computational time and accuracy. The zones which are near to the origin zones were given considerable gravity based on the location accuracy, so the spatial resolution was kept smaller whereas the farther destination zones were of higher spatial resolution depending on the distance from origin zone. Each origin zone was surrounded by many small destination zones and the zone resolution was enlarged as the distance from the origin was increasing. This method supported in enhancing the computational time by 70% with respect to the accustomed models.

2.2 Drawbacks of Previous Zone System´s Generation Methods

From the above discussed literature review, it is evident that approaches used to spawn zone systems have many deficiencies which require the obligation to address them. In most of the techniques, the shape of the zones was either overlooked or were of unreliable shapes and were not given legitimate attention. In four-step transport planning model, the production and attraction trips are originated from the centroid of the zones. For this, consistent and regular shaped zones are required. Moreover, to weaken the demand to model intrazonal trips is dependent on zone spatial resolution. The contraction of size of transport analysis zones will limit the frequency of intrazonal trips (Okrah, 2017). But the conventional zoning design systems do not transfer us with a finer resolution of zones. These methods also carry great data processing complexity and require longer procedural runs and time to layout. Hence, with the upgradation of automation, the apprehension of Raster Cells can comfort in addressing these drawbacks.

2.3 Use of Rasterization

Rasterization refers to the fact that polygons are decomposed into a set of cells of uniform regular shapes arranged in rows and columns. Batty, Xie, & Sun

(1999) benefited from the theory of Cellular Automata (CA) in which the spatial objects are exemplified in terms of cells directly influenced by the activities proceeding in neighboring cells, hence, forming a spatial system in pattern of a grid. These grids or cells can easily be exported in GIS software as raster-based representation (Wagner, 1997). These raster cells were aggregated across locations to model land-use by keeping the spatial resolution of the cells finer. Khan, Abraham, & Hunt (2002) used a system of 10x10 sized zones in his business location choice model to evaluate various values of parameter to simulate behavior of small and medium sized firms. Similarly, raster cells were utilized by Moeckel (2013) to model location choice models by comparing the location choices of firms against the one used by the employees. Pendyla, et al. (2013) also modelled integrated land-use using temporal parcels.

Ding (1998) established a GIS-based human-interactive algorithm to automatically design transport analysis zones of homogeneous nature and has concluded that spatial data aggregation has a symbolic outcome on the results of transport models when the number of zones is kept smaller. Another approach developed by Martinez, Viegas, & Silva (2009) was used to automatically create transport analysis zones of regular and uniform shape and carrying homogeneous characteristics. This algorithm serviced to minimize the location error of the trip end location i.e. minimizing the intrazonal trips and to keep production homogeneity within a zone.

Mostly spatial zone design is based on the explanation of zone system distribution and the same design cannot be applied on different fields such as transportation, land-use, environmental, economic and business location models. In transportation, modelling requires a balanced level of spatial resolution which should be an automated process and should define zones that are not too large sized because of the loss of information and more intra-zonal trips within the zone and the zones should not be so fine that it exceeds the computational ability and complexity. The zones should have a systematic shape, but the size of the zones should be dependent on the characteristics of the location of the zone. For example, in denser areas where the activities are greater, the zones should be finer to capture all sort of activities to be properly assigned to the network. And in areas where the activities are not so significant can be given larger zone resolutions.

Keeping in mind, all these complexities of zonal system design, Moeckel & Donnelly (2015) designed an algorithm of rasterization for the statewide model of the Georgia Department of Transportation (GDOT). Population and employment were taken as threshold to split the raster cells. The algorithm used quadtree concept to divide the area into four equal parts unless each raster cell achieves a household threshold of 5000. Areas with greater population density received a finer grid while sub-urban areas on the outer skirt of the region had larger resolution of raster cells as the process of rasterization is shown in figure 5 how the algorithm worked.

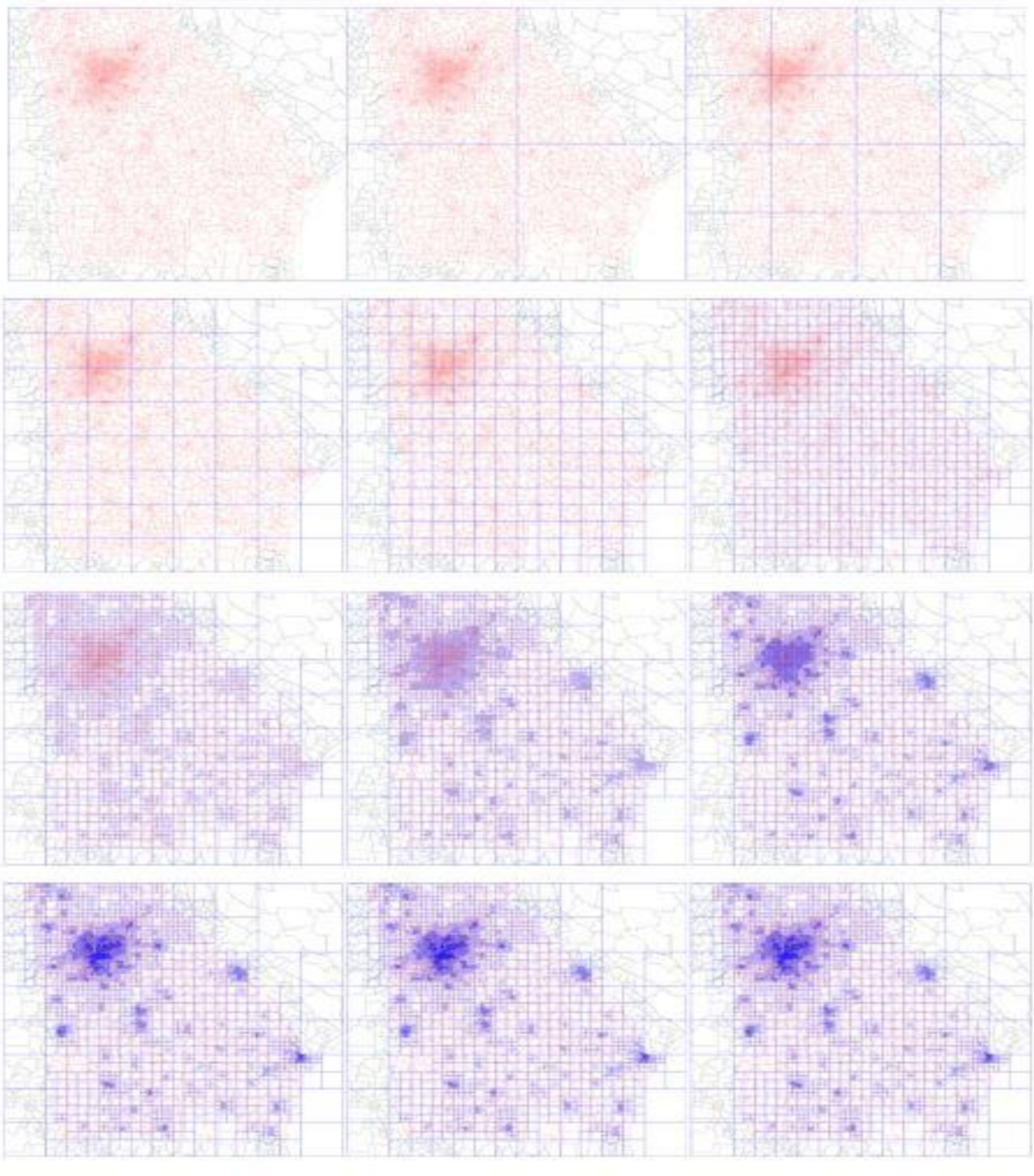

Figure 5: Rasterization Process in Georgia State

Source: (Moeckel & Donnelly, 2015, p. 897)

The main zones of GDOT model were disaggregated to the newly formed raster cells which greatly improved the model validation without changing the model design and also brought improvement in traffic assignment to the network.

The algorithm created by Moeckel & Donnelly (2015) had some shortcomings as the process neglected the geographical boundaries making the allocation of socio-economic data to raster cells difficult and inaccurate. Moreover, some raster cells on the outskirt of the region had only green areas or water areas adding unnecessary computational time and energy for analysis. To overcome these drawbacks of the rasterization process, Molly & Moeckel (2017) revised the algorithm with keeping the basic concept of quadtree and adding new features such as the split and merge process and socioeconomic data allocation to the small sized raster cells. The approach was applied to the Munich metropolitan region with the availability of population data and land-use data and provided a zone system within the boundary of study area at a cost of forfeiting of homogenous squares as show in figure 6.

Figure 6: Resulting Zone System of Munich after Gradual Rasterization

Source: (Molly & Moeckel, 2017)

To reduce the need to model non-motorized intrazonal trips, Okrah (2017) used the same approach of automated gradual rasterization (Molly & Moeckel, 2017) to find an appropriate zonal resolution. Dachau region was used to compare model results from 24 different zone systems. Minimal zone size system of 75m x 75m was taken as a reference raster cell system to which other zone systems were to be compared and to achieve a very detailed level of spatial resolution to analyze non-motorized trips. The threshold was taken as network length per raster cell as the network doesn't change often and is easily available as compared to socioeconomic data. The initial trip tables of the study area were then disaggregated to the zone systems and traffic assignment was carried out. The deviation of other zone systems from the reference network volumes were set side by side and analyzed. It was summarized from the correlation of results that zone system of 1000m network length per raster cell is an appropriate zonal resolution and provides cost-effective model results.

2.4 Review of Previous Research Results

All the approaches which were adopted to generate zone systems had some shortcomings and hindrance. Most of the techniques lacked regularity and uniformity in shape and size. With the betterment of the technology, it became easy to design an automated process which can give homogeneous zones, but it increased the computation complexity, time and accuracy. This dilemma was enlightened by automated gradual rasterization process which break down the zones according to the attributes of the zones into regular shapes.

As this thesis is based on the research work done by Okrah (2017), it is essential to recapitulate the results from his study. The gradual rasterization process was practiced, and trip assignment was done for the study area Dachau as previously interpreted. Then the trip length distribution, number of intrazonal trips and network volumes across different zone systems, that were structured by changing the threshold of network length, were scrutinized and correlated. From the comparison, it was illustrated that by reducing the spatial resolution of zones increased the inaccuracy of average trip length estimation but cutback the loss of information and intrazonal trips. However, the deviation in assigned volumes escalated with the coarser sized spatial zones.

3. Gradual Rasterization

3.1 Selection of Study Areas

Numerous study areas which are related to this research work were feasible. However, it was imperative to prefer those areas which contribute plentiful and substantial material for the convincing analysis outcomes. The selection of explicit regions was not viable due to the insufficiency of data. Therefore, three random areas having divergent attributes were chosen to carry out this research work.

3.1.1 Study Area 1

The first test area selected for the formation of zone systems was Maxvorstadt and its surroundings as shown in the figure 7 below:

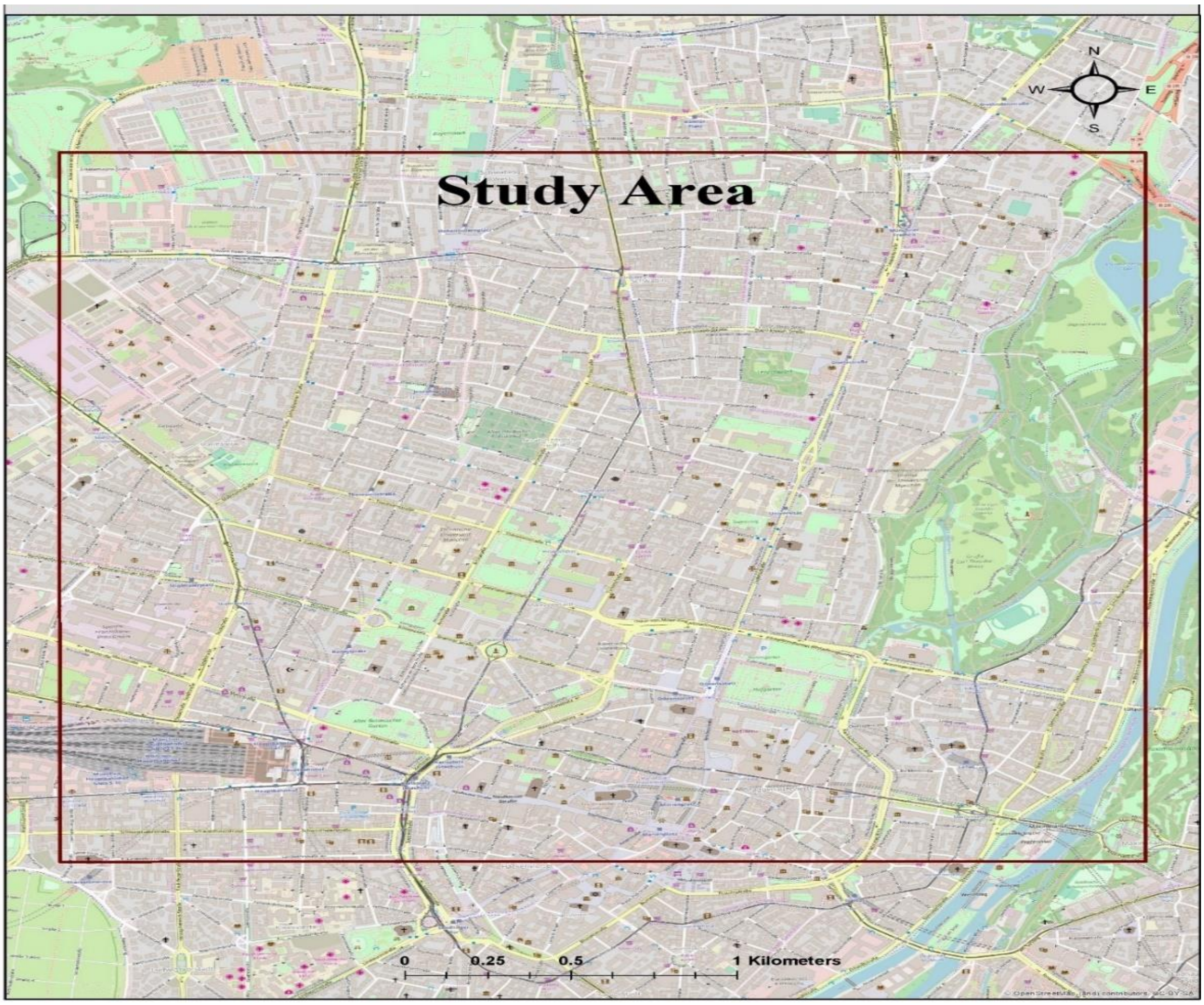

Figure 7: Maxvorstadt

Source: OpenStreetMaps

Maxvorstadt is the central part of the Metropolitan city of Munich, Bavaria, Germany. The area constitutes of dense private transport network and is easily accessible by public transport and many bus lines are running in this part of the city. For this research work, a specific region with defined boundaries was not chosen instead the boundaries of the study areas were defined in terms of an area around a center. The center of Maxvorstadt was selected and then a square area of $10.24km^2$ was selected around it as the square provides preeminent homogeneity which is of greater computational advantages. The geometry of homogeneous square raster cells can be forfeited if the boundary of an area is required.

The magnitude of the test area was restrained by the number of maximum authorized zones sanctioned by the software license attained for this thesis. PTV Visum will be used to analyze zone systems. As rasterization refers to the disjuncture of an area into four equal parts so the number of maximum raster cells should be either multiple of 2 or 4, 8,16 and so on. The software privileges a number of 7500 zones, hence, the maximum number of raster cells which can be used for gradual rasterization is 4,906 (2^{12}) because 2^{13} equals to 8192 which exceeds the software limit.

The resolution of smallest zone system for this research work was chosen to be 50m x 50m so the restrain of allowable number of raster cells provide us with an area section of $10.24km^2$ which is taken from the center of the study area extending to its surroundings in a square shape.

3.1.2 Study Area 2

A $10.24km^2$ section of Puchheim expanding from the center of Puchheim to its outer boundaries and beyond, was chosen as a second test area. Puchheim is a small city near Munich which falls in the district of Fürstenfeldbruck in Bavaria, Germany. It has a population of 20,000 inhabitants and is located in the eastern part of Munich. This region is well connected to the city of Munich by public transport and has also good private transport capabilities. Most of the area in its surroundings comprises of fields, green areas and water bodies whereas the center has dense private transport network.

This section was chosen in order to study and analyze the effects of the same zoning systems, applied on study area 1 which is an urban densely populated and congested private traffic area, on an area which is in suburbs and has segregated population having low traffic density as shown in the figure 8 below:

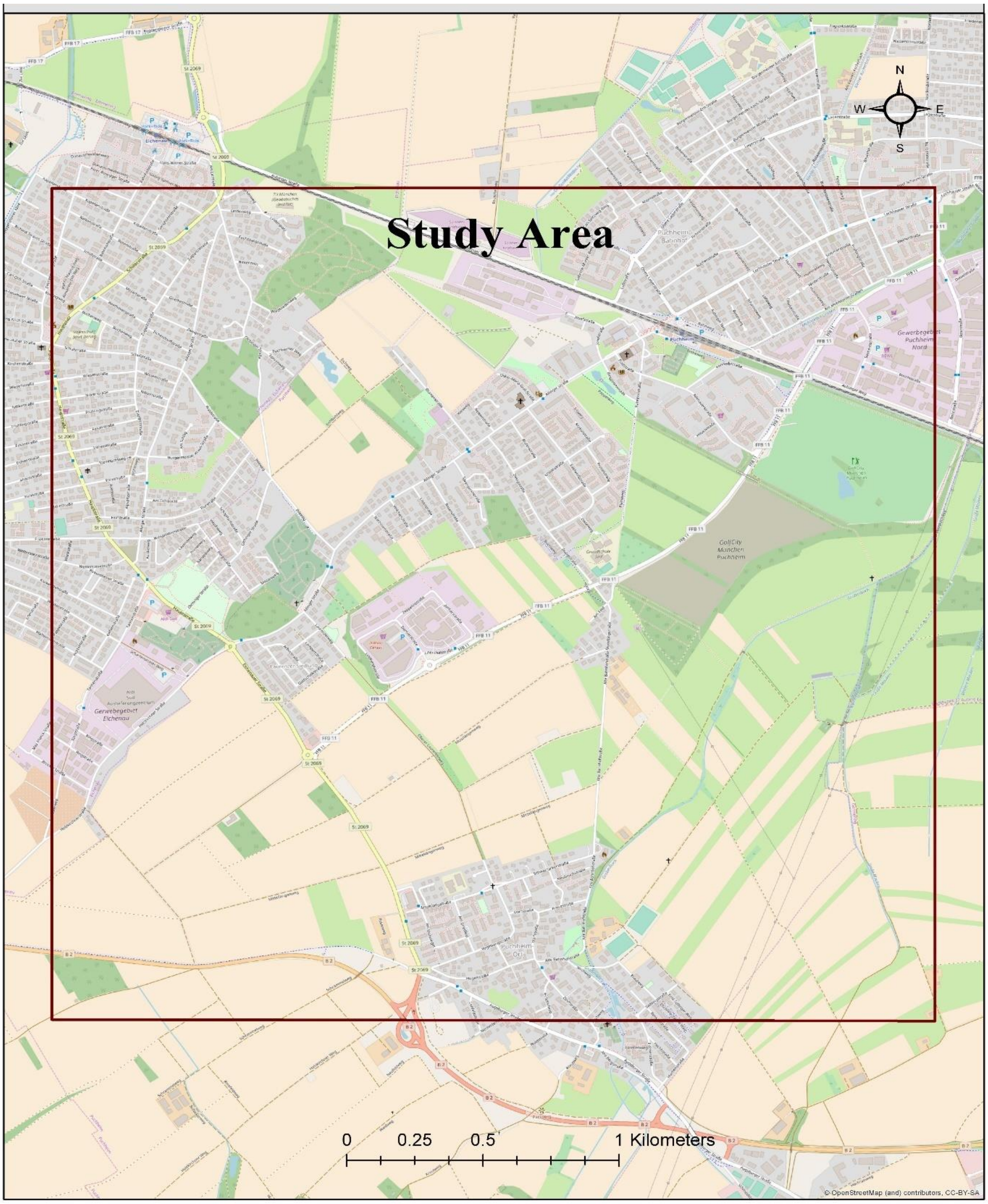

Figure 8: Puchheim

Source: OpenStreetMaps

3.1.3 Study Area 3

After selecting two study areas of urban and suburban nature, it was essential to experiment the same zone systems on a different urban dense region to analyze its results of traffic assignment which will be done in the later part of this thesis.

To do so, a 10.24km^2 area from the center of the city of Augsburg and its surrounding was taken into account. Augsburg is an urban district which is the third largest city in Bavaria, Germany having good public and private transport network as shown in figure 9 below:

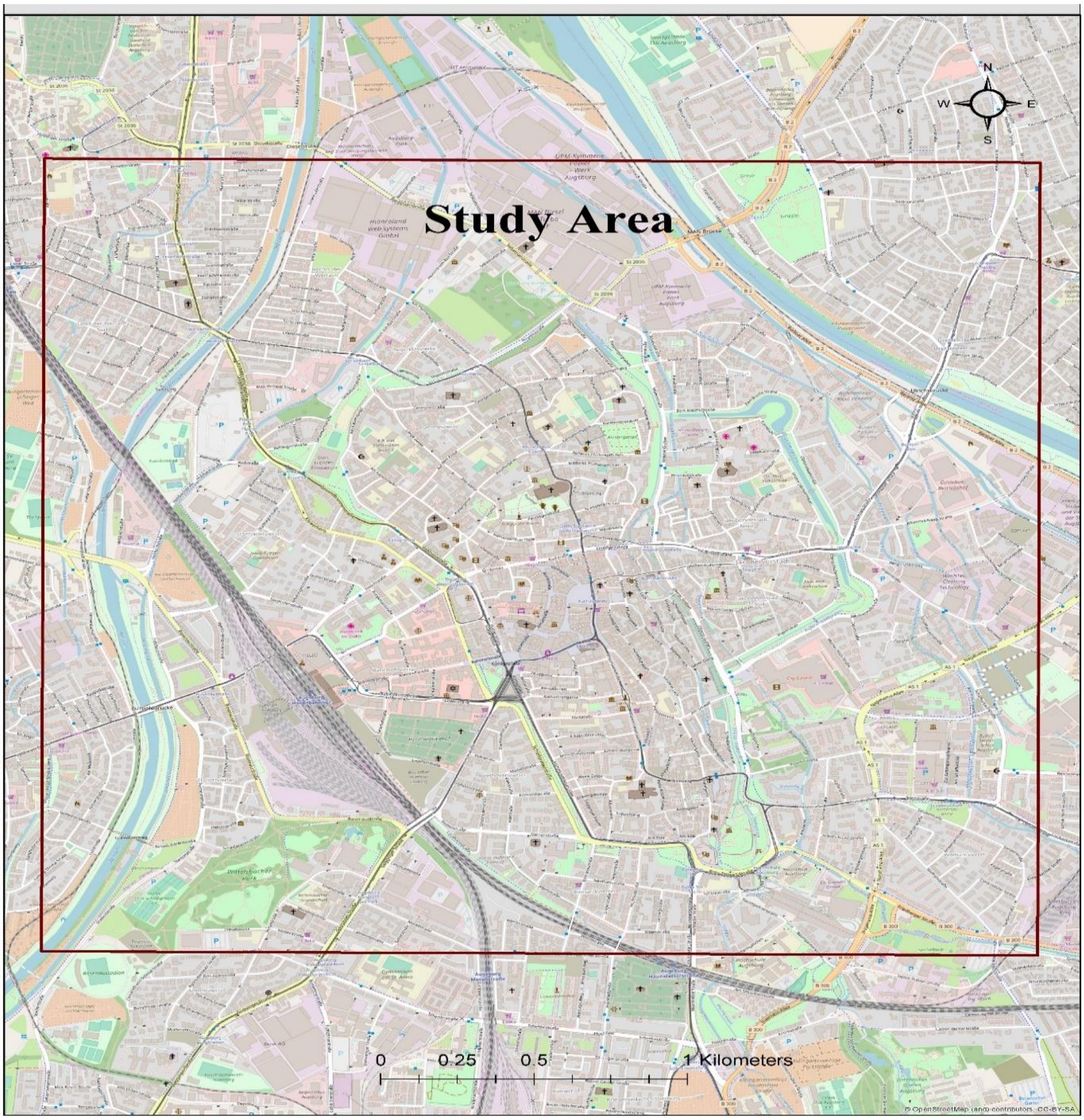

Figure 9: Augsburg

Source: OpenStreetMaps

3.2 Reference Raster Cell System

3.2.1 Maxvorstadt

For reference raster cell system, a very detailed raster cell resolution of 50m x 50m was preferred to accomplish a very comprehensive level for analysis. Keeping in mind the number of allowable zones and resolution of reference raster cell system, a smaller area of 10.24km^2 was selected to implement the process of gradual rasterization as the maximum number of 50m x 50m raster cells for this size of area can be 4096 which is within the authorized limit. Reducing the size of reference raster cell will exceed the number of zones for example considering a reference raster cell system of 25m x 25m will give a resultant of 16384 raster cells which cannot be modelled due to license restriction of software. However, reducing the size of area will not provide efficient results. Other than that, the increase in number of zones will not be helpful in the assignment of resultant trip matrices as the matrices get bigger with inclination of the number of zones which requires lot of computational process and time. Also, Clifton, Singleton, Muhs, Schneider, & Lagerwey (2013) used pedestrian analysis zones of size of 264 feet by 264 feet equivalent to 80m x 80m zones, which is quite fine enough to record and analyze the walking trips. So, our reference zone system is almost the half the resolution of it which can provide us with a very detailed analysis of the non-motorized trips.

For Maxvorstadt, a detailed resolution system of 50m x 50m as explained above, was implemented to create a reference raster cell system from which other zone systems of higher resolution can be compared and analyzed to find a conclusive zone resolution which can be implemented in microscopic travel demand models. The thresholds used to create the reference raster cell system were cell size of 50m x 50m and a limit of network length of 50m within the cell, over a desired study area. As Maxvorstadt, is a densely populated area and having dense transport network, the reference raster cell system created by gradual rasterization process provided us with greater number of finer zones as most of the area comprises of residential and commercial area and have very less green area as depicted in figure 10 below. Each cell has not more than 50m of road length within itself and the smallest cell in this reference raster cell system is of size 50m x 50m.

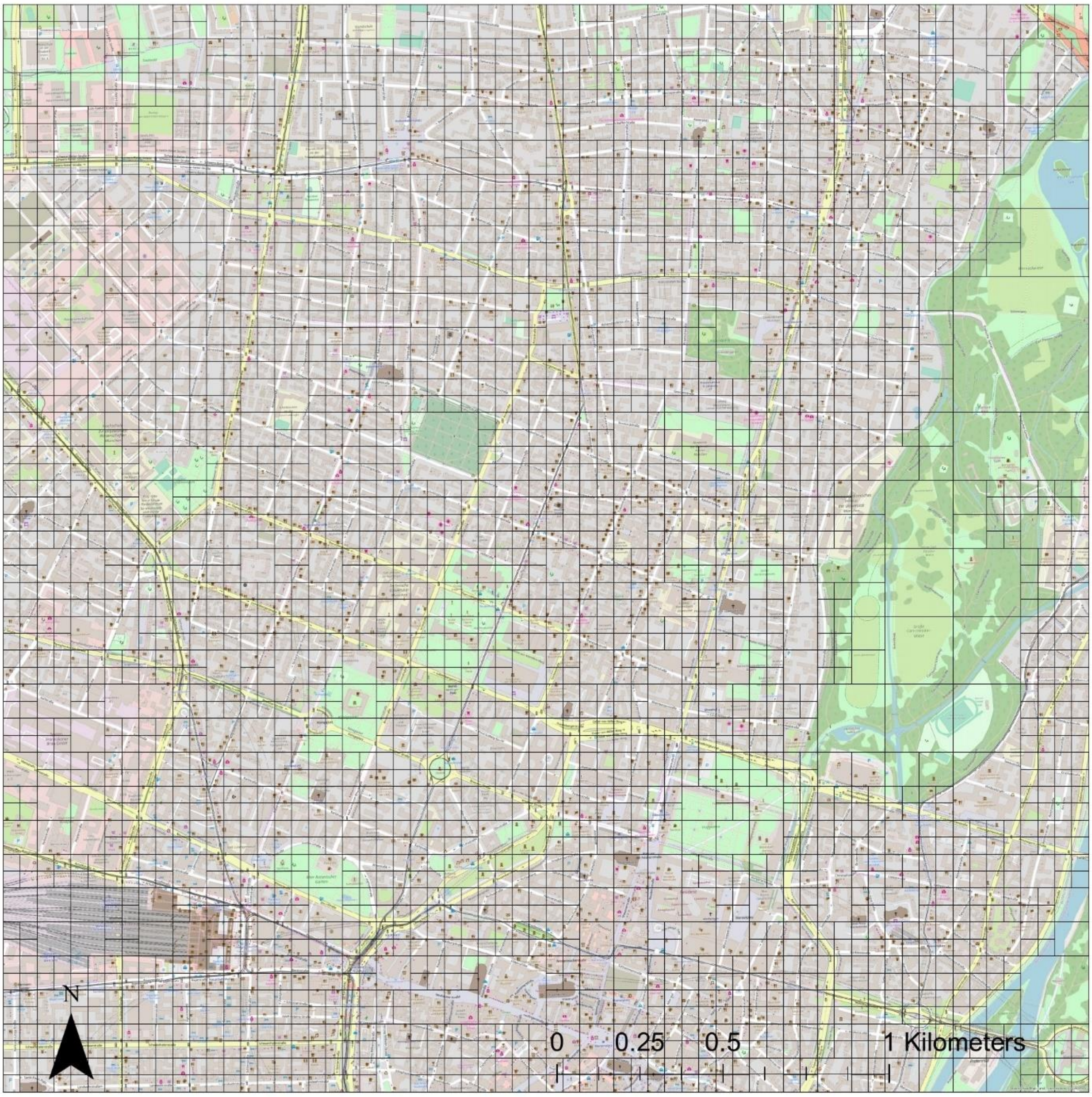

Figure 10: Reference Raster Cell System for Maxvorstadt

Source: OpenStreetMaps

3.2.2 Puchheim

The same zone system of 50m x 50m was applied on a less urbanized area of Puchheim. Keeping the threshold constant, a reference raster cell system was obtained in which the finer cell was of 50m x 50m size and the network length within a cell was not more than 50m. As in figure 11 below, it can be seen that the number of raster cells are relatively lesser as compared to Maxvorstadt because of the area comprising of more green parts and water bodies and also the transport network is relatively not so dense.

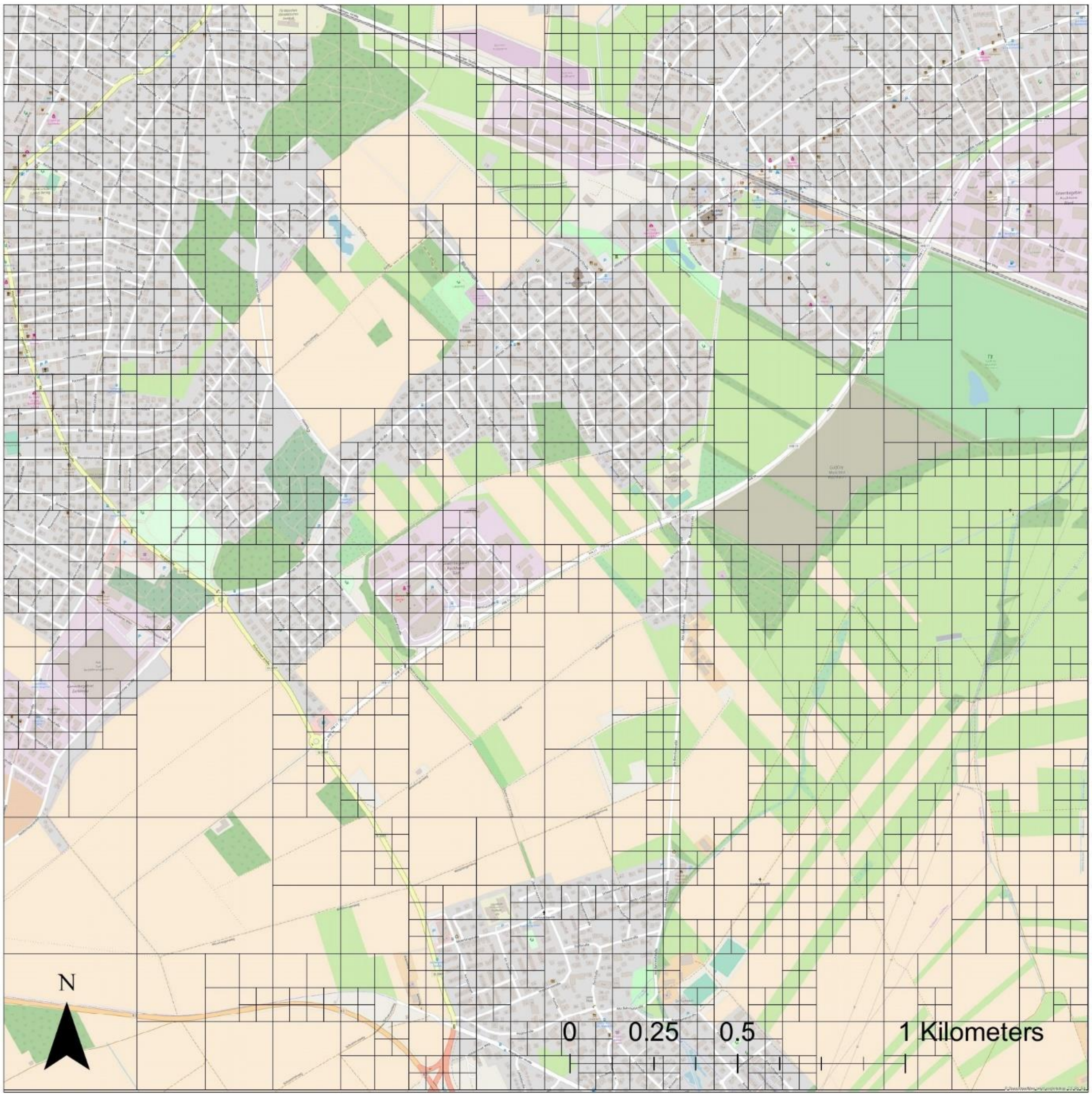

Figure 11: Reference Raster Cell System for Puchheim

Source: OpenStreetMaps

3.2.3 Augsburg

The third study area was also subjected to the thresholds of 50m x 50m raster cells and a network length of 50m to create a reference raster cell system for this region according to which other raster cell systems of higher resolution can be compared. Augsburg is a dense urban region having characteristics similar to

Maxvorstadt where the transport network is very rich, hence, a reference raster cell system of greater number of zones was obtained as in figure 12.

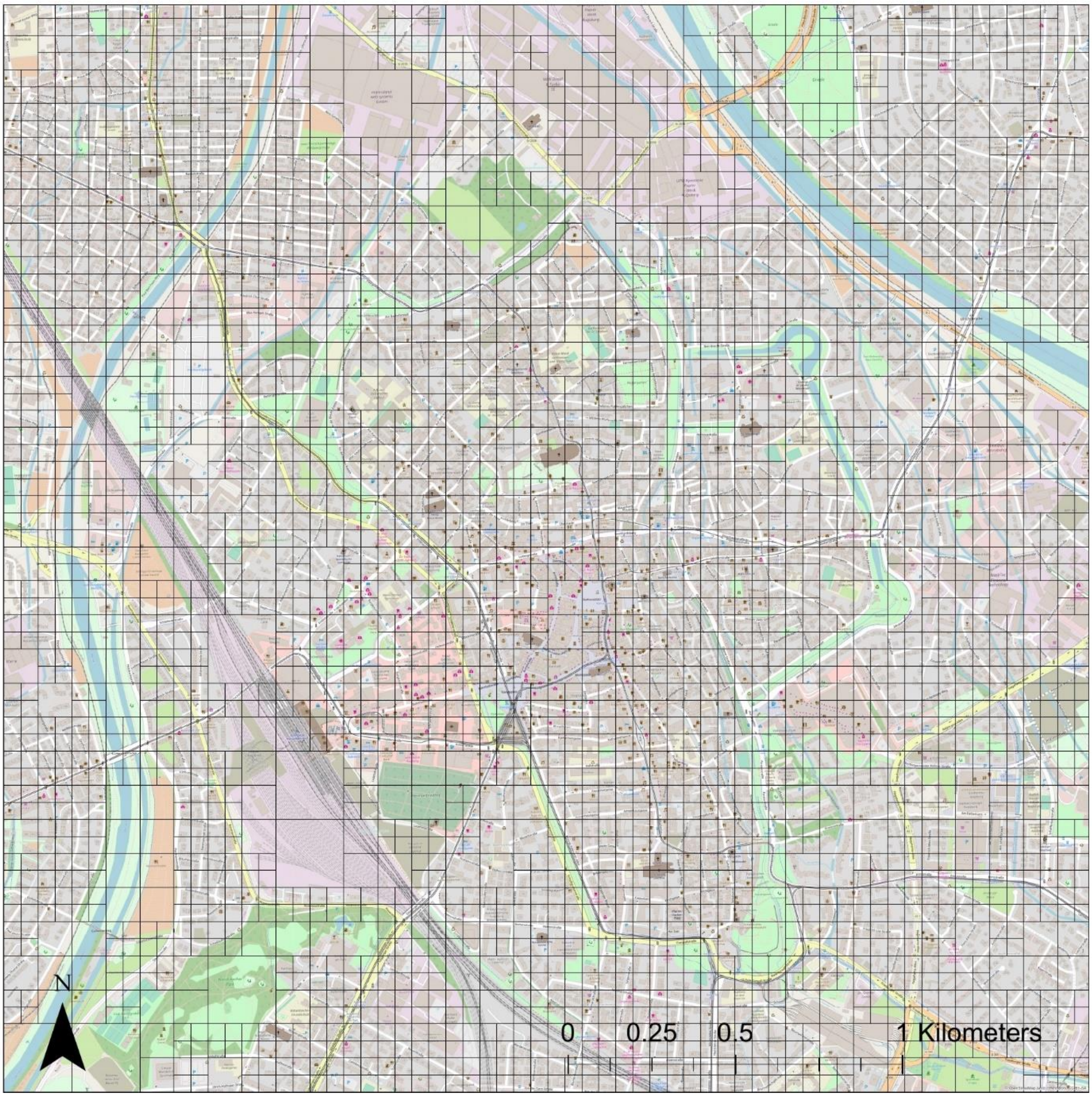

Figure 12: Reference Raster Cell System for Augsburg

Source: OpenStreetMaps

3.3 Creation of Different Raster Cell Systems

After the generation of reference raster cell system, 9 different zone systems were created with the help of gradual rasterization process. The threshold value defined for the formation of these zone systems was network length in meters per raster cell. Network length was chosen as a threshold because of the easy availability of transport network from open street maps whereas it is rather difficult to utilize the demographic data because of its obtainability.

To calculate the network length of the study area, the transport network used for private cars were extracted from open street maps and were cleaned in ArcGIS software. As a trip is originated by its connection to the network, therefore, areas with higher network densities will attract and produce more activity trips compared to the regions lacking in transport network but, trips having longer network length, their production and attraction trips vary based on their density and urban functionality. To reduce this deficiency, links which only provide direct and uninterrupted access to the origin and destination zones were considered. Highways and high-speed roads were connected to the residential areas through connected roads and do not provide direct routes, so they were excluded in the calculation of the network length. The streets network length was calculated in only one direction ignoring the opposite direction. For example, if a street has 50m length, including the opposite direction length will make it 100m but only 50m was considered. To avoid conflicts in calculating the network length per raster cell, the transport network was aggregated into separate links within each raster cell using Intersect tool in ArcGIS software. The threshold values considered to define 9 different zone systems were 100m to 500m, 1000m, 2000m, 3000m and 5000m. After 5000m, the zone size will be considerably coarser to analyze intrazonal trips.

3.3.1 Study Area 1

After the selection of study area and creation of reference raster cell systems, the area of Maxvorstadt was subjected to rasterization process to generate nine different zone systems as illustrated in figure 13, according to the changes in thresholds above explained.

It was previously discussed that Maxvorstadt is an urban dense area and a part of the central area of Munich city, so it can be evidently seen that the zones are quite finer due to the density of network across the region. As the threshold value of the zone systems is increased, the resolution of transport analysis zones also gets coarser.

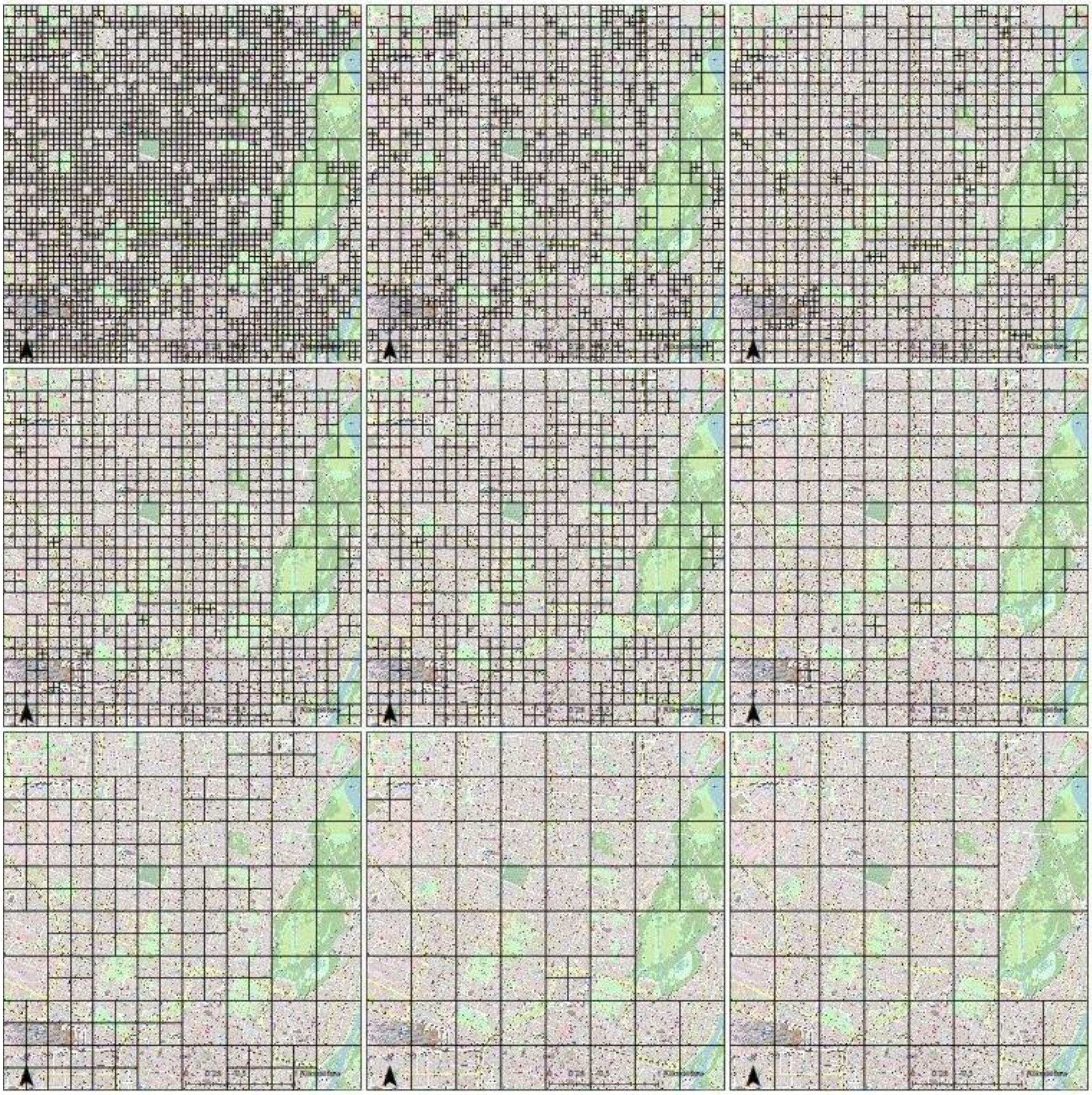

Figure 13: 9 Zone Systems for Maxvorstadt

Source: OpenStreetMaps

3.3.2 Study Area 2

The study area of Puchheim was also subjected to the gradual rasterization process with the network length threshold of 100m to 500m, 1000m, 2000m, 3000m and 5000m and the generated zone systems can be visualized in figure 14.

As Puchheim and its surrounding area is mostly composed of green areas and water bodies and the network is not quite dense, the created zone systems have zones of higher resolution.

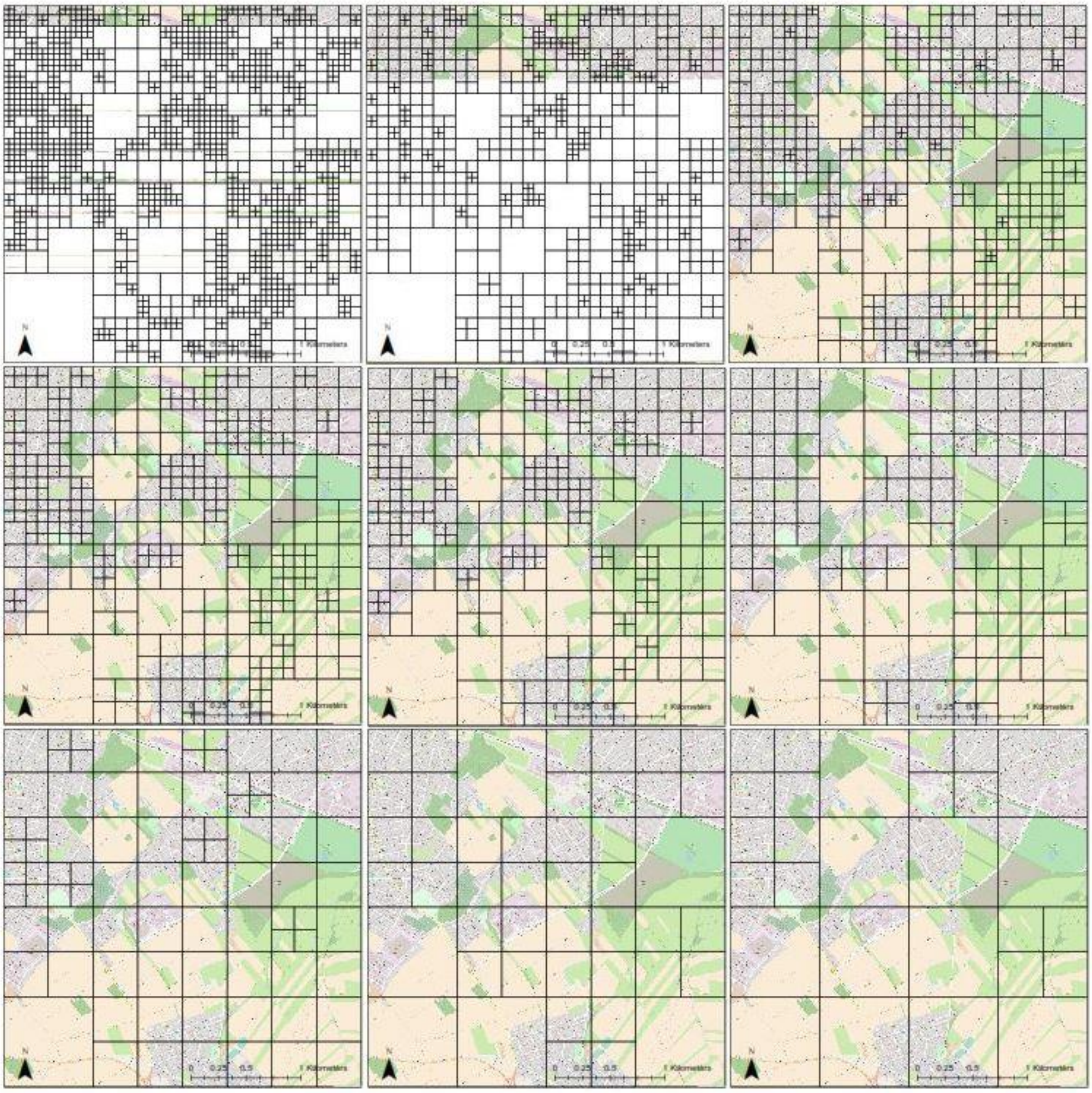

Figure 14: 9 Zone Systems for Puchheim

Source: OpenStreetMaps

3.3.3 Study Area 3

Nine different zone systems were also created for the study area of Augsburg subjected to the change in network length as shown in below figure 15.

Augsburg region is somewhat similar to the Maxvorstadt area in terms of network and urban density, hence the zone systems constitute of finer cells.

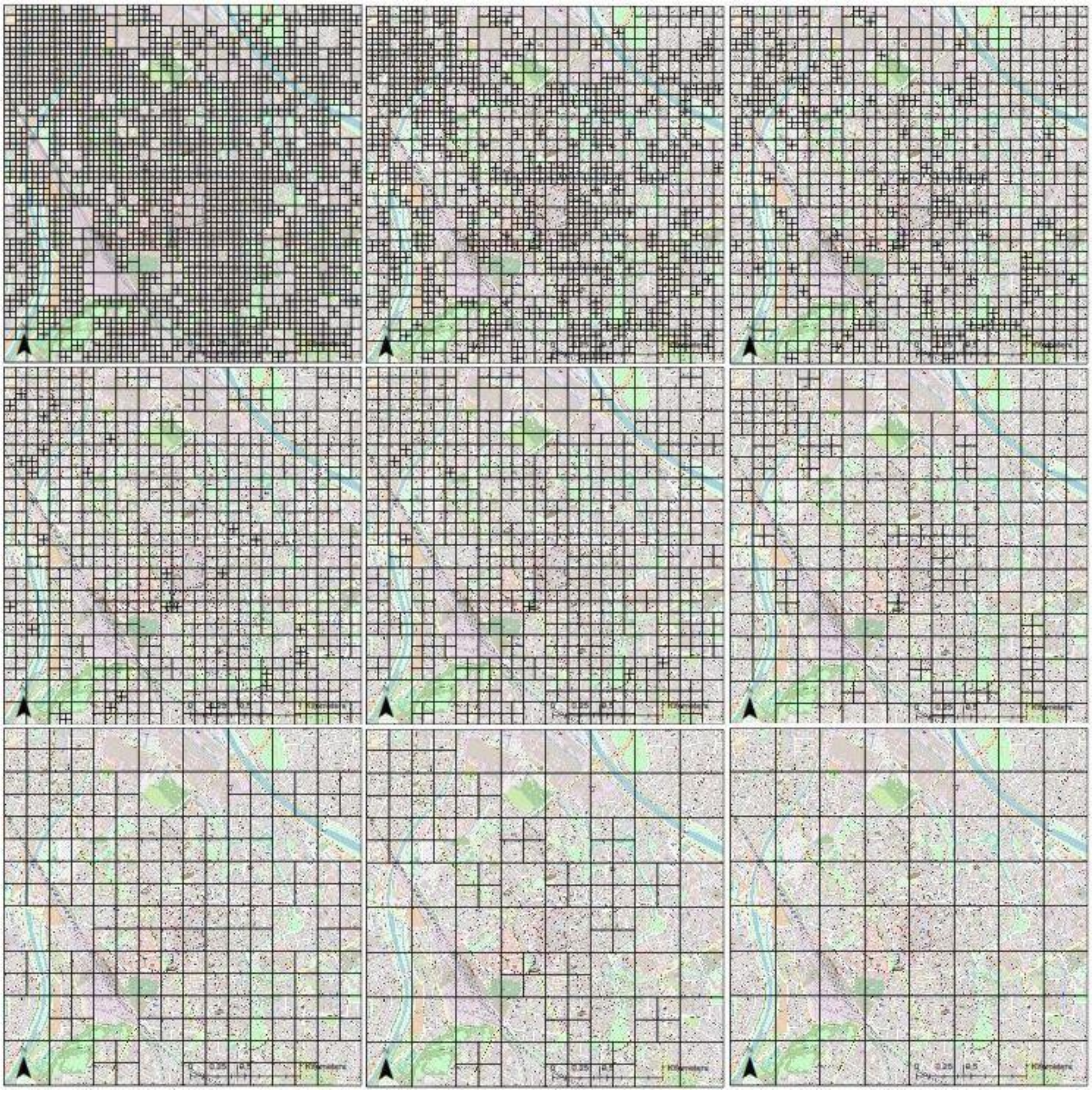

Figure 15: 9 Zone Systems for Augsburg

Source: OpenStreetMaps

3.4 Process of Gradual Rasterization

The process of gradual rasterization is initiated with one larger raster cell surrounding the whole test area. The entire network length of the study area within this one large raster cell is computed. Then a threshold limit is defined to split this raster cell into equal four-square cells. For example, for a zone system of 1000m threshold of network length, the network length within a raster cell is calculated. If the network length exceeds the limit within the cell, the raster cell is further disintegrated into four cells of equal sizes. Again, the same procedure is repeated till the network length is equal to or less than the threshold within a raster cell. If the threshold of network length is not meeting, then the smallest possible raster cell in our case will be of 50m x 50m. This can be referred as the second threshold as briefly explained in the figure 16.

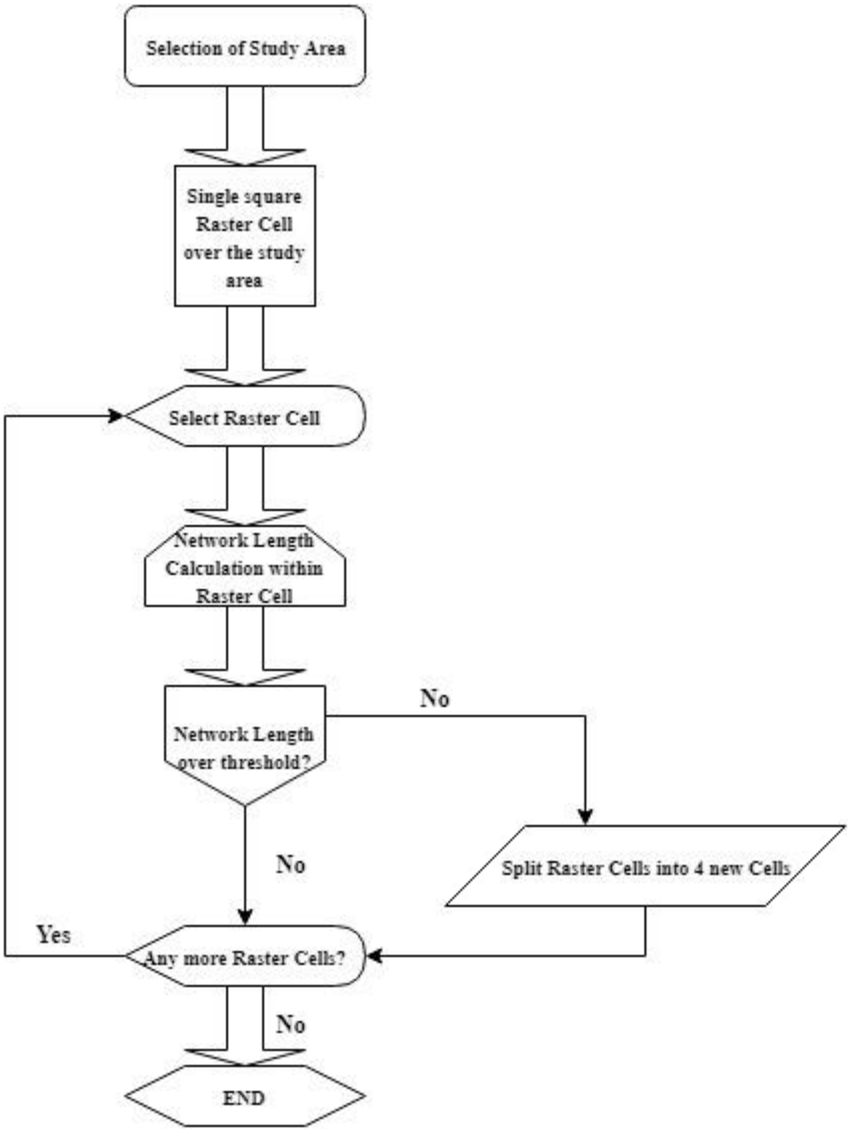

Figure 16: Gradual Rasterization Process

Source: Author’s own based on (Okrah, 2017, p. 98)

Hence, the raster cells of size 50m x 50m with total network length exceeding the pre-defined limit will not be further split in the process of gradual rasterization. The python script which executes this process computationally, is attached in Appendix for further reference.

3.5 Explanation of Algorithm for Gradual Rasterization

We know that uniformly squared raster cells have significant computational advantages, but they do not match up to the irregular land use boundaries of a metropolitan. For our calculation, we need a raster grid whose resolution depends on the geographic (Land use) boundaries lying underneath it i.e. the more the density of data (such as road networks and waterways), the finer should be the resolution of the grid and vice versa.

The algorithm designed to create Raster grid with Data dependent resolution uses a recursive function named 'MakeFishnet' that keeps calling itself and creates finer cells within each cell until the required conditions are met. These conditions are:

1. MIN_GRID_SIZE (Minimum cell size) > a required value (say 50 x 50)
2. MAX_SUM_LENGTH (Sum of lengths of roads within a cell) > a required value (say 1000 m)

Algorithm:

Function: MakeFishnet
Input: Initial Polygon (One Square covering the required area)
Create-Fishnet (into 2 rows and 2 columns)

for each cell in the created fishnet:

> *Intercept-Roads= Roads lying inside the cell*
> *SumLength= Sum (Lengths of Intercept-Roads)*
> *If (Cell-Size/2>MIN_GRID_SIZE) //Divided by 2 so that we check the length of cell after if it is further divided:*
>
> > *If (SumLength>MAX_SUM_LENGTH):*
> >
> > > *MakeFishnet (Input: cell)// Recursive call to the same function*

For all Fishnets create:

> *Merge fishnets*

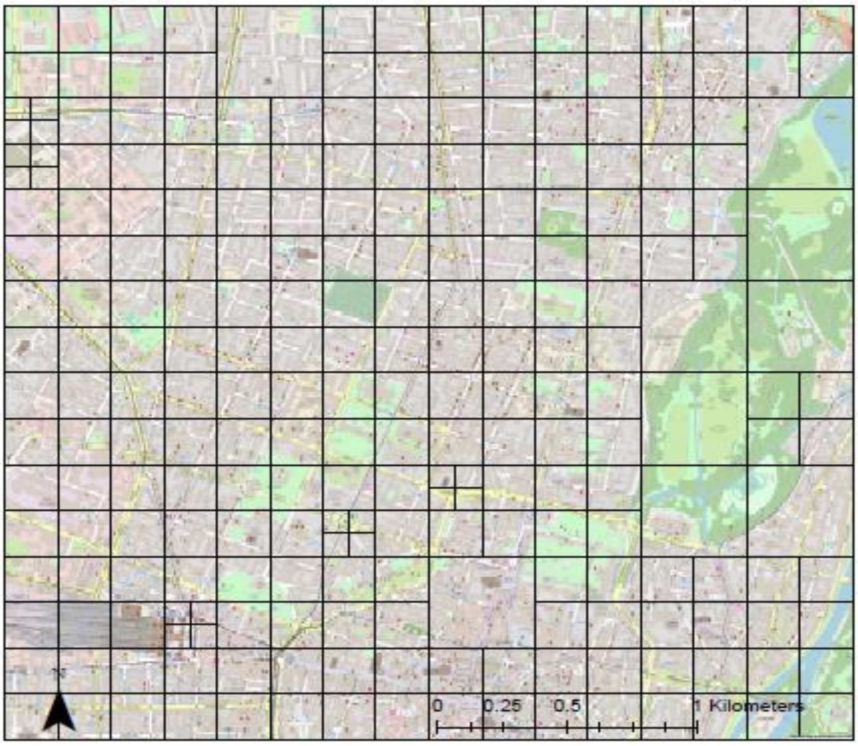

Figure 17: Example Run on MAX_SUM_LENGTH=1000m

Source: OpenStreetMaps

We can clearly observe in the above example that the areas with low density of road network have low resolution of raster cells such as green areas and water bodies whereas the areas which are denser in the center and richer in network carries finer resolution of transport analysis zones.

4. Traffic Assignment

To analyze different zone systems generated previously for acquiring an appropriate resolution of transport analysis zones, traffic assignment is required to compare the assignment results from different zone systems. Traffic Assignment refers to the allocation of route choice to the transport vehicles into the transport network (Mathew, 2017). It provides us with network traffic volumes on the routes, travel costs and congestion analysis. The main reason to do trip assignment is to inquire the deficiencies in the existing transport network by allocating the future trips to the existing network and acquire demand volumes and other attributes for futuristic transport planning (Patriksson, 1994). There are many methods to do traffic assignment to the network such as All or Nothing assignment, Equilibrium assignment, Dynamic assignment and system optimum assignment. They can be used according to the transport model demands as all are subjected to some restrictions and drawbacks.

4.1 Generation of Reference Trip Table

For traffic assignment, the initial requirement is the generation of trip table which can be further assigned to the current transport network to achieve network volumes for analysis and comparison. The trip table is a tabular way to represent the attraction and production rates i.e. how many trips are leaving from one zone and entering another and vice versa, subjected to activities.

Normally, the trip table is developed from the socio-economic data and household surveys but as it is hard to acquire such data and information and a lot of effort is required to collect survey data. In our case, the reference trip table was based on assumption from which trip tables of other generated zones systems can be formed.

In the reference zone systems of the study areas, the minimum resolution of cells is 50m x 50m which is quite fine so for each reference trip table, it was supposed that only one trip is leaving the origin zone into the destination zone and is attracting only one trip. That's how a matrix of trip table was generated keeping the diagonal of the matrix zero to ignore the internal trips. This matrix was used for traffic assignment of reference zone system of the study areas with the help of PTV VISUM software.

4.2 Aggregation of Reference Trip Table

After the trip assignment for the reference zone systems, the trip tables for the nine generated zone systems were formed by aggregation of the reference trip tables. In reference raster cell system, the cells are of the smallest resolution, so they were considered as normal zones, while the raster cells of generated zone systems were considered main zones due to their relative larger resolution. For aggregation of trip tables, the 'Aggregate Zone by Main Zone' function in PTV VISUM software was utilized which will add up all the trips of normal zones falling into the main zones. In simple words, the matrix values of the reference trip table belonging to the same O-D pair will be summed up to create trip tables for the generated zone systems. The same process will be repeated on all study areas to generate reference trip tables for all the zone systems which will further be assigned to network to get car volumes.

4.3 Traffic Assignment for Different Zone Systems

Trip tables are essential requirements for traffic assignment which we have achieved through aggregation. As there are many methods available to do traffic assignment, we will use All or Nothing assignment as it ignores the congestion effects and allows multiple paths to carry traffic. It assigns all trips to links comprising the shortest routes with travel time as fixed input and without variation depending on the congestion on a link. As our study is focused on targeting the network volumes, so this method of assignment seems more suitable because all the other types of effects are held constant.

All the raster cells were connected to the network from their centroid by two-way connectors to the nearest available node that provided path to the cars. Then traffic assignment was carried out for all the zone systems by assigning the trip tables to the car network to achieve network car volumes on each link which will later be compared for analysis to identify appropriate resolution of transport analysis zones. In the same way, trip assignment for all the reference and generated zone systems of all the three study areas was performed, and network car volumes were attained.

5. Comparison of Results for Different Study Areas

5.1 No. of Zones and Network Volumes in Study Area 1

Maxvorstadt is an urban part of the city where the network is quite dense. Along with reference zone system, nine other generated zone systems were formed with the help of gradual rasterization process for the Maxvorstadt study area. Figure 18 represents the comparison of raster cells, which can also be referred as transport analysis zones TAZs, for reference and generated zone systems for study area 1.

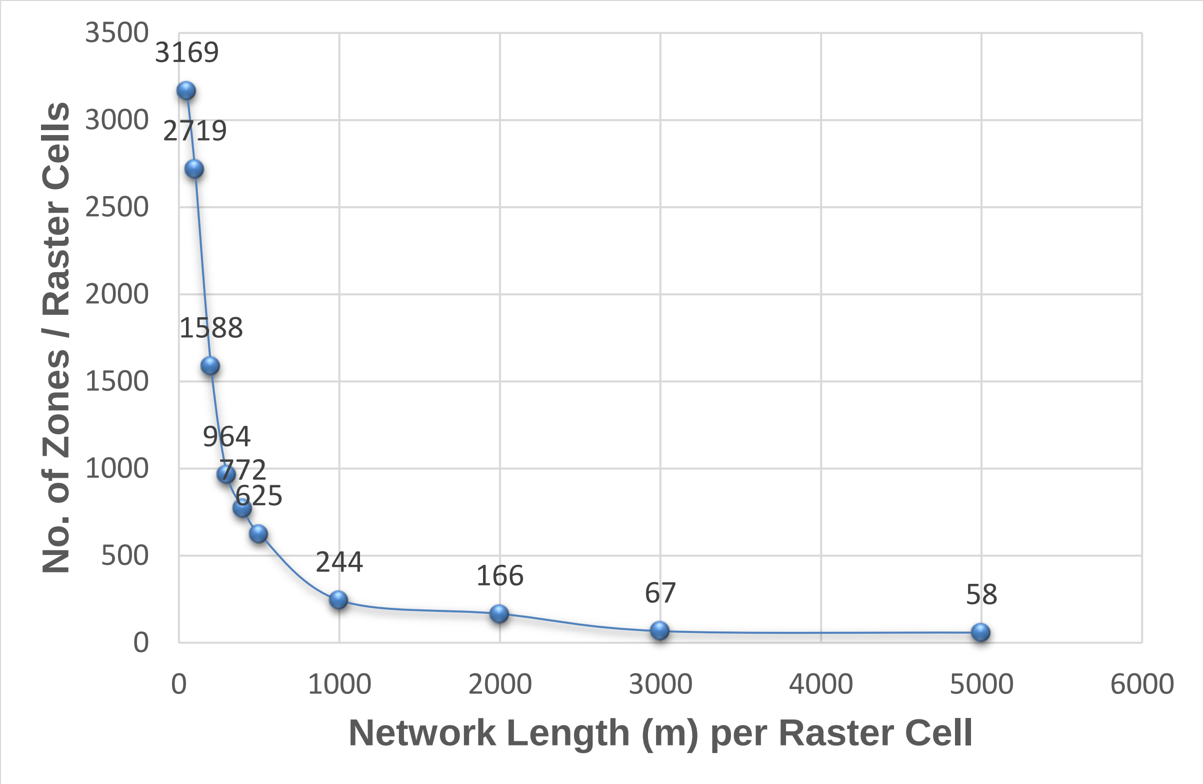

Figure 18: Number of Raster Cells for Maxvorstadt

As can be seen from the graph in figure 18 that the number of zones is declining as the network length within a zone is increasing. On the x-axis of the graph, the threshold values which is network length within a raster cell in meters is plotted against the number of raster cells or zones created on y-axis. From the comparison, it is clearly evident that the relationship of threshold and raster cells is very steep before 1000m network length and the number of zones is declining very significantly as the threshold value is increasing to 1000m. After that the relation becomes more linear and the change is less noticeable. The impact is very little when the threshold is increasing from 2000m to 5000m, the number of generated raster cells are coarser and of lesser numbers.

For all the generated raster cell systems of Maxvorstadt, the car network volumes that were attained from traffic assignment previously done, were also put into comparison against the network volumes from the reference raster cell system. Figure 19 illustrates the deviation in assignment results in relevance to the network volumes of cars at different levels of spatial resolution. This deviation was calculated as percent root mean square error (%RMSE) on all network links for cars as a mode.

This comparison was carried out to analyze the effect on traffic volumes as the zones become of coarser resolution.

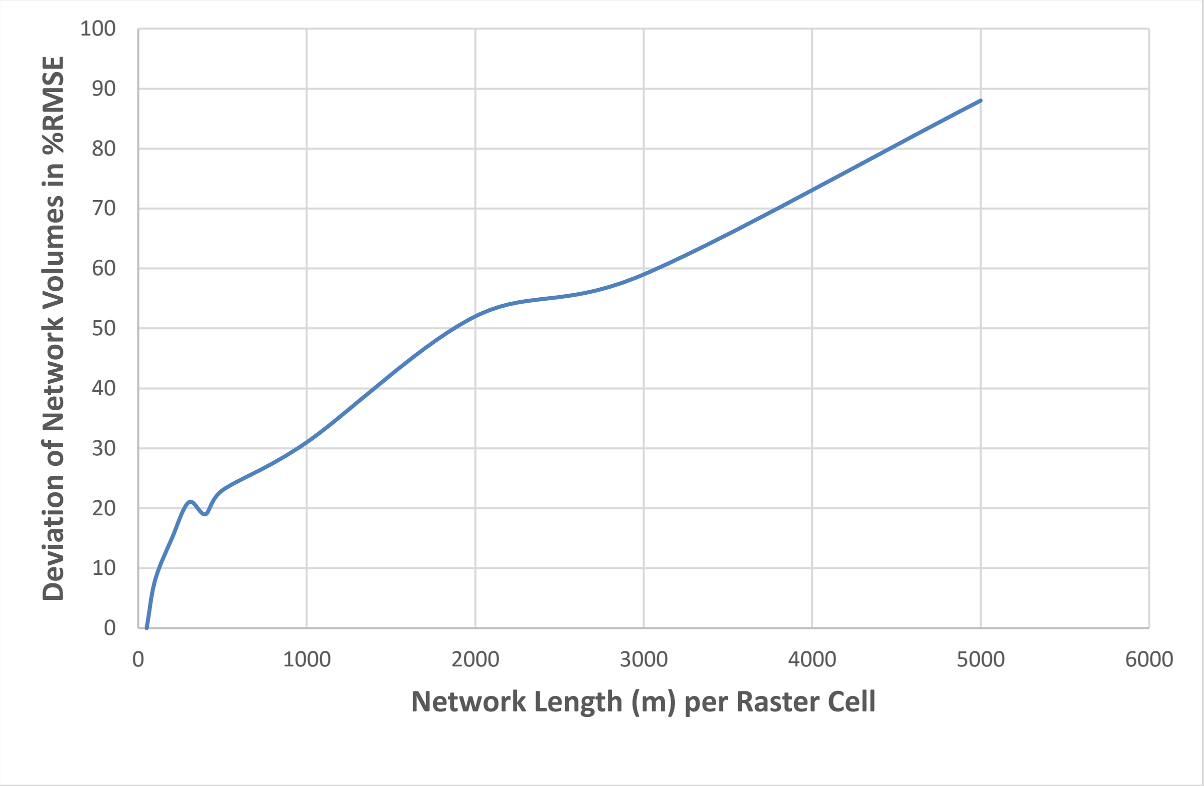

Figure 19: Difference in Network Volumes of Reference and Generated Zone Systems

In the graph shown in figure 19, the difference in network volumes in %RMSE is plotted on y-axis and the network length per raster cell in meters on the x-axis. It can be illustrated from the graph that as the zones are becoming of coarser resolution, the error of network volumes is growing. The deviation is not great till the network length within a cell is less than 1000m. Then, there is a sudden increase in the difference of network volumes between 1000m and 3000m and after 3000m the deviation is too huge.

5.2 No. of Zones and Network Volumes in Study Area 2

The comparison of number of zones for reference and generated zone systems was also done for Puchheim which is a sub-urban region and comprises of not so much dense transport network. Figure 20 illustrates the graph of comparison of zones formed for reference and nine generated zone systems for study area of Puchheim.

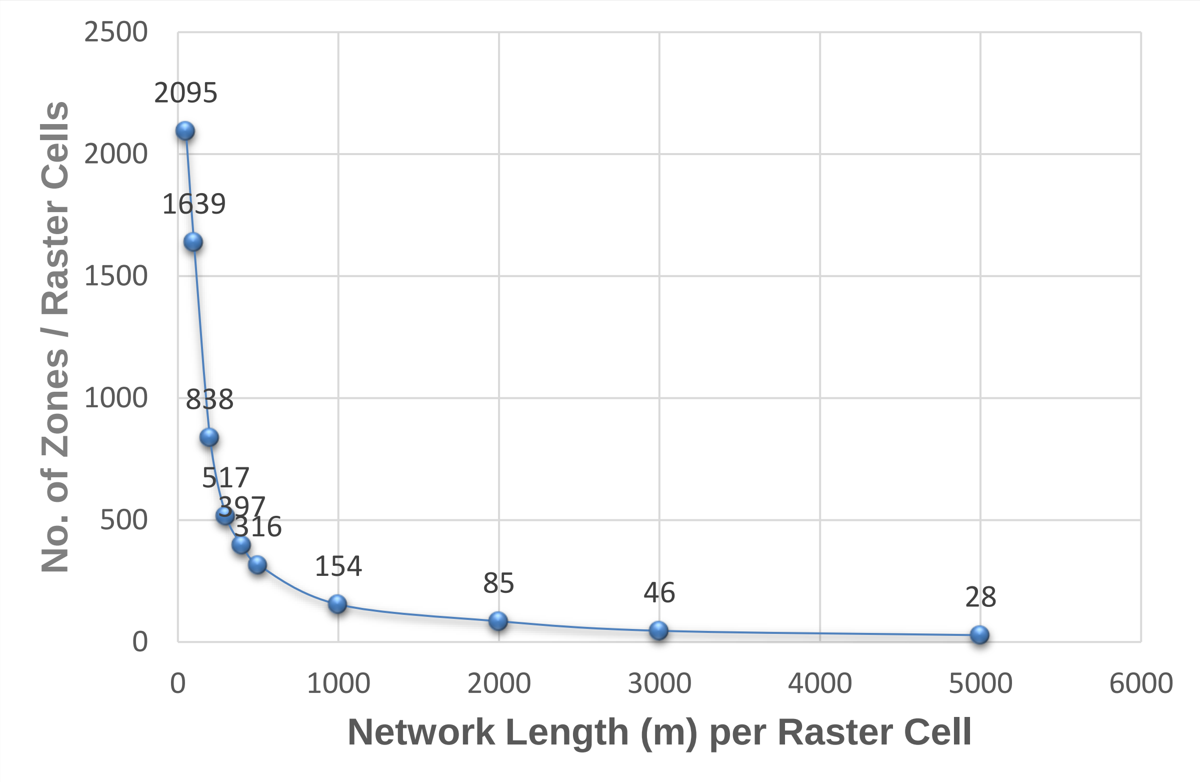

Figure 20: Number of Raster Cells for Puchheim

In the same way as study area 1, the graph is plotted as network length in meters on x-axis and the number of resulting raster cells on y-axis. From the graph, it can be derived that the pattern of slope is mostly similar as study area 1 as the relationship of threshold values and raster cells is significantly abrupt before 1000m network length and after 1000m, the graph shows a linear behavior and very little drop in reduction of the number of zones. As the network length is growing, the zones become coarser and the number of generated zones is becoming less in number.

The car network volumes that were obtained on all links by traffic assignment were also compared to reference network volumes for Puchheim region. The deviation in assignment results were calculated as percent root mean square error (%RMSE) for cars and were then compared as shown in figure 21.

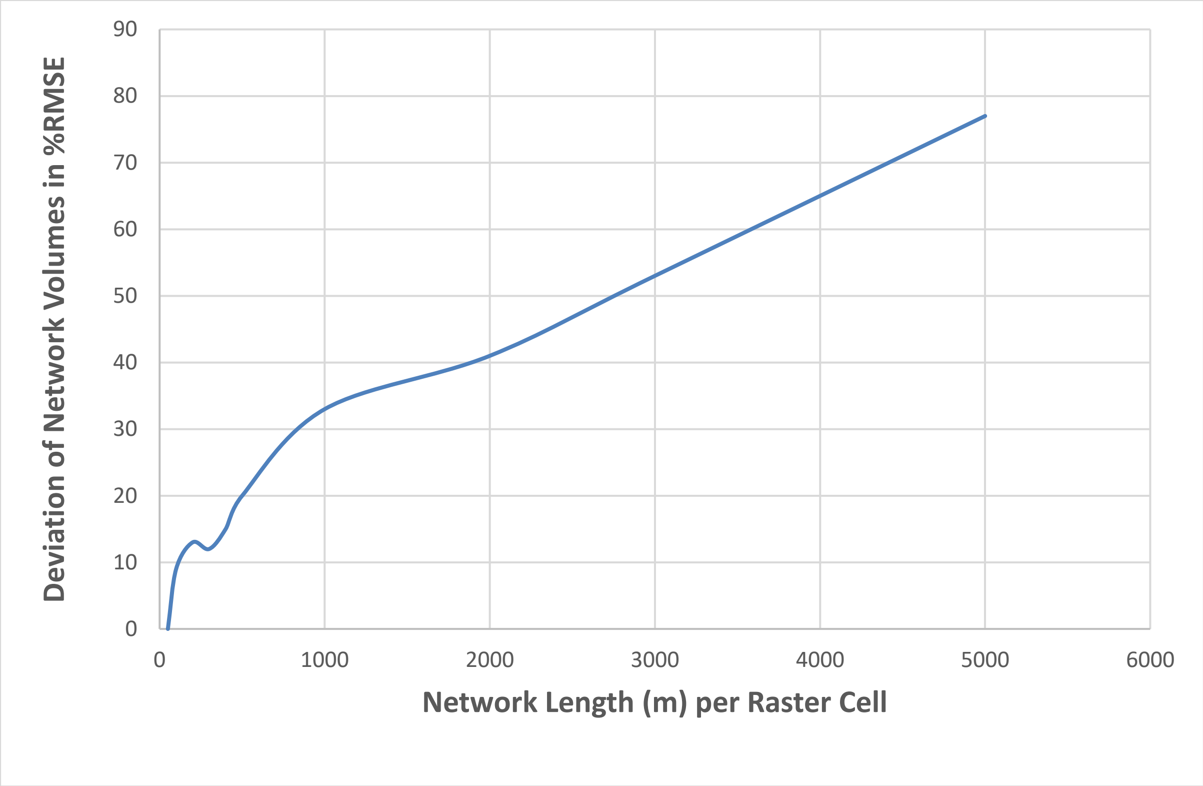

Figure 21: Difference in Network Volumes of Reference and Generated Zone Systems

In figure 21, the graph is plotted between the threshold values and the difference in network volumes between reference and generated zone systems in form of %RMSE. It can be depicted that as the zone size is swelling, the car volumes difference is inclining. It is following the same trend as for study area 1 that the graph has a sudden sheer after 1000m network length and the difference is very noteworthy.

5.3 No. of Zones and Network Volumes in Study Area 3

Number of zones of reference and nine generated zone systems for Augsburg city which has a densely connected network, was also put into comparison. Figure 22 represents the relationship between threshold values and number of resulting raster cells formed by gradual rasterization process.

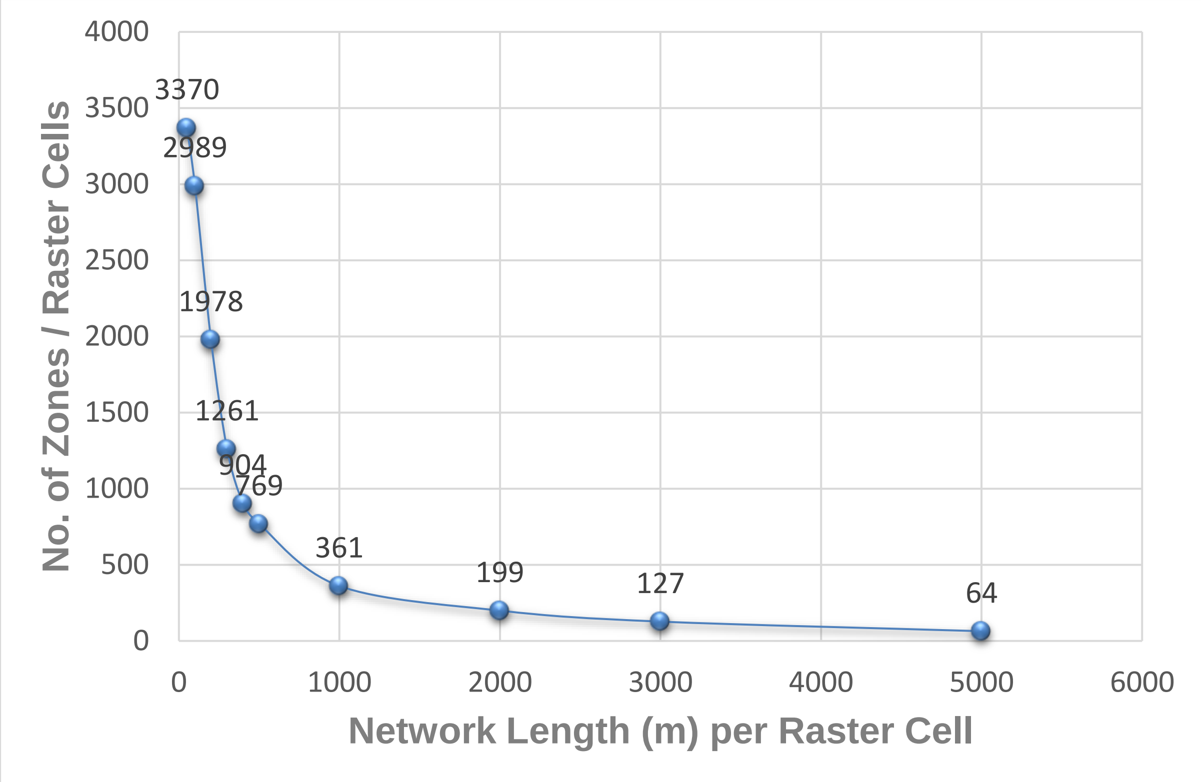

Figure 22: Number of Raster Cells for Augsburg

From the graph in figure 22, which is plotted between network length within a raster cell against the number of cells formed based on these thresholds, it can be imagined that the pattern of decline in number of transport analysis zones TAZ is similar to other study areas. With the incline in threshold values, the number of zones drops expressively till the threshold value reach to 1000m network length. After that the decline is very straight and not so effective.

The network volumes for reference zone system were also compared for study area of Augsburg to the car volumes obtained by trip assignment of nine generated zone systems. %RMSE was plotted against the network length in meters per raster cell to do the comparison as shown in figure 23. From the graph, it can be seen that the deviation is gradually growing as the zone size becomes coarser till the threshold value reaches 1000m and then there is a sudden climb in the deviation after 2000m network length.

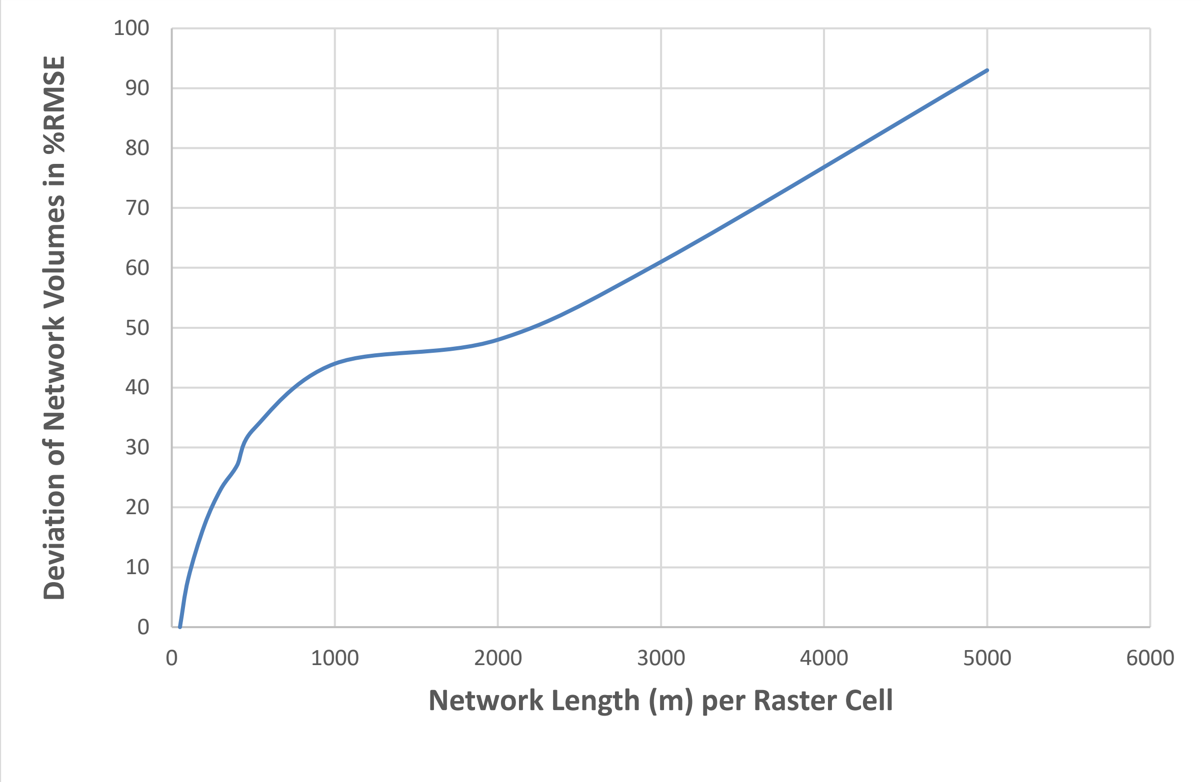

Figure 23: Difference in Network Volumes of Reference and Generated Zone Systems

6. Comparison between Different Study Areas

6.1 Network Volumes

Comparison between the error in network car volumes of reference and nine generated zone systems across different study areas were plotted in figure 24 to see the behavior of resolution change across different regional scales. The graph picturizes that the difference in network volumes in %RMSE is growing as the zone size is increasing. The trend across different regional scales is the same. Maxvorstadt and Augsburg are densely networked regions where the deviation is gradually inclining till 1000m threshold values but then the size of zones become very bulky, so the difference becomes very steep and substantial. Puchheim being a sub-urban region follows the same trend but with lesser deviation in network car volumes comparatively.

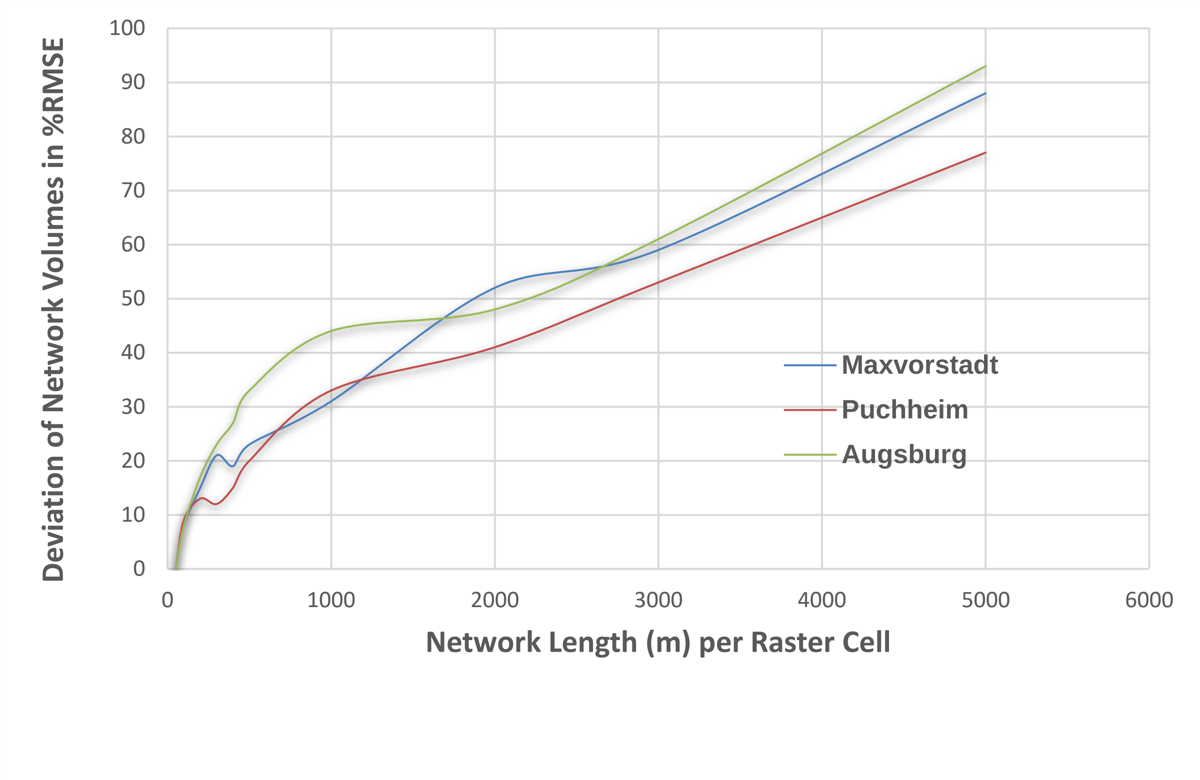

Figure 24: Difference in Network Volumes of Reference and Generated Zone Systems

6.2 Number of zones

The number of reference and generated zones for all the study areas were compared against the network length in meters within one raster cell. This comparison was done to see how threshold of network length effects the number of raster cells across different regional scales as shown in figure 25. There is a sharp decline in the number of raster cells generated in all three regions as the network length is rising to 1000m.

After 1000m threshold value, the trend shows a linear behavior and the reduction in zone formation is less. The zones become of greater size and the network inside the zone becomes of smaller length compared to zone resolution. When the resolution reaches 4000m to 5000m and so on, the zones are very coarser, and the numbers of raster cell are very less.

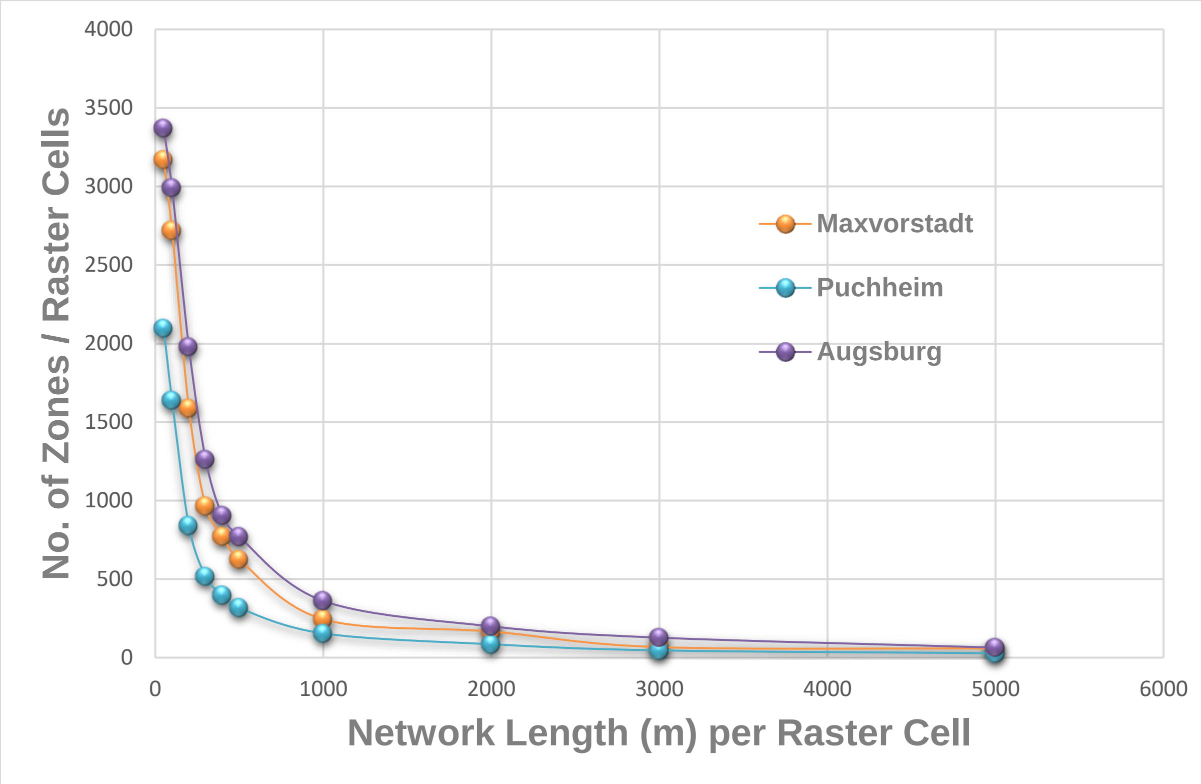

Figure 25: Number of Raster Cells

6.3 Computational Time of Gradual Rasterization

Gradual rasterization is a repetitive procedure to generate raster cells according to the threshold values. It works on the algorithm previously explained which requires powerful computational machines to run the algorithm. In this research work, the process of gradual rasterization was performed on three different study areas of different regional scales to create reference and nine different zone systems. This was done on desktop computer having Intel Core i7 3rd generation processor with RAM of 12GB. The amount of time taken by the machine to form different zone systems is compared in figure 26 for all the three areas.

The graph is between the computational time in minutes compared to the threshold values in meters. It can be derived from the relation in the graph that the finer zone systems required much longer time compared to the coarser ones in all study areas. The time relation is falling pointedly as the network length is slightly growing towards 1000m threshold value. After 1000m, the trend is linear, and the computational requirement is less, and the algorithm runs a lot faster.

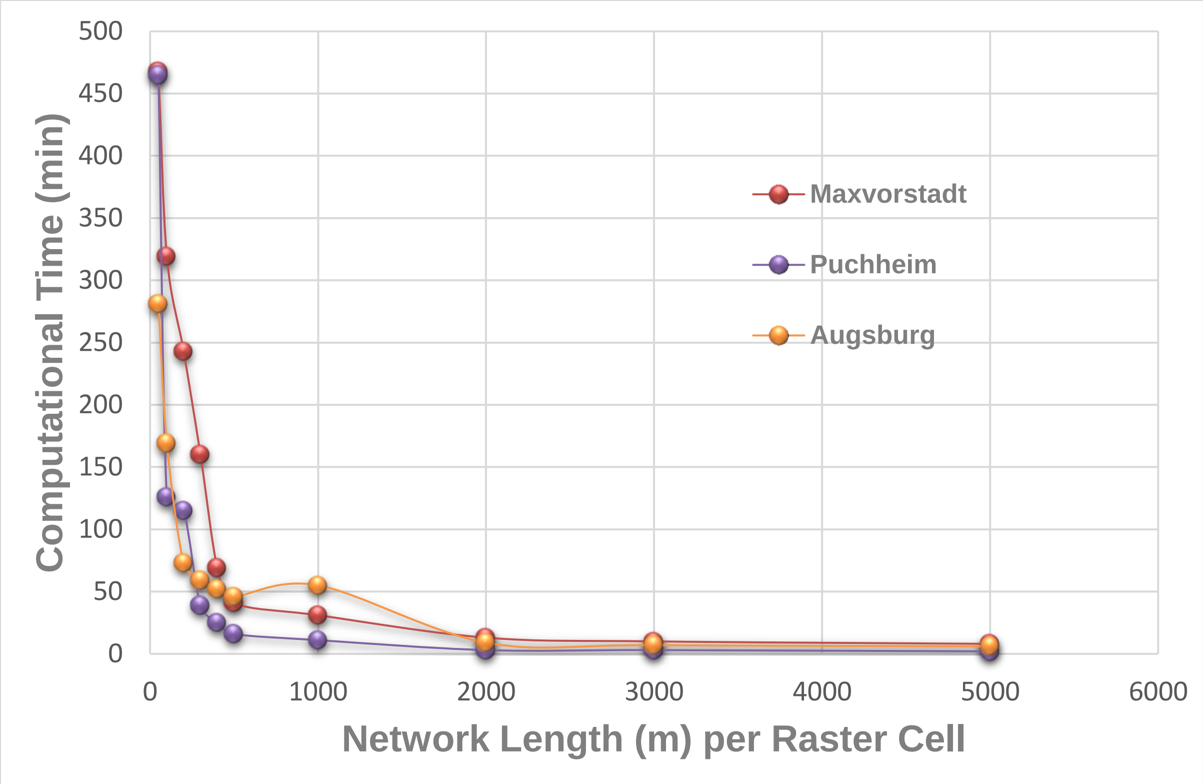

Figure 26: Computational Time

6.4 Intrazonal Trips

For the reference zone systems of all the study areas, it was assumed that as the size of the zones is fine enough, so each raster cell comprises of one attraction and production trip. Hence, there is only one intrazonal trip within a raster cell. The generated zones were of larger size due to increase in threshold values, therefore the intrazonal trips within one raster cell will increase compared to the reference zone system cells. If in the reference zone system, four cells are considered each having one trip and then in the generated zone system, these four cells combine to form a main zone, the main zone will then comprise of four intrazonal trips.

In figure 27, the increase in percentage of number of intrazonal trips in generated zone systems for all three study areas are compared to the threshold values i.e. network length in meters per raster cell. From the relation in the graph, it can be clearly perceived that the intrazonal trip share is snowballing very suddenly as the zone becomes of coarser resolution. The increase is very prominent till 1000m network length, then it becomes gradual as the network length moves to

5000m. It is because the number of zones is not growing expressively so the increase in intrazonal trips is not so significant.

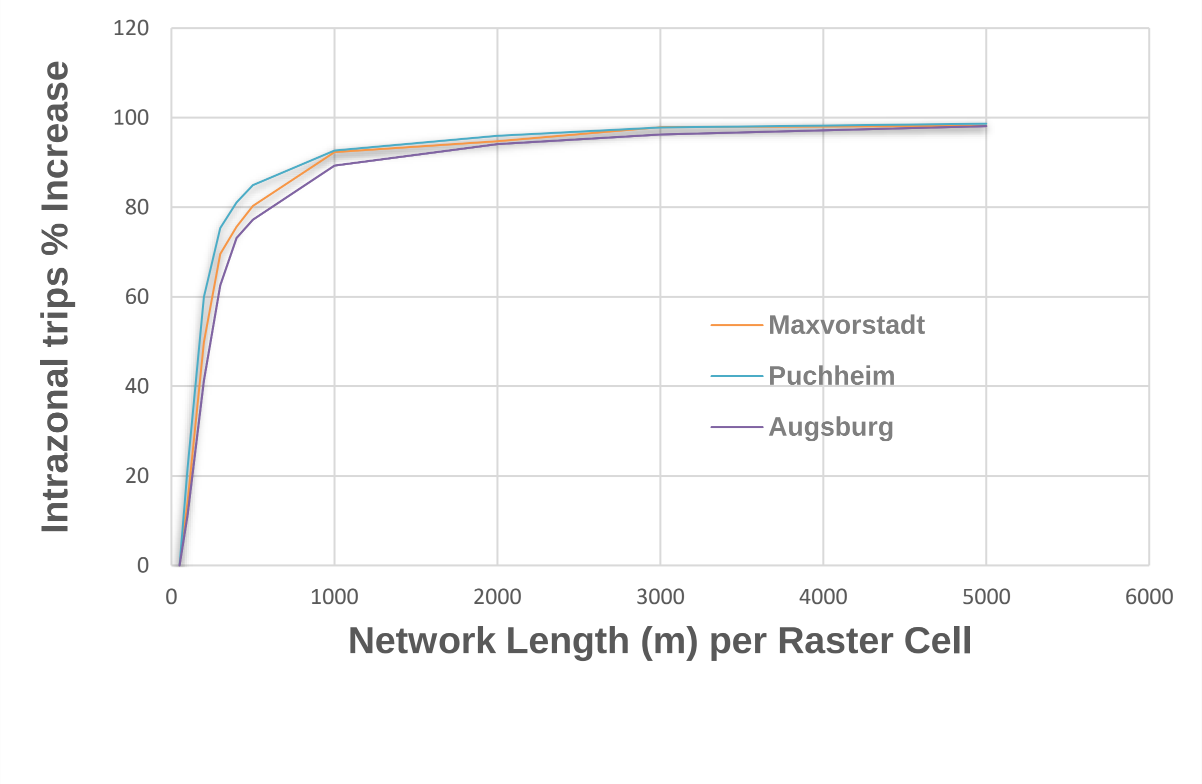

Figure 27: Intrazonal Trips increase compared to Reference Zone System Trips

7. Conclusion

7.1 Conclusion of Research

Analyzing the above comparison of network car volumes, number of raster cells and intrazonal trip share, makes it obvious that the application of smaller size of transport analysis zones helps in improving the assignment results and reduce the loss of information within a zone due to presence of less intrazonal trips. On the other hand, the creation of these fine zonal resolution system demands high computational speed but with the advancement of computers to super computers, the computational speed is of less concern and can easily be coped with.

To find out an appropriate spatial resolution of transport analysis zones mainly depends on the disaggregation of area into transport analysis zones of finer resolution and the improvement of assignment results. There must be a certain limit of disaggregation of an area into TAZs after which the assignment results show no improvements. The best solution to resolve an appropriate resolution of transport analysis zones is to find a balance between the number of raster cells and assignment results.

For this purpose, a normalized cost function is created to give equal weightage both to assignment results and number of raster cells. The variables are of different units hence normalized between 0 and 1 to analyze the comparison of both. The normalized cost function is referred as (Okrah, 2017):

$$F(x, y) = \alpha(x) + \beta(y);\ \alpha + \beta = 1$$

Where x represents the difference in assignment results between reference and generated zone systems while y represents the number of raster cells and α and β shows the relative participation of each variable, each having value of 0.5. Figure 28, 30 and 32 pictures the normalized cost function input variables of car volumes and raster cells for each network length in meters per raster cell. The normal cost function variables of both car volumes and raster cells are summed up to find the normalized function output and is plotted in figures 29, 31,33 as a cost function curve.

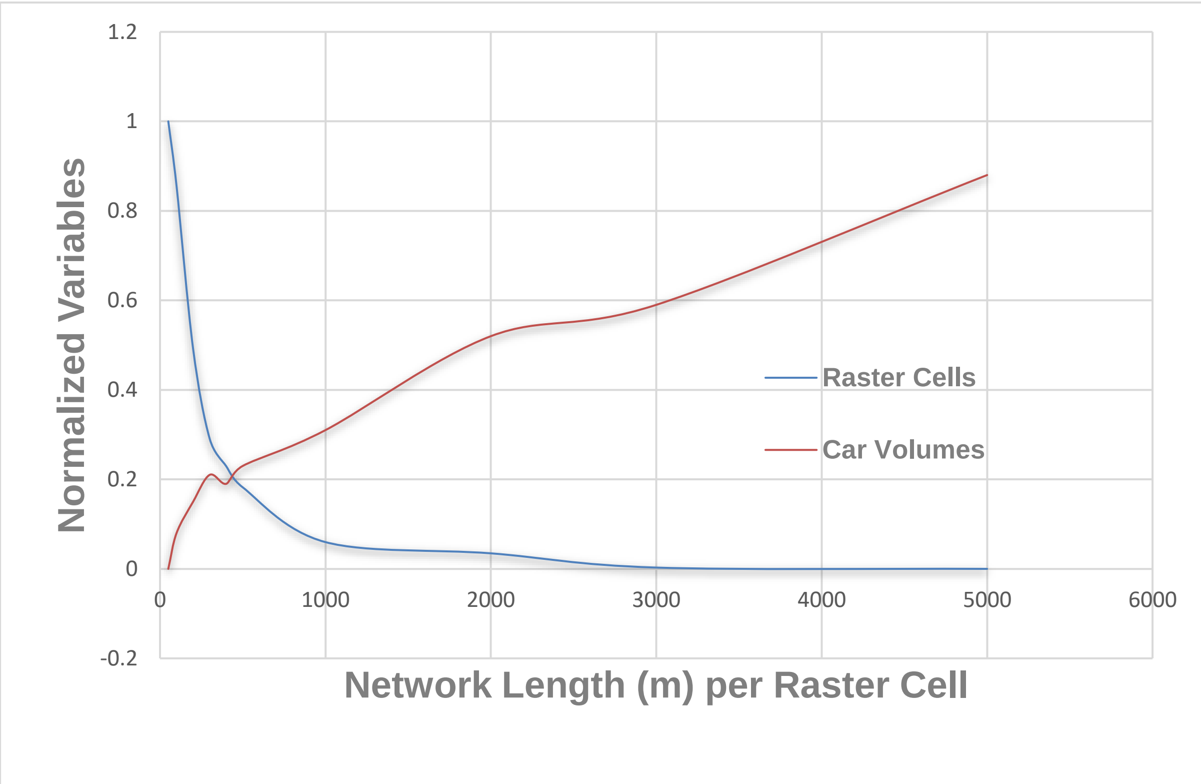

Figure 28: Normalized Cost Function Input for Maxvorstadt

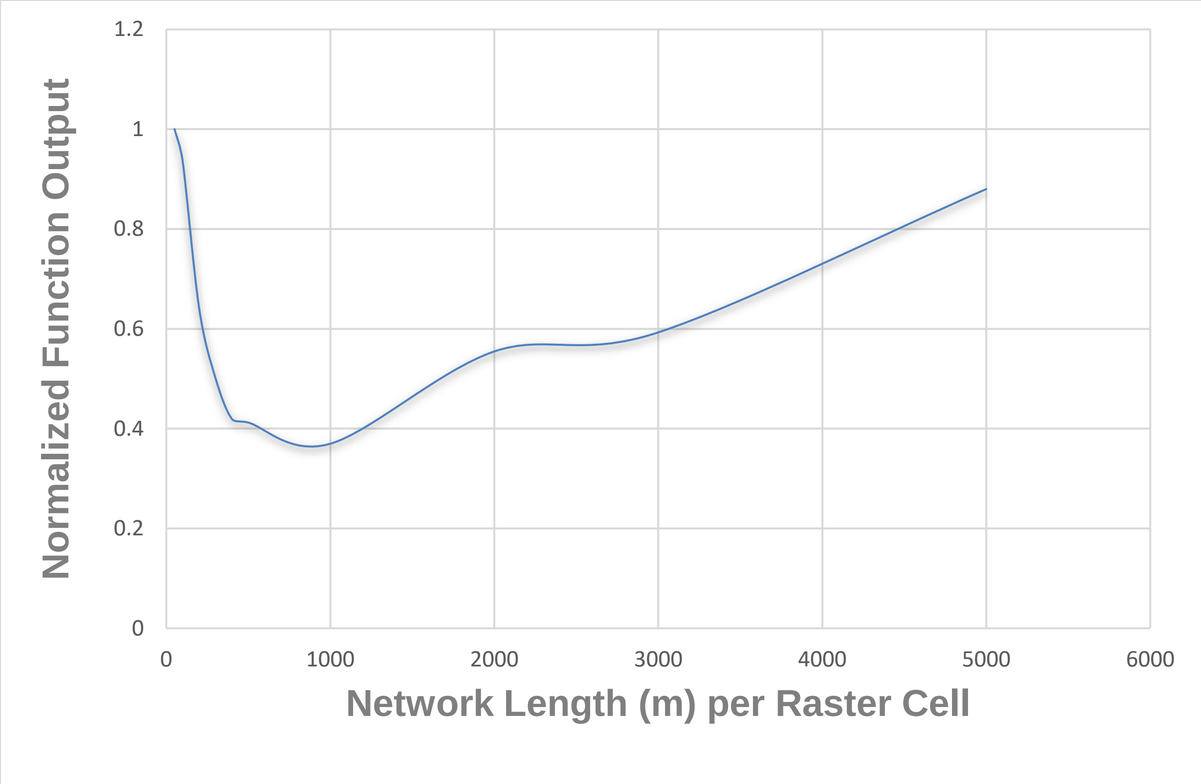

Figure 29: Cost Function Curve for Maxvorstadt

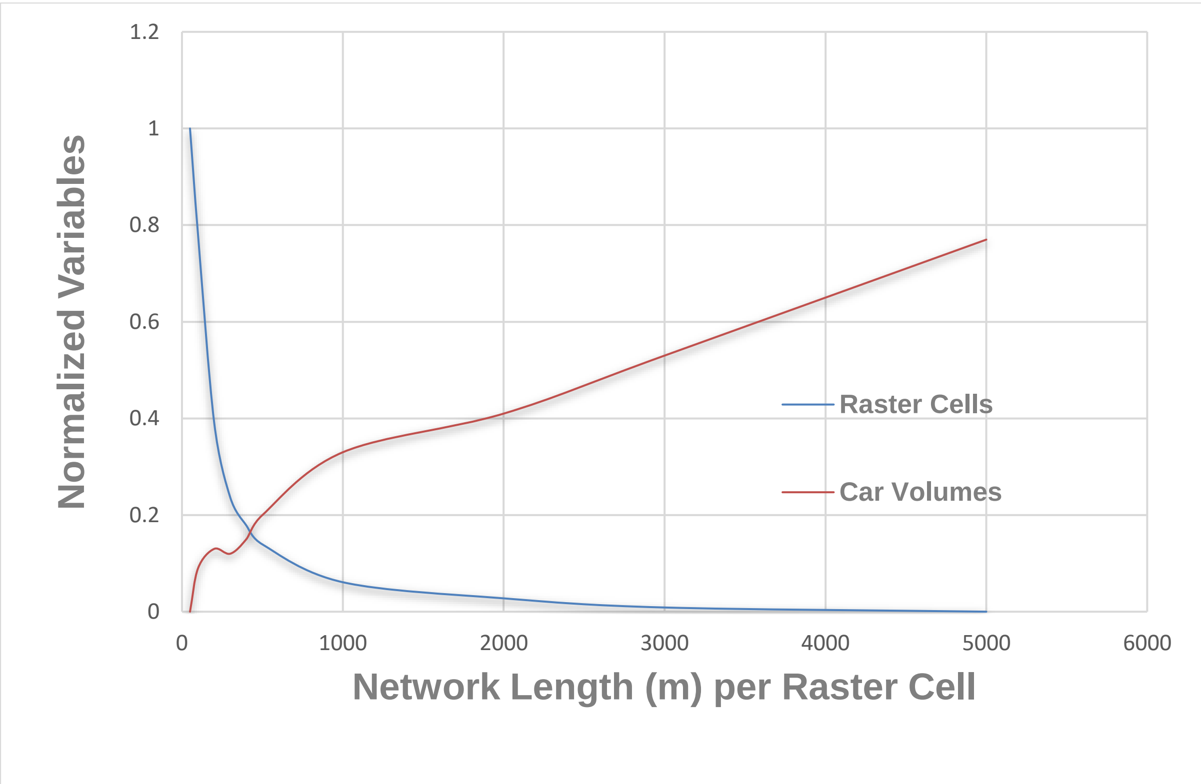

Figure 30: Normalized Cost Function Input for Puchheim

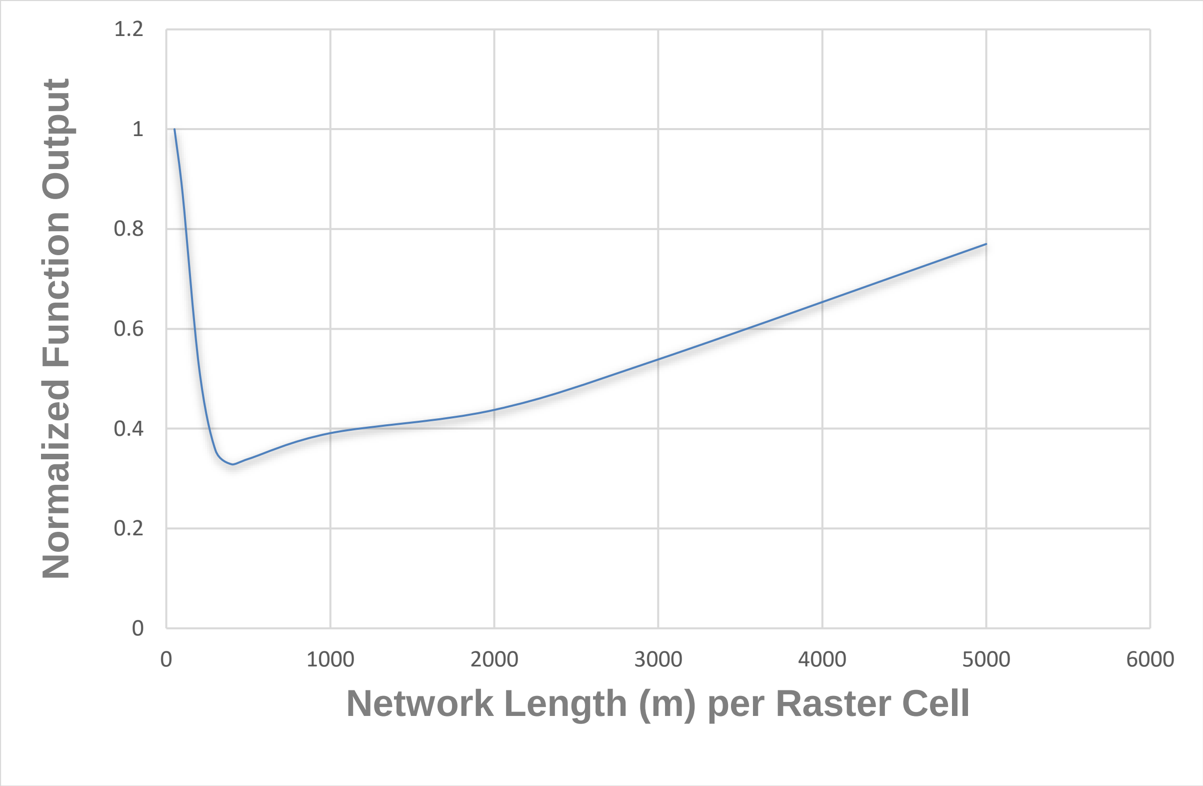

Figure 31: Cost Function Curve for Puchheim

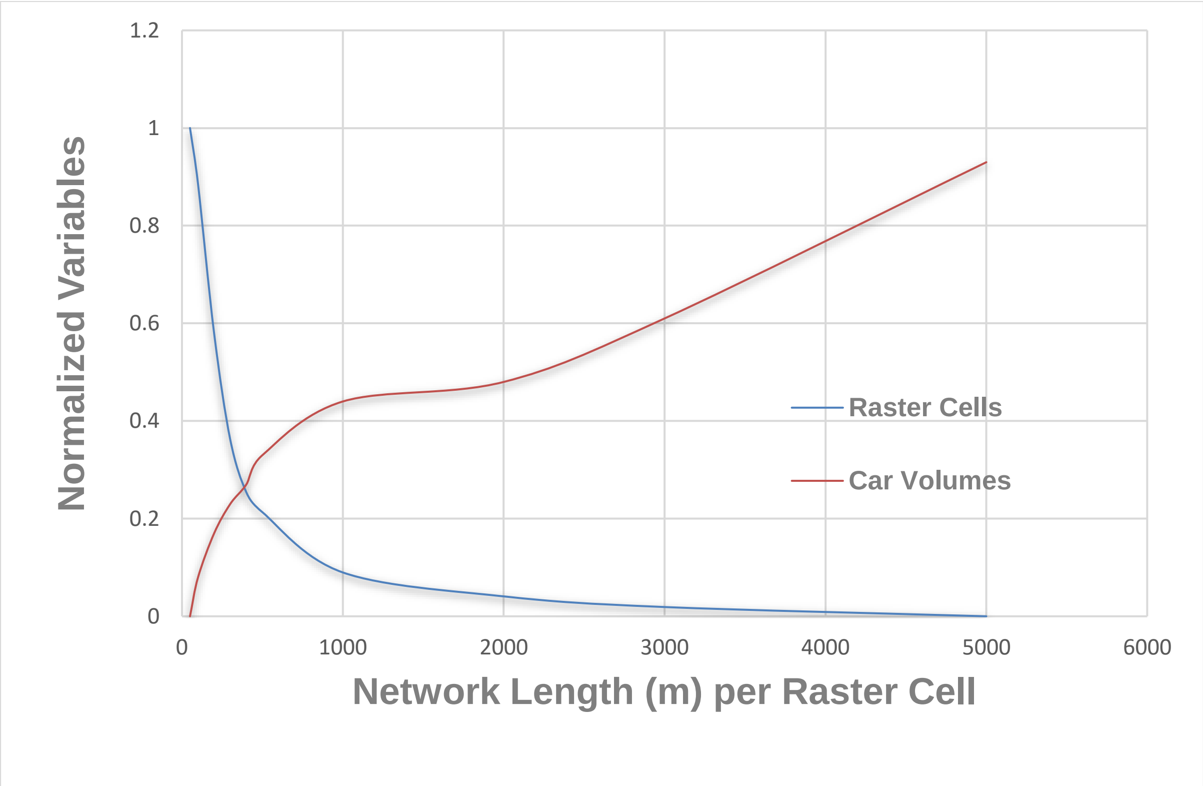

Figure 32: Normalized Cost Function Input for Augsburg

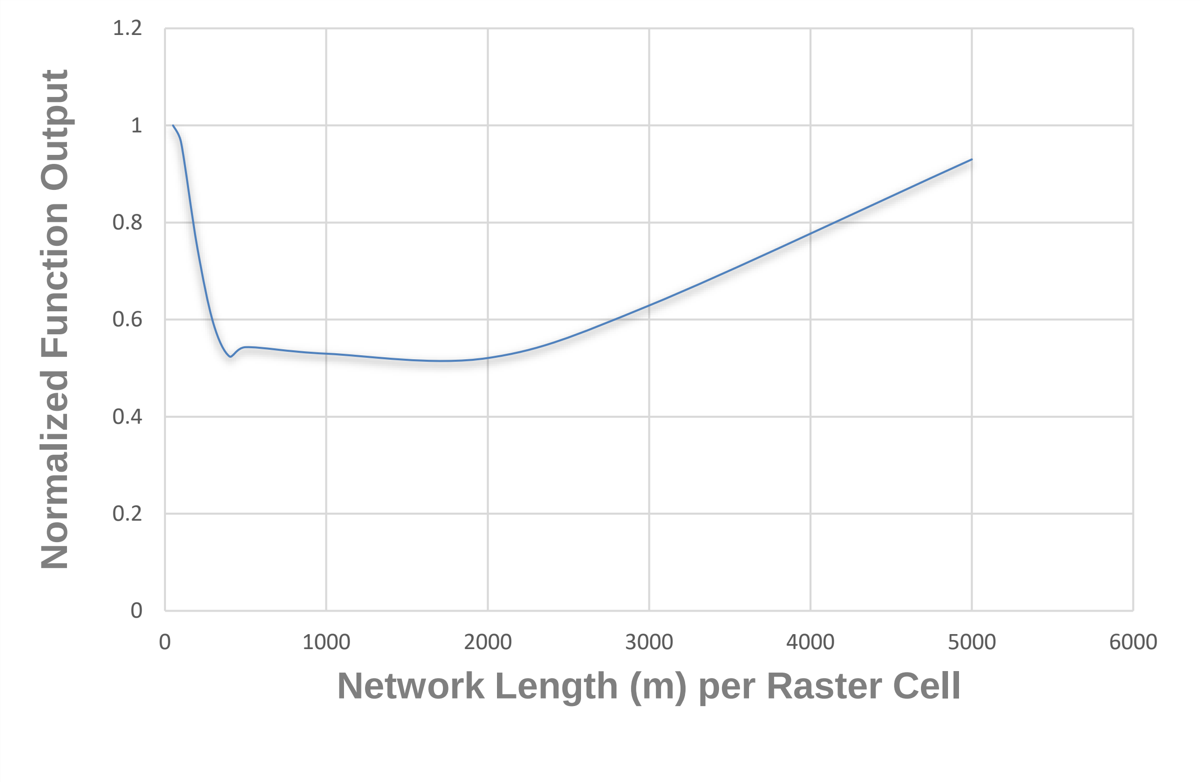

Figure 33: Cost Function Curve for Augsburg

From the graph in figure 28, the number of raster cells for Maxvorstadt region keep falling as the network length in meters increases. On the other hand, the network volumes error is on the rise. Both lines cut each other at 400m threshold value. Before 400m, the decrease in number of raster cells is very sharp and the increase in deviation of network volumes is also very projecting but after the meeting point, the trend shows a gradual behavior for both variables. The same sequence can be observed in figure 30 for Puchheim area where both the variables meet each other at 400m network length. Same is the case for Augsburg region in figure 32. The network volume deviation becomes very noteworthy after the 400m cut point and the number of raster cells rise a lot if the network length is reduced beyond this point for all study areas.

In figure 29 of cost function curve for Maxvorstadt, it can be described that the minimum cost occurs at 800m threshold value. However, in figure 31 for Puchheim and in figure 33 for Augsburg region, the minimum curve point is at 400m which is the same as deducted from input variables graph where the cost of deviation in network volumes and raster cells meet each other. The cost function graph provides us with the combined cost effect of both network car volumes and number of raster cells generated. The lowest point in the curve represents the minimum cost of both input variables. In figure 34, the comparison of cost curve can be envisioned for all the three study areas.

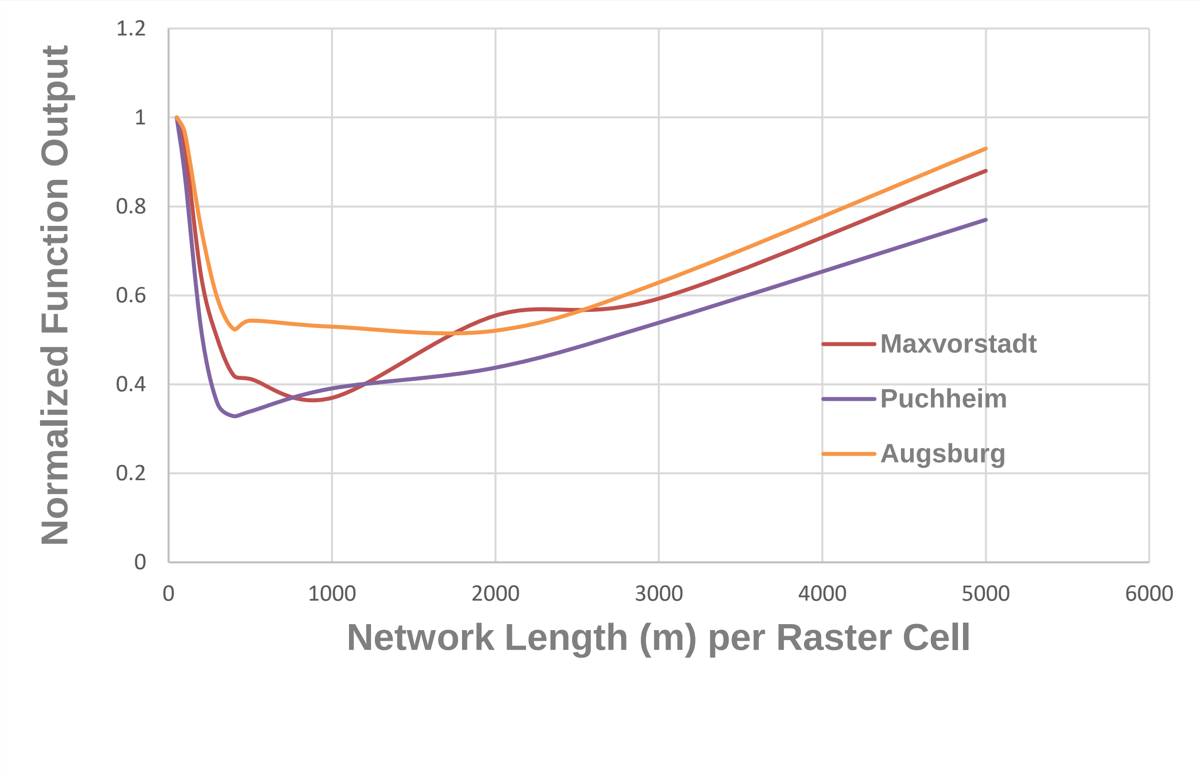

Figure 34: Comparison of Cost Function Curve

After the comparison and analysis of all parameters, it can be derived that the appropriate spatial resolution of transport analysis zones TAZs can be taken in between 400m and 1000m threshold values which will provide cost effective resolution in terms of assignment results and the number of generated cells, computational speed and loss of information as intrazonal trips. It is difficult to specify a single threshold value to generate zones as in this research work the Maxvorstadt area gives us a cost-effective resolution at 800m network length but Puchheim and Augsburg provides minimum cost at 400m threshold value. The difference is due to the difference in network density and region characteristics. However, it can be obviously seen that 400m network length is the limit of disaggregation of transport analysis zones below which the cost rises in all parameters for all study areas.

7.2 Limitations of the Study

This research work was subjected to some limitations and restrictions such as the limitation of number of allowable transport analysis zones by PTV Visum software. Due to this reason, a smaller area was taken into consideration for analysis. The availability of demographic data and real values of attraction and production trips can provide more realistic results. The assignment results were only calculated for cars and can be also computed for pedestrians and bikes.

7.3 Future Research Recommendations

For future research, it is recommended that an open source software such as MATSim can be used to assign trips which has no restrictions on the use of number of zones. As MATSim is an activity-based modelling software, the zones centroids can be referred as activity agents and assigned to the network to model the results.

A reference zone system of 25m x 25m resolution can also be taken into consideration for a larger study region and can be related to an area of same urban nature. The comparison can also be performed at different regional scales such as municipality or state level and the results could be analyzed to end the debate of appropriate level of spatial resolution of transport analysis zones choice which can be utilized in all models for all types of regions. For improvement in computational time of gradual rasterization process, high speed RAM is recommended.

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Appendix I: Script for Gradual Rasterization

Created on 17 Dec 2017 16:00

@creator: Adnan Raees

```
import arcpy;

FINAL_FISHNET=r'E:\Project Adnan\Augsburg\Fishnets.gdb\FinalFishnet';

INITIAL_SHAPE=r'E:\Project Adnan\Augsburg\Initial Polygon\Initial_Shape.gdb\Initial_Shape';

ROADS_SHAPE=r'E:\Project Adnan\Augsburg\Roads\Roads.gdb\Roads'

FISHNET_GDB = r'E:\Project Adnan\Augsburg\Fishnets.gdb';

INTERSECT_GDB=r'E:\Project Adnan\Augsburg\Intersects.gdb';

TEMPPOLYGON=r'E:\Project Adnan\Augsburg\Temp.gdb\temp_polygon'


MIN_GRID_SIZE= 50;

MAX_SUM_LENTH = 1000;


fishnetcount=0;

intersectcount=0;


def MakeFishnet(Polygon):

        global  fishnetcount

        global intersectcount

        extent=Polygon.extent;

        #print extent.XMin,extent.YMin

        #print extent.XMax,extent.YMax

# Replace a layer/table view name with a path to a dataset (which can be a layer file) or create the layer/table view within the script

# The following inputs are layers or table views: "Initial_Shape_Intersect"

fishnetcount = fishnetcount + 1;

arcpy.CreateFishnet_management(out_feature_class=FISHNET_GDB+"\MyFishnet3EXTT"+str(fishnetcount),

        origin_coord=str(extent.XMin)+" "+str(extent.YMin),

        y_axis_coord=str(extent.XMin)+" "+str(extent.YMax),cell_width="", cell_height="",

        number_rows="2", number_columns="2",
```

```
            corner_coord=str(extent.XMax)+" "+str(extent.YMax),
            template=Polygon, geometry_type="POLYGON")
with
arcpy.da.UpdateCursor(FISHNET_GDB+"\MyFishnet3EXTT"+str(fishnetcount), ['Shape_Length', 'Shape@',
'Shape@X', 'Shape@Y']) as cursor_rec:
for row2 in cursor_rec:
            Polygon=row2[1]
            extent = Polygon.extent;
            intersectcount=intersectcount+1;

#Creating temp polygon feature class
array = arcpy.Array([arcpy.Point(extent.XMin, extent.YMin),
            arcpy.Point(extent.XMin, extent.YMax),
            arcpy.Point(extent.XMax, extent.YMax),
            arcpy.Point(extent.XMax, extent.YMin)
            ])
polygon = arcpy.Polygon(array)
cursor = arcpy.da.InsertCursor(TEMPPOLYGON, ['SHAPE@'])
cursor.insertRow([polygon])
# Delete cursor object
del cursor
#_____________________________________________________
arcpy.Intersect_analysis([TEMPPOLYGON,ROADS_SHAPE],INTERSECT_GDB+'\
Intersect'+str(intersectcount), "ALL", "",
                    "")

arcpy.DeleteRows_management(TEMPPOLYGON);
if ((extent.XMax-extent.XMin)/2>MIN_GRID_SIZE):
Sum_Length=0;
with arcpy.da.SearchCursor(INTERSECT_GDB+'\Intersect'+str(intersectcount),
            ['Shape_Length']) as cursor_sumlength:
for row_rd in cursor_sumlength:
```

```
        Sum_Length=Sum_Length+row_rd[0]

if (Sum_Length>MAX_SUM_LENTH):
        cursor_rec.deleteRow()
        print "extent.XMax-extent.XMin: ",extent.XMax-extent.XMin
        print "Sumlength: ", Sum_Length
        MakeFishnet(Polygon)

arcpy.env.workspace = FISHNET_GDB
for row in arcpy.ListFeatureClasses():
        arcpy.Delete_management(row)
        arcpy.env.workspace = INTERSECT_GDB
for row in arcpy.ListFeatureClasses():
        arcpy.Delete_management(row)

with arcpy.da.SearchCursor(INITIAL_SHAPE,['Shape_Length', 'Shape@', 'Shape@X', 'Shape@Y']) as cursor_rec:
for row in cursor_rec:
        MakeFishnet(row[1]);
        fishnet_finalpolygons=[];
        arcpy.env.workspace = FISHNET_GDB

# Use the ListFeatureClasses function to return a list of
#  shapefiles.
featureclasses = arcpy.ListFeatureClasses();
for row in featureclasses:
        if row.endswith('label'):
        arcpy.Delete_management (row)
else:
        fishnet_finalpolygons.append(row)
        #arcpy.Delete_management (row)
        arcpy.Merge_management(inputs=fishnet_finalpolygons, output=FINAL_FISHNET)
```