# Three-Dimensional Visualisation of Traffic Volume Changes in the Metropolitan Area of Minneapolis-Saint Paul in 1996 and 2016

**Simon Zwick[1]; Andreas Keler[2]; Jukka M. Krisp[3]**

## Abstract

Investigating traffic volume is essential in order to be able to determine the impact of current and future traffic on road networks. The present study examines the Annual Average Daily Traffic (AADT) and the Heavy Commercial Annual Average Daily Traffic (HCAADT) in the metropolitan area of Minneapolis-St. Paul in 1996 and 2016. In particular, the traffic volume data is visualized both two- and three-dimensionally using various visualisation techniques. Comparisons based on these 2D and 3D visualisations strongly indicate an overall increase in traffic volume from 1996 to 2016. Differences between the increase of AADT and HCAADT data as well as spatially differing patterns could also be identified. The paper documents initial findings on visualizing traffic volumes in a two and three-dimensional way.

**Keywords**
traffic; traffic volume; AADT; HCAADT; visualisation;
twin cities Minneapolis–St. Paul

## Zusammenfassung

Um die Auswirkungen des aktuellen sowie zukünftigen Verkehrsaufkommens auf Straßennetze bestimmen zu können, ist eine Analyse der Verkehrsstärke unabdingbar. Die vorliegende Studie untersucht in diesem Zusammenhang den sog. Annual Average Daily Traffic (AADT) und den sog. Heavy Commercial Annual Average Daily Traffic (HCAADT) in der Metropolregion Minneapolis-St. Paul in den Jahren 1996 und 2016. Dazu werden die Daten über die Verkehrsstärke mit verschiedenen Visualisierungstechniken sowohl zwei- als auch dreidimensional dargestellt. Ein auf diesen 2D- und 3D-Visualisierungen basierender Vergleich weist deutlich auf einen allgemeinen Anstieg des Verkehrsaufkommens von 1996 bis 2016 hin. Dabei konnten auch Unterschiede zwischen dem Anstieg der AADT- und HCAADT-Daten sowie sich räumlich unterscheidende Muster festgestellt werden. Zudem dokumentiert die Studie erste Erkenntnisse zur zwei- und dreidimensionalen Visualisierung der Verkehrsstärke.

**Schlüsselwörter**
Verkehr; Verkehrsstärke; AADT; HCAADT; Visualisierung;
Zwillingsstädte Minneapolis-St. Paul

## 1 Introduction and Purpose

Comprehensive and precise traffic data is essential when both the impact of existing traffic on a road network as well as the current condition of the network need to be assessed. Additionally, such data can be used to predict the impact of future traffic demand and the future performance of road networks (U.S. DOT 2016).

In this context, data about traffic volume is especially important, because it provides information about necessary maintenance, renovation and improvement measures. When combined with maximum capacity specifications of a road network, traffic disruptions and traffic jams can also be predicted (Jedlička et al. 2015b). Furthermore, traffic volume data is very useful for identifying critical traffic flow time periods, for determining the influence of large vehicles or pedestrians on vehicular traffic flow, or for documenting traffic trends (CTRE 2002).

Traffic volume denotes the number of vehicles passing a road segment within a certain time window. However, the traffic volume count heavily depends on the measurement type, i.e. the measurement station, the traffic flow direction, the vehicle types and the chosen time frame (Jedlička et al. 2015a). According to Sharma et al. (1996) three major types of traffic volume measures can be distinguished:

- Annual Average Daily Traffic (AADT)
- Annual Average Weekday Traffic (AAWT)
- Average Daily Traffic (ADT)

This study mainly deals with the Annual Average Daily Traffic (AADT). AADT is a theoretical estimate of the

[1, 3] Applied Geoinformatics, Institute of Geography, University of Augsburg (UniA), Alter Postweg 118, 86159 Augsburg, Germany
[2] Department of Civil, Geo and Environmental Engineering, Technical University of Munich (TUM), Arcisstraße 21, 80333 Munich, Germany

total number of vehicles using a specific road segment (in both directions) on any given day of the year, i.e. it represents the total number of cars per year divided by 365 while considering factors that adjust for season, day of the week and vehicle type (MnDOT 2017a). A more specific type of traffic volume estimate is the Heavy Commercial Average Annual Daily Traffic (HCAADT). As the HCAADT is part of the AADT, it is measured and calculated in the same way (MnDOT 2017b). A heavy commercial vehicle can be defined as a commercial vehicle with a gross vehicle weight of at least 10,000 pounds (lbs), which equals ca. 4,500 kilograms (kg) (49 U.S.C. § 32901 2014). Therefore, we aim to investigate an approach on how to efficiently and effectively visualize traffic volume so that spatio-temporal changes may be identified. This paper focuses on the visualisation and comparison of AADT and HCAADT counts from 1996 and 2016 in the metropolitan area of Minneapolis-St. Paul in Minnesota.

## 2 Types of Visualisation

When visualizing traffic related data the illustration of spatial properties is one of the main aspects to consider (Chen et al. 2015; Picozzi et al. 2013). According to Chen et al. (2015), the visualisation of spatial properties can be categorized into three classes:

- Point-based visualisation: This rather simple visualisation method represents samples of traffic information as discrete dots (Keler and Krisp 2016). The advantage of point-based visualisation is that it can show the distribution of data records. It is, however, inefficient at showing continuous information (Chen et al. 2015).
- Line-Based Visualisation: Line-based visualisation techniques are designed to display traffic trajectories, roadmaps or traffic flow. Usually, a trajectory is represented by a line or curve. Since trajectories pose the most common form of traffic data (Chen et al. 2015), multiple studies investigate their visualisation and analysis (Guo et al. 2011; Liu et al. 2011; Scheepens et al. 2016; Tominski et al. 2012; Wang et al. 2013).
- Region-Based Visualisation: Region-based visualisation shows traffic related data based on individual regions. Typically, traffic data is aggregated within regions according to predetermined rules. Such techniques are useful for revealing macro patterns in traffic data (Chen et al. 2015).

Which type of visualisation is most suitable mainly depends on what type of data is to be visualized. There are several kinds of traffic related data: Data about traffic incidents (VanDaniker 2009), traffic speed (Guo et al. 2011; Keler et al. 2016) traffic congestions/ jams (Chacon and Kornhauser 2012; Keler et al. 2016; Wang et al. 2013), traffic bottlenecks (Keler et al. 2017; Liu et al. 2011), traffic volume/density/flow (IS-practice n.d., 2017; Jedlička et al. 2015a; Scheepens et al. 2016) and travel efficiency (Zeng et al. 2014). The type of visualisation also depends on further requirements, e.g. whether the illustration should be interactive and/or flexible (Picozzi et al. 2013).

Since traffic related data sets often include huge numbers of records, line or polygon aggregation and visualisation techniques are usually preferred to simple visualisations (Andrienko and Andrienko 2007). Basically, traffic related data can be aggregated using heat, density or cluster maps (Andrienko and Andrienko 2007; Liu et al. 2011; Picozzi et al. 2013; Scheepens et al. 2016). More specifically, it is also possible to spatially aggregate traffic data by imposing a predefined grid over a certain region and computing average, minimum, and maximum values or the number of entities fitting in each polygon (Andrienko and Andrienko 2007; Liu et al. 2011). Furthermore, data records can also be aggregated within polygons like road segments (Chen et al. 2015). Generally three-dimensional maps offer the possibility to visualize the data in a different way, but the information included remains the same as in a two-dimensional map. In some cases, the use of the third dimension can aid the visualisation of spatial datasets consisting of two thematic variables and allows comparing them more directly (Krisp and Fronzek 2003).

A widely accepted and often used technique of visualizing traffic related data comprises the colouring of polygons according to different types of data (Guo et al. 2011; IS-practice n.d., 2017; Jedlička et al. 2015a; Jedlička et al. 2015b; Keler et al. 2016; Keler and Krisp 2016; Liu et al. 2011; Wang et al. 2013; Zeng et al. 2014). This approach is both selective and associative and can therefore contribute to an easier understanding of the illustrated traffic data (Tominski et al. 2012). Another possibility of visualizing traffic related data is to vary the thickness of cells or polygons according to the given data (Andrienko and Andrienko 2012; IS-practice n.d., 2017; Jedlička et al. 2015a; Jedlička et al. 2015b; Zeng et al. 2014). Sometimes, multiple coordinated views or mashup visualisations are applied as well. Such techniques utilize various visualisation methods for different data types simultaneously, i.e. they may vary the colour and thickness of a polygon according to two different variables for example (Jedlička et al. 2015a; Picozzi et al. 2013). Additionally, 2D and 3D visualisation techniques have to be distinguished. Whereas 2D illustrations are more common and have been used for many years, 3D visualisations represent more recent approaches, which still have to be brought to perfection. It is difficult to visually compare objects within a 3D scene and most 3D visualisations still suffer from symbol occlusion. One of their advantages, however, is the increase of data shown, i.e. the user is able to perceive a larger amount of contextual information (Shepherd 2008). Moreover, there are also hybrid visualisations (Keler et al. 2017; Tominski et al. 2012) or studies using both 2D and 3D maps (Keler et al. 2016).

## 3 Data and Methodology to identify Traffic Volume Changes in the Metropolitan Area of Minneapolis-Saint Paul

The chosen area of interest for this paper is the metropolitan area of Minneapolis-St. Paul in the U.S. state of Minnesota. More specifically, the investigation area encompasses the urbanized area of the mentioned twin cities, which is under jurisdiction of the Metropolitan Council (Metropolitan Council n. d.b). This area consists of seven counties, namely the Anoka, Carver, Dakota, Hennepin, Ramsey, Scott and Washington County (Metropolitan Council n. d.a). The total area covered by these seven counties accumulates to approximately 7,700 square kilometres (km$^2$) (Metropolitan Council 2017). According to the United States Census Bureau, the total population in the urbanized area of Minneapolis-St. Paul amounted to roughly 2.29 million in 1990 (U.S. Census Bureau 1995) and 2.85 million in 2010 (U.S. Census Bureau 2020a, 2020b). This leads to a general population density in the investigation area of approximately 297 people per km$^2$ in 1990 and 370 people per km$^2$ in 2010.

The geospatial data about traffic volume in Minnesota from 1996 to 2016 is made available by the Minnesota Department of Transportation (MnDOT). In particular, data containing information about the AADT and the HCAADT in Minnesota from 1992-2016 (MnDOT 2020) are utilized. The first file contains 34,017 unique location IDs of measuring stations, whereas the second file contains 4,558 location IDs. Each measuring station included in these datasets is associated with an exact description of its location and the corresponding AADT/HCAADT count for every year shown exemplary in Figure 1.

The Department of Transportation also provides data including the corresponding road segments for both the AADT and the HCAADT. These datasets feature every road on which an AADT or HCAADT measuring station is installed (MnDOT 2020). Each of the 35,499 AADT and 4,858 HCAADT road segments listed is associated with a detailed description of its location and its latest traffic volume count. Additionally, this study makes use of the overall road network in Minnesota, including a classification (e.g. Interstates, Highways etc.) of each of the 446,797 road segments (MnDOT 2012). A dataset which comprises all county boundaries in Minnesota along with some general information about each county is used as well (MNDNR 2013). In order to be able to process the previously described data, some basic preprocessing steps were required. First, the polygons of the seven counties making up the metropolitan area of Minneapolis-St. Paul had to be extracted. With these polygons, the spatial extent of all the other datasets was clipped to fit the investigation area. This procedure reduced the number of AADT and HCAADT locations to 9,843 and 1,012. At the same time, the number of AADT and HCAADT road segments decreased to 10,321 and 1,111.

All road segments which are denoted as 'Interstate', 'US High-way', 'MN Highway' or 'County State Aid Highway (CSAH)' were then extracted from the shapefile containing the overall road network of Minnesota. As a next step, the number of AADT and HCAADT road segments was further reduced. This was necessary because the current number of segments would have led to so-called 'overplotting' when visualized (Scheepens et al. 2016). Therefore, only those AADT and HCAADT road segments were selected, which share a line segment with the previously extracted segments of the general road network. Finally, overlapping segments of short length were deleted as well, which led to 3,300 AADT and 772 HCAADT remaining road segments.

These segments were buffered with a buffer radius of one meter. Afterwards, the average values of all measuring locations within a buffered segment were computed for each polygon. This way the AADT and HCAADT road segments were enriched with average traffic count values. However, as

| OBJECTID | ROUTE_NAME | LOCATION_D | CURR_YEAR | CURR_VOL | AADT_2016 | AADT_2015 |
|---|---|---|---|---|---|---|
| 709 | CR 61 | N OF CSAH4 (250th ST W) | 2016 | 315 | 315 | 300 |
| 710 | CSAH 2 | E OF TH13 | 2016 | 3300 | 3300 | 3050 |
| 711 | CSAH 23 | S OF CR56 (250th ST E) | 2016 | 2050 | 2050 | 2000 |
| 712 | TH 13 | N OF TH13 &19 | 2016 | 4250 | 4250 | 0 |
| 713 | CSAH 11 | N OF TH19 | 2016 | 1000 | 1000 | 1100 |
| 714 | TH 13 | &19 W OF E JCT TH13 | 2016 | 7400 | 7400 | 0 |
| 715 | CR 73 | S OF 245th AV NE IN EAST BETHEL | 2015 | 740 | 0 | 740 |
| 716 | CR 72 | W OF VERDIN ST NW in ST FRANCIS | 2015 | 1350 | 0 | 1350 |

*Fig. 1. Sample of basic traffic volume data (adapted from MnDOT 2020)*

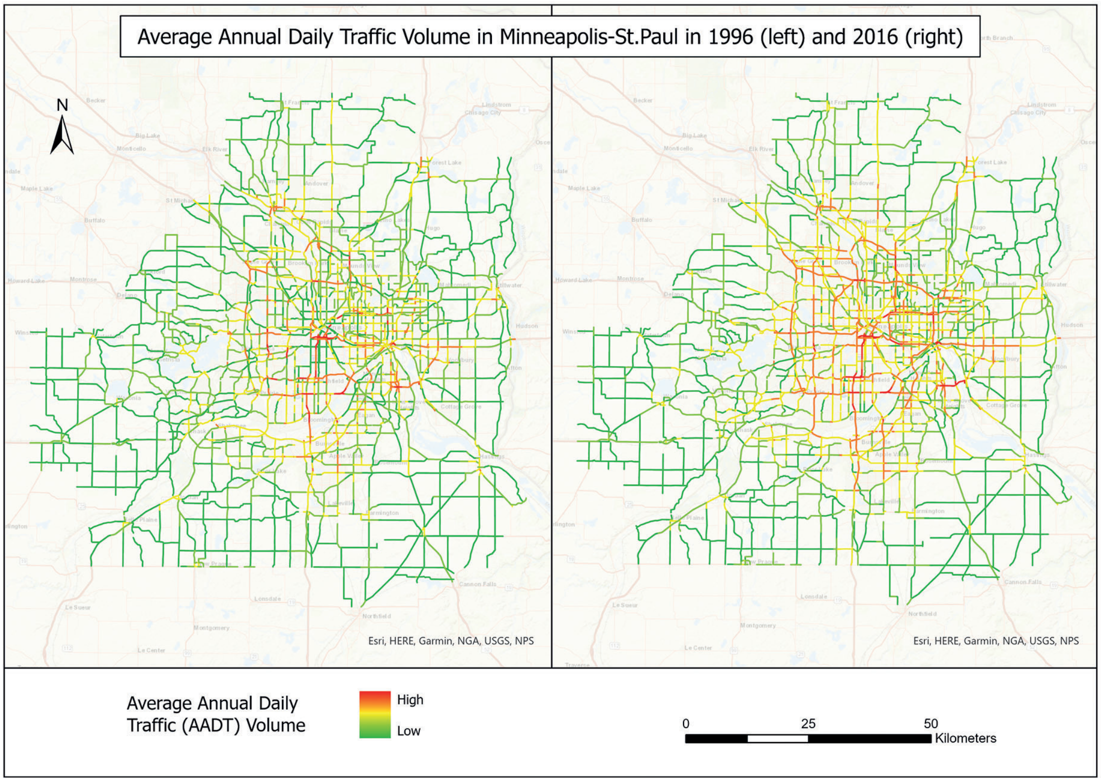


*Fig. 2. Two-dimensional plot of the AADT traffic volume in 1996 on the left side and 2016 on the right side*

can be perceived from Figure 1, some records do not contain any values for 1996 and 2016. That may lead to an average value of zero, which is why such records had to be recomputed. When the average traffic count of the mentioned years equals zero, the value of the previous year was used.

The enriched road segments were classified according to their traffic volume count. For this purpose, a data classification method called 'Geometric Interval' was used (ESRI n. d.). This was essential for the datasets from 2016 because the given data is not normally distributed. The number of classes was specified as five. The classification of the dataset from 1996 was adapted to match the classification boundaries of 2016 so that the corresponding visualisations could be compared. As a result, the traffic volume count was split up into five classes, each of which was assigned a different colour. Since opposing colours simplify discerning any patterns, a continuous colour scheme from green to red was chosen. That means that green road segments denote a low traffic volume, whereas red road segments denote a high volume.

Figure 2 depicts the two-dimensional visualisation of the AADT volume in 1996 and 2016. It shows that in 1996 lower values of AADT volume cluster especially on the roads in the outer regions and in the very centre of the metropolitan area (Figure 2, left side). Around the centre there is a ring-like area with medium traffic volume. The few roads with high traffic volume concentrate on the central area as well. In comparison, there are significantly fewer roads with low AADT volume in 2016 (Figure 2, right side). The roads with medium traffic are more numerous and spread farther from the centre. There are also noticeably more roads with high traffic volume. Thus Figure 2 indicates that the overall AADT volume in 2016 is higher than in 1996, in particular in the centre of the twin cities.

Figure 3 features the two-dimensional visualisation of the HCAADT volume in Minneapolis-St. Paul in 1996 and 2016. Since this data concentrates on heavy commercial vehicles, only the main roads are displayed. As before, the outer roads feature a lower traffic volume, whereas roads with high traffic volume can be found around the centre. As opposed to the AADT volume, there are less significant increases or decreases discernible when the HCAADT volumes of 1996 and 2016 (Figure 3) are compared.

3D visualisations provide an increase in illustrated contextual information (Shepherd 2008). Therefore, both the AADT and the HCAADT count in 1996 and 2016 are also represented in a three-dimensional map. However, for reasons of comparability, the classifi-

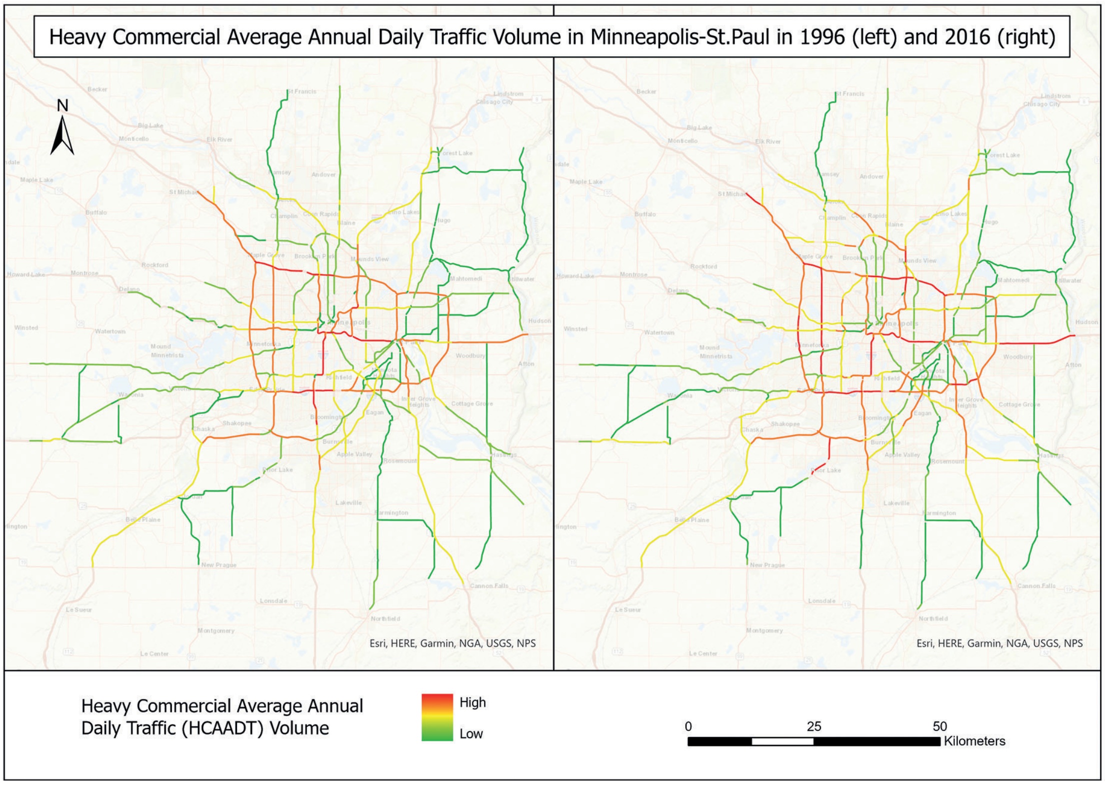


*Fig. 3. Two-dimensional plot of the HCAADT traffic volume in 1996 on the left side and 2016 on the right side*

cation and coloration of the data remains the same as before. The only difference is that the traffic volume count of each road segment polygon is now illustrated by colours as well as extrusion. Finally, each segment is extruded by a third of its absolute volume count.

Figure 4 and Figure 5 feature the three-dimensional visualisations of the AADT and HCAADT volume in Minneapolis-St. Paul. The 3D representations from 1996 and 2016 suggest that the overall AADT volume increased significantly in that period (Figure 4). More specifically, the AADT volume in the outer central regions multiplied more often than not, whereas the increase in the very centre of the investigation area is not as high. In contrast, the 3D representations of the HCAADT volume (Figure 5) show that there is no considerable rise. Yet, as some road segments indicate, the overall HCAADT volume increased slightly.

The visualisations of AADT and HCAADT data imply that from 1996 to 2016 the overall traffic volume in the metropolitan area of Minneapolis-St. Paul increased – especially in the city centre and the adjoining areas. However, while the AADT volume has increased significantly, no substantial changes of the HCAADT volume are discernible.

## 4 Discussion & Conclusion

In this study, two visualisation techniques were used: Colouring the road segments according to their respective traffic volume on the one hand and varying the thickness of the segments on the other hand. However, only the first method proved useful because the scale necessary to feature the whole investigation area led to overplotting of the road segments when their thickness was increased. The same problem occurred when multiple coordinated views were applied. Hence, the different colouration of the segments yielded the best results.

The 2D visualisations were useful for observing how low or high the traffic volume is on certain road segments and if the volume decreases or increases. The advantage of 2D visualisations is that the distribution and the changes of the data can be tied to spatial areas. Due to the classification method and the number of classes, however, it is difficult to discern and compare the absolute amount of traffic volume and its spatial distribution. Moreover, the effectiveness of this approach lessens with the expansion of the investigation area. If a large region is to be studied, the scale necessary to display the whole study area again leads to overplotting which in turn makes it hard to discern single road segments.

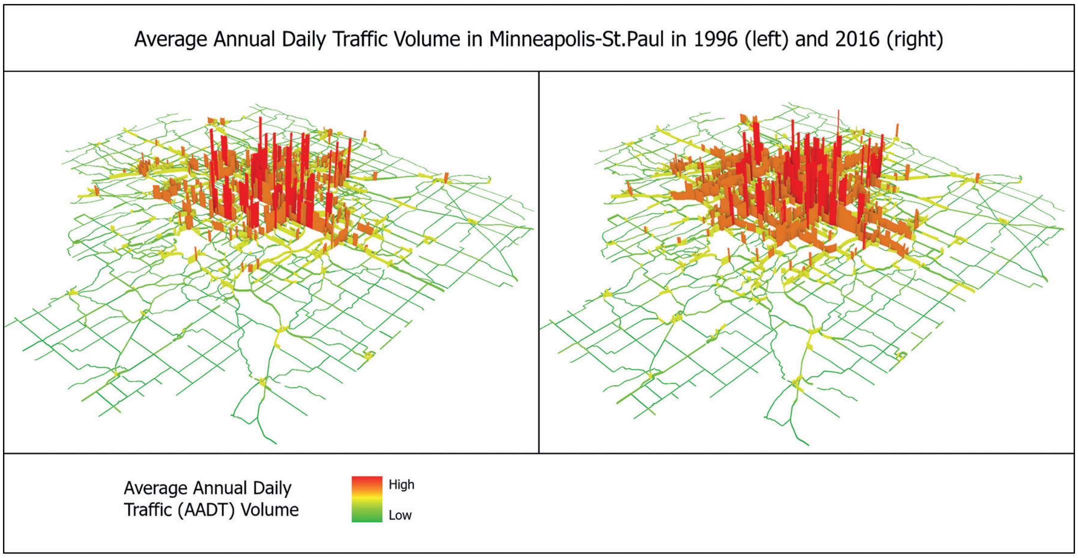


*Fig. 4. Three-dimensional plot of the AADT traffic volume in 1996 on the left side and 2016 on the right side*

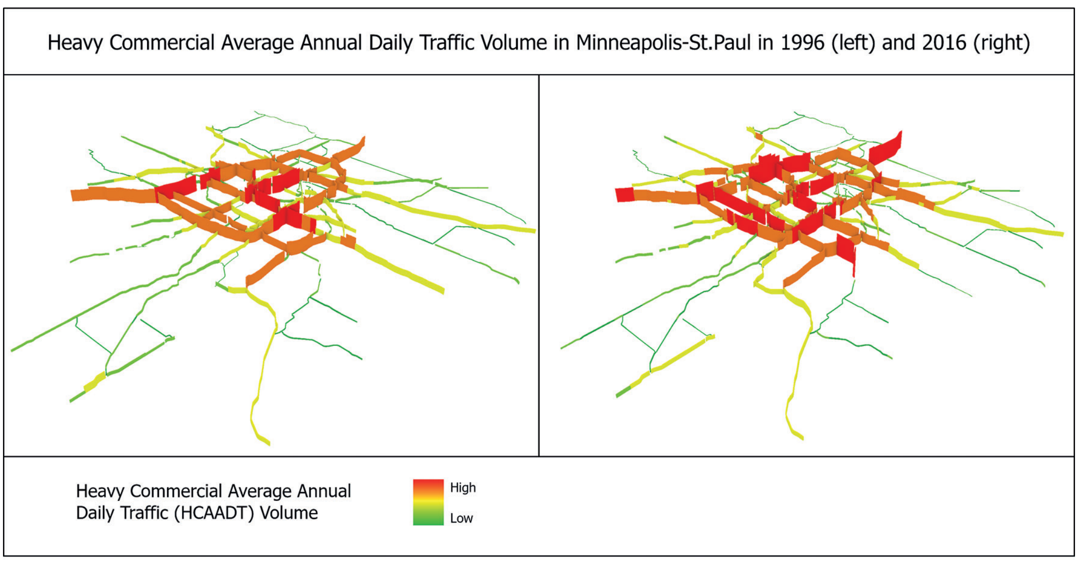


*Fig. 5. Three-dimensional plot of the HCAADT traffic volume in 1996 on the left side and 2016 on the right side*

As mentioned previously, occlusion poses a problem within the presented 3D maps, especially in Figure 4. Extruded road segments in the background which have a lower traffic volume cannot be seen because the objects up front conceal them. On the other hand, the three-dimensional visualisations provide a more expressive overview as far as the absolute amount of traffic volume per road segment is concerned. Additionally, spatio-temporal differences in the AADT and HCAADT count, i.e. the spatial distribution of increases or decreases of traffic volume between 1996 and 2016, can also be observed more clearly than in 2D visualisations. The problem of diminishing effectiveness with the expansion of the study area because of even greater object occlusion remains, though.

This study proposed an approach to visualize and compare the AADT and HCAADT volume from 1996 and 2016 in Minneapolis-St. Paul by using both 2D and 3D visualisations. The most promising results were achieved by colouring the individual road segments according to their respective traffic volume. In combination with two- and three-dimensional visualisations this proved to be a sound approach. The weaknesses of the 2D maps were compensated by the 3D illustrations and vice versa. As a result, the spatial distribution of the average traffic volume in the investigation area could be displayed. Furthermore, the spatio-temporal differences of AADT and HCAADT counts from 1996 to 2016 could be identified as well.

In general, the applied techniques are comparatively easy to perform and computationally efficient. Little time and resources are needed for both (pre-)processing the data and developing appropriate visualisations. This is why this approach is attractive for analysts who want to both efficiently and effectively visualize traffic volume in search of spatio-temporal patterns. However, two downsides of this model are evident: (1) This approach is very dependent on the data available and (2) the applied visualisation methods only allow an aggregated view of averaged values.

Consequently, the approach proposed in this paper must be denoted as preliminary. In order to be able to make more reliable statements about the current and the future traffic volume, their spatial distribution and their effects on the existing road network, further and more detailed studies will have to be conducted. Other methods of visualisation could be applied and spatio-temporal differences in traffic volume could be visualized in other ways. For example, the differences between 1996 and 2016 could be calculated by subtracting the traffic volume values of one layer from the other and visualizing the results.

## References

49 U.S.C. § 32901 (2014): 49 United States Code § 32901 - Definitions. Source: Cornell Law School, Legal Information Institute. Available online at https://www.law.cornell.edu/uscode/text/49/32901, checked on 2/17/2020.

Andrienko, N.; Andrienko, G. (2007): Designing Visual Analytics Methods for Massive Collections of Movement Data. In Cartographica: The International Journal for Geographic Information and Geovisualization 42 (2), pp. 117–138.

Andrienko, N.; Andrienko, G. (2012): Visual analytics of movement. An overview of methods, tools and procedures. In Information Visualization 12 (1), pp. 3–24.

Chacon, S.; Kornhauser, A. L. (2012): Analysis, Characterization, and Visualization of Freeway Traffic Data in Los Angeles. In 53rd Annual Transportation Research Forum, Tampa, Florida.

Chen, W.; Guo, F.; Wang, F.-Y. (2015): A Survey of Traffic Data Visualization. In IEEE Transactions on Intelligent Transportation Systems 16 (6), pp. 2970–2984.

CTRE (2002): Handbook of Simplified Practice for Traffic Studies. Center for Transportation Research and Education (CTRE), Iowa State University, Institute for Transportation. Ames, Iowa. Available online at http://publications.iowa.gov/11874/1/tr455web.pdf, checked on 2/17/2020.

ESRI (n. d.): ArcGIS Pro. Data classification methods. Enironmental Systems Research Institute (ESRI). http://pro.arcgis.com/en/pro-app/help/mapping/layer-properties/data-classification-methods.htm (17.02.2020).

Guo, H.; Wang, Z.; Yu, B.; Zhao, H.; Yuan, X. (2011): TripVista. Triple Perspective Visual Trajectory Analytics and its application on microscopic traffic data at a road intersection. In G. Di Battista (Ed.): 2011 IEEE Pacific Visualization Symposium (PacificVis). Hong Kong, China, 1/3/2011 - 4/3/2011. Piscataway, NJ: IEEE, pp. 163–170.

IS-practice (n.d.): Traffic volume in Plzen. With assistance of Plan4All. https://intenzitadopravy.plzen.eu/ (17.02.2020).

IS-practice (2017): Visualisation of Traffic Intensity for Plzen, Czechia. Edited by J. Bouchal. http://www.is-practice.eu/visualisation-of-traffic-intensity-for-plzen-czechia/ (17.02.2020).

Jedlička, K.; Ježek, J.; Kepka, M.; Hájek, P.; Mildorf, T.; Kolovský, F.; Beran, D. (2015a): Dynamic Visualization of Volume of Traffic. In Papers ICC, pp. 1–13.

Jedlička, K.; Mildorf, T.; Charvat, K.; Kozhukh, D.; Martolos, J.; Šťastný, J. (2015b): Benefits of Using Traffic Volumes Described on Examples in the Open Transport Net Project Pilot Regions. In AGRIS on-line Papers in Economics and Informatics VII (2.2015), pp. 39–46.

Keler, A.; Ding, L.; Krisp, J. (2016): Visualization of traffic congestion based on Floating Taxi Data. In Kartographische Nachrichten 66 (1.2016), pp. 7–13.

Keler, A.; Krisp, J. (2016): Visual Analysis of Floating Taxi Data Based on Interconnected and Timestamped Area Selections. In G. Gartner, M. Jobst, H. Huang (Eds.): Progress in Cartography. EuroCarto 2015. Cham: Springer International Publishing (Lecture Notes in Geoinformation and Cartography), pp. 115–131.

Keler, A.; Krisp, J.; Ding, L. (2017): Visualization of Traffic Bottlenecks. Combining Traffic Congestion with Complicated Crossings. In M. P. Peterson (Ed.): Advances in Cartography and GIScience. Selections from the International Cartographic Conference 2017. Cham: Springer International Publishing (Lecture Notes in Geoinformation and Cartography), pp. 493–505.

Krisp, J.; Fronzek, S. (2003): Visualizing Thematical Spatial Data by Using the Third Dimension. In: 9th Scandinavian Research Conference on Geographical Information Science (ScanGIS). Espoo, Finland, pp. 157–166.

Liu, H.; Gao, Y.; Lu, L.; Liu, S.; Qu, H.; Ni, L. M. (2011): Visual analysis of route diversity. In S. Miksch (Ed.): IEEE Conference on Visual Analytics Science and Technology (VAST), 2011. Providence, RI, USA, 23 - 28 Oct. 2011. Piscataway, NJ:

IEEE, pp. 171–180.
Metropolitan Council (n. d.a): Community Profiles. https://stats.metc.state.mn.us/profile/Default.aspx (16.02.2020).
Metropolitan Council (n. d.b): The Twin Cities Region. A great place to live, work, raise a family and do business. https://metrocouncil.org/About-Us/Who-We-Are/The-Twin-Cities-region.aspx (17.02.2020).
Metropolitan Council (2017): Community Profiles. Community Profile for Twin Cities Region (7-county). https://stats.metc.state.mn.us/profile/detail.aspx?c=R11000 (16.02.2020).
MNDNR (2013): County Boundaries, Minnesota. Minnesota Department of Natural Resources (MNDNR); Minnesota Geospatial Commons. https://gisdata.mn.gov/dataset/bdry-counties-in-minnesota (17.02.2020).
MnDOT (2012): Roads, Minnesota, 2012. Minnesota Department of Transportation (MnDOT); Minnesota Geospatial Commons. https://gisdata.mn.gov/dataset/trans-roads-mndot-tis (17.02.2020).
MnDOT (2017a): Annual Average Daily Traffic Count Locations, Minnesota. Minnesota Department of Transportation (MnDOT); Minnesota Geospatial Commons. https://gisdata.mn.gov/dataset/trans-aadt-traffic-count-locs (17.02.2020).
MnDOT (2017b): Heavy Commercial Annual Average Daily Traffic Count Locations, Minnesota. Minnesota Department of Transportation (MnDOT); Minnesota Geospatial Commons. https://gisdata.mn.gov/dataset/trans-hcaadt-traffic-count-locs (17.02.2020).
MnDOT (2020): Traffic Forecasting & Analysis. Data Products. Minnesota Department of Transportation (MnDOT). https://www.dot.state.mn.us/traffic/data/data-products.html (17.02.2020). Available online at https://www.dot.state.mn.us/traffic/data/maps-muni-front.html, checked on 2/17/2020.
Picozzi, M.; Verdezoto, N.; Pouke, M.; Vatjus-Anttila, J.; Quigley, A. (2013): Traffic Visualization. Applying Information Visualization Techniques to Enhance Traffic Planning. In S. Coquillart (Ed.): Proceedings of the International Conference on Computer Graphics Theory and Applications and International Conference on Information Visualization Theory and Applications. Barcelona, Spain, 21-24 February. S.l.: SciTePress, pp. 554–557.
Scheepens, R.; Hurter, C.; van de Wetering, H.; van Wijk, J. J. (2016): Visualization, Selection, and Analysis of Traffic Flows. In IEEE transactions on visualization and computer graphics 22 (1), pp. 379–388.
Sharma, S. C.; Gulati, B. M.; Rizak, S. N. (1996): Statewide Traffic Volume Studies and Precision of AADT Estimates. In Journal of Transportation Engineering 122 (6), pp. 430–439.
Shepherd, I. D. H. (2008): Travails in the Third Dimension. A Critical Evaluation of Three-Dimensional Geographical Visualization. In M. Dodge, M. McDerby, M. Turner (Eds.): Geographic visualization. Concepts, tools and applications. Hoboken: John Wiley & Sons Ltd, pp. 199–222.
Tominski, C.; Schumann, H.; Andrienko, G.; Andrienko, N. (2012): Stacking-Based Visualization of Trajectory Attribute Data. In IEEE transactions on visualization and computer graphics 18 (12), pp. 2565–2574.
U.S. Census Bureau (1995): Minnesota. Population of Counties by Decennial Census: 1900 to 1990. Edited by R. L. Forstall. United States Census Bureau (U.S. Census Bureau). https://www.census.gov/population/cencounts/mn190090.txt (17.02.2020).
U.S. Census Bureau (2020a): QuickFacts. Anoka County, Minnesota; Carver County, Minnesota; Dakota County, Minnesota; Hennepin County, Minnesota. United States Census Bureau (U.S. Census Bureau). https://www.census.gov/quickfacts/fact/table/anokacountyminnesota,carvercountyminnesota,dakotacountyminnesota,hennepincountyminnesota/POP010210 (17.02.2020).
U.S. Census Bureau (2020b): QuickFacts. Ramsey County, Minnesota; Scott County, Minnesota; Washington County, Minnesota. United States Census Bureau (U.S. Census Bureau). https://www.census.gov/quickfacts/fact/table/ramseycountyminnesota,scottcountyminnesota,washingtoncountyminnesota/POP010210 (17.02.2020).
U.S. DOT (2016): Traffic Monitoring Guide. United States Department of Transportation (U.S. DOT); Federal Highway Administration, Office of Highway Policy Information. Washington, D.C. Available online at https://www.fhwa.dot.gov/policyinformation/tmguide/, checked on 2/17/2020.
VanDaniker, M. (2009): Visualizing real-time and archived traffic incident data. In : IEEE International Conference on Information Reuse & Integration (IRI), 2009. Las Vegas, NV, USA, 10/8/2009 - 12/8/2009. Piscataway, NJ: IEEE, pp. 206–211.
Wang, Z.; Lu, M.; Yuan, X.; Zhang, J.; van de Wetering, H. (2013): Visual traffic jam analysis based on trajectory data. In IEEE transactions on visualization and computer graphics 19 (12), pp. 2159–2168.
Zeng, W.; Fu, C.-W.; Arisona, S. M.; Erath, A.; Qu, H. (2014): Visualizing Mobility of Public Transportation System. In IEEE transactions on visualization and computer graphics 20 (12), pp. 1833–1842.