

**Analysis and Optimization of the**

**Charging Station Network in Germany**

Scientific work for the attainment of the degree

Master of Science

at the TUM School of Management

of the Technical University of Munich

Examiner: Univ.-Prof. Dr. Dr. h. c. mult. Horst Wildemann

Research Institute

Corporate management, logistics and production

Supervisor: Sebastian Junker M.Sc.

Course of study: Master TUM-BWL

Submitted by: Giovanni Filomeno

Arcistraße 21

80333 Munich

Matriculation number 03669006

Submitted on:

Table of contents

[Table of contents I](#_Toc104306641)

[List of Figures II](#_Toc104306642)

[List of tables III](#_Toc104306643)

[1. Introduction 4](#_Toc104306644)

[1.1 Subsection 1 4](#_Toc104306645)

[1.2 Subsection 2 5](#_Toc104306646)

[2. Section 2 6](#_Toc104306647)

[2.1 Subsection 1 6](#_Toc104306648)

[2.1.1 Subsection 1 6](#_Toc104306649)

[2.1.2 Subsection 2 6](#_Toc104306650)

[Bibliography IV](#_Toc104306651)

List of figures

[Figure 1: Figure 1 4](#_Toc480276945)

# 

# List of tables

[Table 1: Example table 5](#_Toc480276941)

# Introduction

Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diam voluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet[[1]](#footnote-2) . Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diam voluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet.

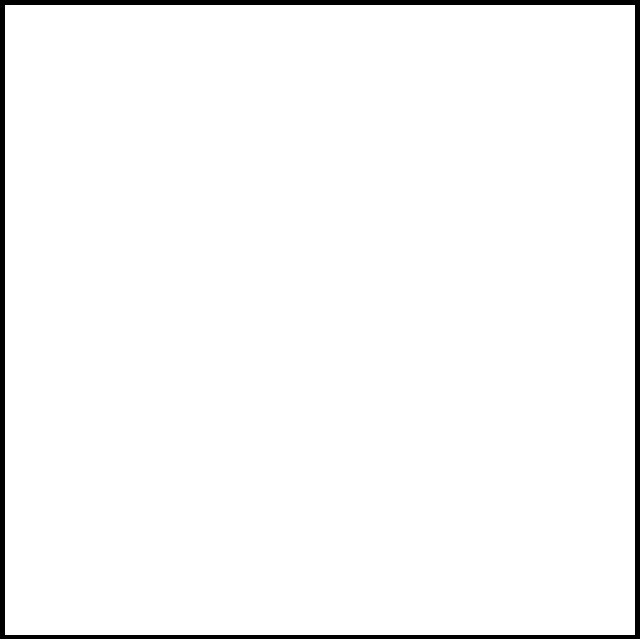


Figure 1: Figure 1

Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat nulla facilisis at vero eros et accumsan et iusto odio dignissim qui blandit praesent luptatum zzril delenit augue duis dolore te feugait nulla facilisi. Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat[[2]](#footnote-3) .

## Subsection 1

Ut wisi enim ad minim veniam, quis nostrud exerci tation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat. Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat nulla facilisis at vero eros et accumsan et iusto odio dignissim qui blandit praesent luptatum zzril delenit augue duis dolore te feugait nulla facilisi.

Nam liber tempor cum soluta nobis eleifend option congue nihil imperdiet doming id quod mazim placerat facer possim assum. Lorem ipsum dolor sit amet, consectetuer adipiscing elit, sed diam nonummy nibh euismod tincidunt ut laoreet dolore magna aliquam erat volutpat. Ut wisi enim ad minim veniam, quis nostrud exerci tation ullamcorper suscipit lobortis nisl ut aliquip ex ea commodo consequat.

Duis autem vel eum iriure dolor in hendrerit in vulputate velit esse molestie consequat, vel illum dolore eu feugiat nulla facilisis.

## Subsection 2

At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet. Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod tempor invidunt ut labore et dolore magna aliquyam erat, sed diam voluptua. At vero eos et accusam et justo duo dolores et ea rebum. Stet clita kasd gubergren, no sea takimata sanctus est Lorem ipsum dolor sit amet. Lorem ipsum dolor sit amet, consetetur sadipscing elitr, At accusam aliquyam diam diam dolore dolores duo eirmod eos erat, et nonumy sed tempor et et invidunt justo labore Stet clita ea et gubergren, kasd magna no rebum. sanctus sea sed takimata ut vero voluptua. est Lorem ipsum dolor sit amet. Lorem ipsum dolor sit amet, consetetur sadipscing elitr, sed diam nonumy eirmod tempor invidunt ut labore et dolore magna aliquyam erat.

|  |  |
| --- | --- |
| **A** | **B** |
| Lorem | 42,0% |
| Ipsum | 37,5% |
| Dolor | 37,5% |

Table 1: Example table

# Model and Analyse

## Network Theory

### Diameter

The diameter of a graph is a fundamental concept in the field of graph theory, offering significant insights into the overall structural properties of the graph.

In a formal sense, the diameter of a graph is defined as the greatest shortest path length between any pair of vertices within the graph. It signifies the longest of all the shortest paths which can be navigated from one vertex to any other vertex within the graph (Diestel, 2010).

To express this mathematically, let's denote a graph as G = (V, E), where V is the set of vertices and E is the set of edges present in the graph. For any pair of vertices, u and v in V, let d(u, v) denote the shortest path distance between these vertices. Thus, the diameter D of G is represented by the formula:

D = max {d(u, v) | u, v ∈ V}

Here, the diameter D is the maximum over all shortest path distances d(u, v) for every pair of vertices u and v in the graph (Cormen et al., 2009).

In the case of a disconnected graph, where there exist vertices that do not have a path between them, the diameter is often defined as infinity. For a graph containing only a single vertex, the diameter is defined as 0.

The concept of the diameter of a graph is applied in numerous applications, such as in network design and analysis, devising algorithms for effective information routing in distributed systems, and in discerning the structure of social networks among others (Newman, 2010).

It's important to note that the process of calculating the diameter of a graph can be computationally expensive, particularly for large graphs. A number of algorithms have been developed to compute the diameter of a graph, which include but are not limited to, the Floyd-Warshall algorithm and Johnson’s algorithm (Cormen et al., 2009).

References:

Cormen, T. H., Leiserson, C. E., Rivest, R. L., & Stein, C. (2009). Introduction to Algorithms (3rd ed.). The MIT Press.

Diestel, R. (2010). Graph Theory, 4th Edition (Vol. 173). Springer.

Newman, M. (2010). Networks: An Introduction. Oxford University Press.

### Average Distance

The average distance in a graph, also known as the average path length or the characteristic path length, is another crucial concept in graph theory. This metric gives an indication of the overall navigability and connectivity of the graph.

Formally, the average distance L is the mean shortest path length between all pairs of vertices in the graph. That is, it represents the expected distance between two vertices chosen uniformly at random (Newman, 2010).

Let's denote a graph as G = (V, E), where V is the set of vertices and E is the set of edges in the graph. For any pair of vertices, u and v in V, let d(u, v) denote the shortest path distance between these vertices. The average distance L of G can be given by the formula:

L = Σ d(u, v) / n(n - 1)

Here, the sum is over all pairs of distinct vertices, and n is the number of vertices in the graph. Essentially, we are summing up the shortest path distances between all pairs of vertices and then dividing by the total number of such pairs (Cormen et al., 2009).

The average distance is a critical metric in understanding the properties of real-world networks, which often exhibit the small-world property. The small-world property describes networks where the average path length is relatively small, meaning that one can get from any given node to any other node in the network through a small number of steps (Newman, 2010).

It's important to note that the average distance only makes sense for connected graphs, where a path exists between every pair of vertices. If a graph is not connected, this metric can't be defined without modification.

The computation of average distance can be a computationally intensive process, especially for larger graphs, due to the necessity to calculate the shortest path between each pair of vertices. Efficient algorithms have been developed to aid in this calculation, such as the Floyd-Warshall algorithm (Cormen et al., 2009).

References:

Cormen, T. H., Leiserson, C. E., Rivest, R. L., & Stein, C. (2009). Introduction to Algorithms (3rd ed.). The MIT Press.

Newman, M. (2010). Networks: An Introduction. Oxford University Press.

### Average Clustering

The average clustering coefficient is an essential measure in the field of graph theory, frequently used to evaluate the tendency of nodes in a network to cluster together. It provides insights into the overall clustering of the graph and the interconnectedness of its nodes.

The clustering coefficient of a single node in a graph quantifies how close its neighbors are to being a complete graph. A complete graph is one where every pair of vertices is connected by a unique edge. The average clustering coefficient is simply the mean of the clustering coefficients of all the nodes in the graph (Newman, 2010).

To be more precise, for a given node v in a graph G = (V, E), where V is the set of vertices and E is the set of edges, let Kv denote the number of vertices that are neighbors of v, and let Ev denote the number of edges between the neighbors of v. The clustering coefficient Cv for the node v is given by:

Cv = 2Ev / Kv(Kv - 1)

The average clustering coefficient C of the graph is then calculated as:

C = Σ Cv / n

Here, the sum is over all vertices in the graph, and n is the total number of vertices (Cormen et al., 2009).

The average clustering coefficient measures the degree to which nodes in a graph tend to cluster together. It has found widespread application in the study of various types of networks, such as social networks, biological networks, and the World Wide Web, among others (Newman, 2010).

In calculating the average clustering coefficient, it is important to note that it is typically only defined for nodes with at least two neighbors, since the denominator of the formula for Cv would be zero for nodes with fewer than two neighbors.

Computing the average clustering coefficient can be a computationally intensive task, especially for larger networks. Various algorithms have been developed to more efficiently calculate it, but the computational complexity is generally high due to the need to examine the local neighborhood of each node (Cormen et al., 2009).

References:

Cormen, T. H., Leiserson, C. E., Rivest, R. L., & Stein, C. (2009). Introduction to Algorithms (3rd ed.). The MIT Press.

Newman, M. (2010). Networks: An Introduction. Oxford University Press.

## Genetic Algorithm

Test

### Mutation

Test

### Selection

Test

# Results

Test

## Qualitative Statistics

Test

## Optimization

Test

# Conclusion and Further Implementations

# Bibliography

**Insurance**

I certify that I have written the above thesis independently and have not used any outside help. All passages taken verbatim or in spirit from published or unpublished literature have been marked as such.

\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Name

**Blocking notice**

Inspection of the thesis "*Title*" is not permitted. Exceptions to this are the supervising lecturers and the authorised members of the examination board.

Publication and reproduction of the work - even in excerpts - is not permitted up to and including xy.

1. Here is the 1st footnote [↑](#footnote-ref-2)
2. Here is the 2nd footnote [↑](#footnote-ref-3)