Using Air Traffic as a Delay-Tolerant Networking Backbone

Semester Thesis

Gökmen Çetin
gcetin@ee.ethz.ch

Advisor:
Dr. Franck Legendre

Supervisor:
Prof. Dr. Bernhard Plattner

Communication Systems Group
Computer Engineering and Networks Laboratory (TIK)
Department of Information Technology and Electrical Engineering

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Eidgenössische Technische Hochschule Zürich
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I would like to thank also Alexander Erath from the Institute for Transport Planning and Systems at ETH Zurich and Françoise Guenin-Rambaud from Eurocontrol, the European Organisation for the Safety of Air Navigation, for delivering flight schedules. The flight schedules build the fundament of this semester thesis and indicate the important collaboration of these two persons.

Abstract

Adults are impossible to imagine without a mobile phone nowadays. And the trend shows that more and more handheld devices are integrating wireless communication features like Wireless Lan, Bluetooth and Infrared. Establishing a delay tolerant communication network using the wireless communication ability of handhelds in order to distribute content is one of the projects of the Communication Systems Group at the ETH.

Using the air traffic network as a backbone for the delay tolerant network is one approach. In this thesis the static characteristics of the air traffic network over Europe are analyzed and so on a fundament for further dynamical statistics research is build.

A flight schedule and a flight record over Europe build the data collections which are parsed and transformed into a common Pajek [8] network file format.

In Pajek, software to analyze and illustrate large networks, static characteristics like indegree, outdegree and line value distributions are calculated and plotted.

In analyzing the distributions of these static characteristics we find out whether the network is random or scale-free.

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1 Introduction

Nowadays well established communication networks relay on continuous end-to-end connectivity (Internet, Telephony System). But many handheld devices like the mobile phone, organizers, cameras etc. have the ability to establish a communication line to another handheld device over a wireless link. The characteristic of such a link is influenced by the human mobility. Wireless devices can be used to let content distribute in a peer-to-peer manner when mobile users interact. Opportunities to transfer content occur when a lot of people are interacting, such as in public transportations, cinemas, libraries and in spots which are occupied by humans in general.

1.1 Delay Tolerant Networks

A communication is established when information from a source to a destination is transferred. Therefore a communication network must have the ability to transport data from a source to a destination. The wired Internet has an underlay with an instantaneous end-to-end path. Popular ad hoc routing protocols try to establish a complete route and transfer the actual data. In a wireless communication network with mobile users it is difficult or impossible to establish an end-to-end path. In order to distribute data in such a network, the data has to be stored and forwarded to linked mobile devices in the hope that it will eventually reach its destination. In order to maximize the probability of a successful message transfer to a destination a frequently used technique is to replicate many copies of this message and hope that one will arrive at the destination [1].

1.2 Message Ferrying via Air Traffic Network

Message Ferrying Mediums [2] are tracking prescribed traces and interacting with Data Mules in order to assure content dissemination. Data Mules are devices which are collecting or distributing data autonomously without any predefined traces. Inhere Data Mules are mobile devices and Message ferrying Mediums are airlines. If one or more mobile users from one agglomeration want to send a content to one or more mobile users from another agglomeration and if there is no direct link using mobile devices the link could be established with airlines. The Air Traffic Network is used as an underlay for the Delay Tolerant Network [3].

1.3 Goals

The goals of this semester thesis are:

- Represent the Air Traffic Network as a Graph
- Determine static characteristics of the Air Traffic Network
- Build a basis for prospective research

1.4 Outline

The subsequent chapters are organized as follows. In the second chapter a short introduction in to graph theory which is used to model the Air Traffic Network is given. Chapter 3 presents the data collections which are present and how they are structured. In Chapter 4 basic properties of Pajek, software to analyze and visualize Large Networks, are covered. Chapter 5 explains in a generalized logic how the data collections are parsed and transformed in order to use them with Pajek. In Chapter 6 the results obtained analyzing the Air Traffic over Europe with Pajek are shown.
A conclusion and an outlook build the content of Chapter 7.

2 Air Traffic Network as a Graph

This Chapter illustrates how the Air Traffic Network is modeled as a Graph and how the characterizations are defined.

2.1 The Graph Model

A *graph* is a set of vertices (nodes) and a set of lines between pairs of vertices.

In the Analysis of the Air Traffic Network a vertex represents an airport and a line an air flight between two airports.

A line in a graph is directed or not directed. A directed line is called an *arc* and an undirected line is an *edge*. A graph which contains at least one arc is a *directed graph* and a graph which contains only edges (no arcs) is an *undirected graph*.
An air flight from an airport A to an airport B does not necessarily imply an air flight from airport B to A and vice versa. Therefore an air flight is represented with an arc.

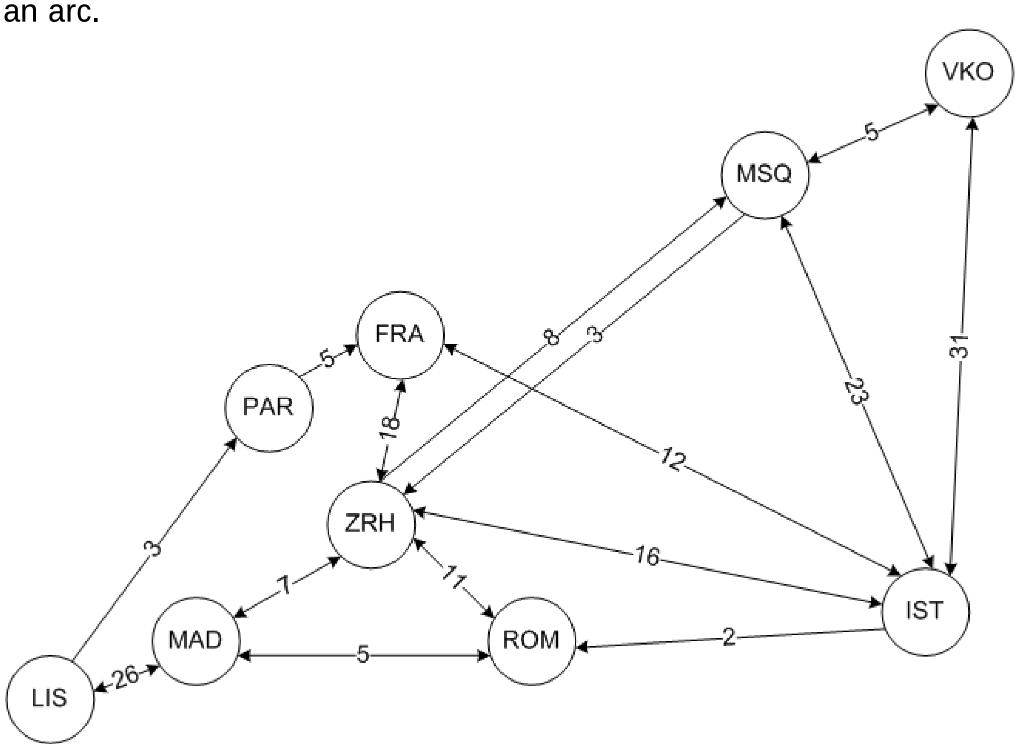

Figure 2-1: Air Traffic Network Graph

The graph of the Air Traffic Network is directed.

In Figure 2-1 a model of the Air Traffic Network is shown how it can look like as a graph. The three letter codes [4] represent the abbreviations of the airports. MSQ stands for Minsk and VKO for Moskav Vnukovo. The numbers printed on the arcs offer additional information. They represent the number of connections in a time period and are also designated as arc weight. Let us have a look to air flights between Zurich (ZRH) and Minsk (MSQ). There are 8 air flights from Zurich to Minsk and 3 air flights from Minsk to Zurich. This fact states the explanation that an air flight has not to be reversed.

2.2 Graph Metrics

In this subchapter some graph metrics are explained which are used to obtain the characteristics of the Air Traffic Network.

Degree:
The Degree of a vertex (airport) is the number of lines incident with it.

Indegree:
The Indegree of a vertex is the number of arcs it receives.

Outdegree:
The Outdegree of a vertex is the number of arcs it sends.

Example: In Figure 2-1 the airport in Istanbul has an indegree of 4 and an outdegree of 5.

Two airports are *adjacent* if they are connected by a line (arc or edge).

Walk:
A walk from airport UUU to airport VVV is a sequence of arcs such that the end Airport of one air flight is at its tail and the starting airport of the next air flight is at its origin. The sequence starts at airport UUU and ends at airport VVV.

Path:
A path is a walk in which no airport in between the first and last airport of the walk occurs more than once

Geodesic:
A geodesic is the shortest path between two airports.

Distance:
The distance from airport UUU to airport VVV is the length of the geodesic (counting number of arcs) from UUU to VVV.

Diameter:
The Diameter is the length of the longest shortest path in a network.

2.3 Random and Scale-Free Networks

A random network [5] is generated by some random process. The most known model is the Erdõs-Rényi model. In this model a set of *n* vertices is given and with a probability of *p* an edge respectively an arc occur indepently. It is obvious that in such a model a graph can be constructed which is not connected.

The degree distribution of a scale free network [6] shows a power law like many real networks. The similarity of vertices with a degree which exceeds greatly the average is a main characteristic of scale free networks. The highest degree nodes are often called hubs. In scale free networks the major hubs are closely followed by smaller ones and these again by vertices with even smaller degrees. This property allows for a good connectedness when edges or arcs drop out.

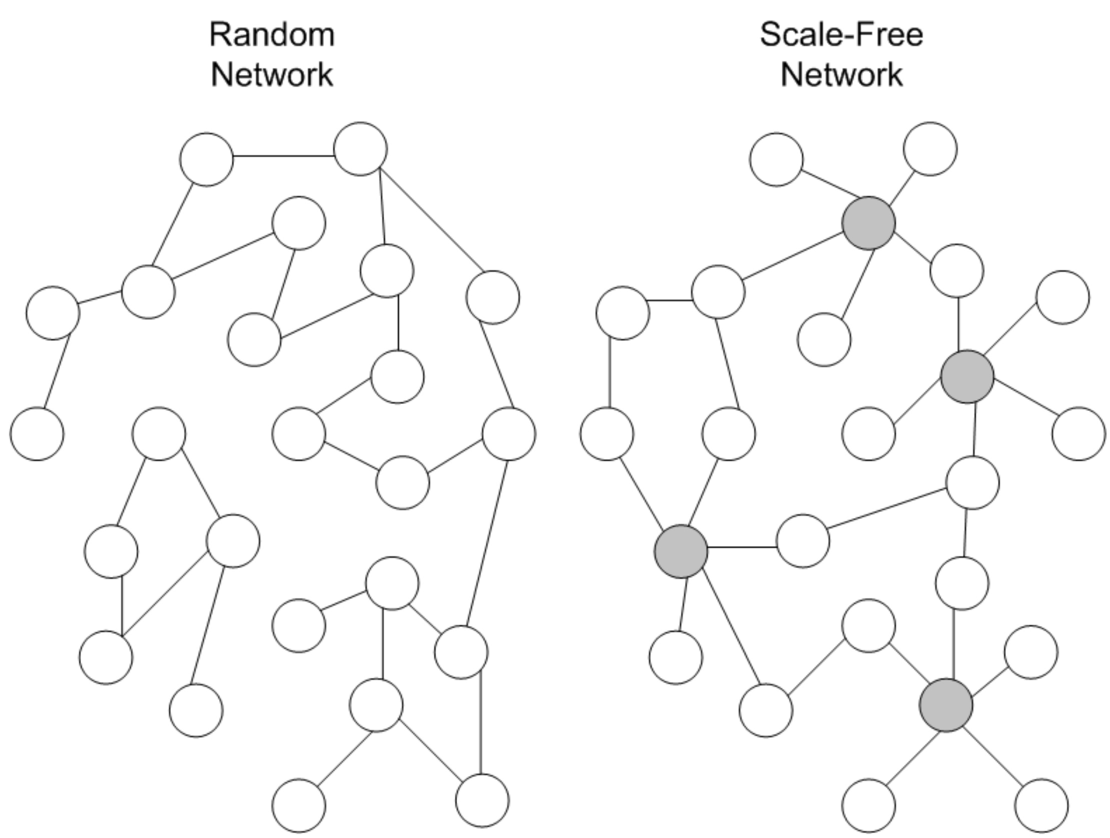

Figure 2-2: Random and Scale-Free Networks

3 Data Collections

In order to represent the Air Traffic Network as a graph a record of air flights or a flight schedule is needed.

Following companies and institutes have been requested for flight schedules and records:

- OAG Travel Information www.oag.com
- FlyteComm www.flytecomm.com
- FlightAware www.flightaware.com
- Flughafen Zürich AG www.unique.ch
- EUROCONTROL European Organisation for the Safety of Air Navigation www.eurocontrol.com
- Institute for Transport Planning and Systems www.ivt.ethz.ch
- A community of Radar Box owners exists, which track individually flights and collect them. www.openatc.com

The Institute for Transport Planning and Systems (short IVT) delivered a flight schedule and EUROCONTROL delivered a flight record.

3.1 Data Collection from the IVT

The IVT delivered a flight schedule for a whole week covering all European flights in 2006. The flight schedule is stored in the file `Flugverbindungen.att`. The airports are coded as numbers. The relevant airports and their geographical coordinates can be found in the file `Knotenliste.att`.

1	07:15:00	08:00:00	40340	40333	0D 010	_H	>	1	1	1	1	1
	0	0	0									
2	08:35:00	09:25:00	40333	40340	0D 011	_H	>	1	1	1	1	1
	0	0	0									
3	10:45:00	11:35:00	40340	40333	0D 014	_H	>	1	1	1	1	1
	1	0	1									
4	12:35:00	13:25:00	40333	40340	0D 015	_H	>	0	0	0	0	0
	1	0	1									
5	16:35:00	17:25:00	40333	40340	0D 017	_H	>	1	1	1	1	1
	0	0	0									
6	18:15:00	19:05:00	40340	40333	0D 018	_H	>	1	1	1	1	1
	0	0	1									
7	19:35:00	20:25:00	40333	40340	0D 019	_H	>	1	1	1	1	1
	0	0	1									
8	09:10:00	10:25:00	40423	40340	0D 151 A	_H	>	1	1	1	1	1
	0	0	0									
…………												
…………												

Above a snapshot of the file `Flugverbindungen.att` is shown. The Schedule starts at the line with the label 1.

In one row following informations are listed tab separated (Line 1 as example in Brackets):

Departure Time	(07:15:00)
Arrival Time	(08:00:00)
Departure Airport	(40340)
Arrival Airport	(40333)
Flight Code	(0D 010 _ H >)
Tuesday	(1)
Thursday	(1)
Friday	(1)
Wednesday	(1)
Monday	(1)
Saturday	(0)
Seats	(0)
Sunday	(0)

A one by the weekdays indicates that the flight will take off at that day a zero that it will be not take off. The Label “Seats” is not relevant for this thesis.

40001	IVL	Ivalob	737137.6875	1913630.0000	FI	IVL	
40002	ENF	Enontekioe	581974.1875	1858523.0000	FI	ENF	
40003	KTT	Kittilae	645208.5000	1784889.0000	FI	KTT	
40004	KRN	Kiruna	447395.5000	1766883.0000	SE	KRN	
40005	GEV	Gaellivare	480020.5000	1692137.0000	SE	GEV	
40006	RVN	Rovaniemi	717375.8125	1667027.0000	FI	RVN	
40007	KAO	Kuusamo	882537.8125	1635637.0000	FI	KAO	
40008	KEM	Kemi-Tornio	677715.8750	1569113.0000	FI		
40009	LLA	Luela - Kallax	569095.8125	1523420.0000	SE	LLA	
40010	AJR	Arvidsjaur	427456.9063	1510933.0000	SE	AJR	
………………………………							
………………………………							

Above a snapshot of the file `Knotenliste.att` is shown.

In one row following informations are listed tab separated (Line 40001 as example in Brackets):

Airport No	(40001)
World Airport Code	(IVL)
Name of the Airport	(Ivalob)
X-Coordinate	(737137.6875)
Y-Coordinate	(1913630.000)
Country code	(FI)
World Airport Code	(IVL)

Both data files above are extracted from Visum [7] a traffic platform. The coordinates of the airports are coded for use in Visum as well.

3.2 Data Collection from EUROCONTROL

Eurocontrol delivered a record of all flights for the all days of November 2007. Below you can find a snapshot of one of the data files.

```
0059124420071101        LZKZ    LZIB    01.11.2007 00:04:00     01.11.2007      00:04:00
        01.11.2007 00:36:15     01.11.2007 00:32:45
0059402220071101        ESSA    ESOK    01.11.2007 00:15:00     31.10.2007      23:58:00
        01.11.2007 01:01:10     01.11.2007 00:43:25
0060588220071101        EHKD    ZZZZ    01.11.2007 00:10:00     01.11.2007      00:10:00
        01.11.2007 00:33:45     01.11.2007 00:33:45
0061217920071101        EDDK    LFPG    01.11.2007 00:10:00     01.11.2007      00:22:55
        01.11.2007 00:46:40     01.11.2007 01:00:00
0061580720071101        EDDF    EDDT    01.11.2007 00:15:00     01.11.2007      00:14:00
        01.11.2007 01:02:55     01.11.2007 00:54:25
0061670220071101        EHKV    EHKD    01.11.2007 00:15:00     01.11.2007      00:15:00
        01.11.2007 00:32:55     01.11.2007 00:32:55
...........................................
...........................................
```

In one row following informations are listed tab separated (first line 40001 as example in Brackets):

Flight Identifier	(0059124420071101)
Departure Airport	(LZKZ)
Arrival Airport	(LZIB)
Planned Departure Date and Time	01.11.2007 00:04:00
Actual Departure Date and Time	01.11.2007 00:04:00
Planned Arrival Date and Time	01.11.2007 00:36:15
Actual Arrival Date and Time	01.11.2008 00.43:25

The airports and flight numbers from Eurocontrol are anonymous.

3.3 Differences between the Data Collection from IVT and Eurocontrol

In this thesis the results of analyzing the data collection from IVT are shown.
The advantage over the data collection from Eurocontrol is that the airports and flights are identified and it is easier to demonstrate and bring them into relation with the real world.
Another fact is that the IVT delivers a flight schedule and Eurocontrol a flight record. In the data set from Eurocontrol also flights are recorded which are not accessible for everybody. These flights are not always usable for distributing information over handhelds. Also flights are recorded which start and end at the same airport.

	Airports	**Flights**
IVT	487	5227
Eurocontrol	2220	50155

Table 1: Differences IVT and Eurocontrol Vertices and Lines

Anyhow the data collection from Eurocontrol is parsed, transformed to Pajek-file representation and the results are represented in Appendix C.

In the next chapter the use of the network analysis software Pajek is described.

4 Pajek Analysis and Visualization of Large Networks

Pajek [8] is a free software running under Windows in order to analyze and visualize networks with a thousand even million of nodes. Once a network is described in Pajek you have many opportunities to analyze graph matrices and let them compute. In this chapter the commands and utilities which have been used to visualize and analyze the Air Traffic Network are shown.

4.1 The Network Data Format in Pajek

There are several ways to type in a Network in Pajek. You can do it manually by creating a new .net file via the *File>Network>Read* command in Pajek and then typing in the number of vertices and adding lines to the net after drawing the vertices with *Draw>Draw*.

The method used in this semester thesis is to generate the `*.net` file with *C++* after parsing the original data collection from the IVT.
At the next page an example of a network file with 20 vertices and 31 arcs is illustrated.
The first line is followed by a list of vertices. Each line is containing the vertex number, the vertex label, which is here the letter v followed by a number by default and the x, y and z coordinates of the vertex in a drawing.
The line **Arc*s indicates the start of the list of arcs. At the next line the first number indicates the starting vertex and the second number the ending vertex of an arc. The third number is indicating the value of the arc.

```
*Vertices      20
       1 "v1"                                       0.1000    0.5000    0.5000
       2 "v2"                                       0.1196    0.3764    0.5000
       3 "v3"                                       0.1764    0.2649    0.5000
       4 "v4"                                       0.2649    0.1764    0.5000
       5 "v5"                                       0.3764    0.1196    0.5000
       6 "v6"                                       0.5000    0.1000    0.5000
       7 "v7"                                       0.6236    0.1196    0.5000
       8 "v8"                                       0.7351    0.1764    0.5000
       9 "v9"                                       0.8236    0.2649    0.5000
      10 "v10"                                      0.8804    0.3764    0.5000
      11 "v11"                                      0.9000    0.5000    0.5000
      12 "v12"                                      0.8804    0.6236    0.5000
      13 "v13"                                      0.8236    0.7351    0.5000
      14 "v14"                                      0.7351    0.8236    0.5000
      15 "v15"                                      0.6236    0.8804    0.5000
      16 "v16"                                      0.5000    0.9000    0.5000
      17 "v17"                                      0.3764    0.8804    0.5000
      18 "v18"                                      0.2649    0.8236    0.5000
      19 "v19"                                      0.1764    0.7351    0.5000
      20 "v20"                                      0.1196    0.6236    0.5000
*Arcs
1 2 4
1 8 8
1 6 3
1 15 10
1 20 7
20 3 9
2 1 4
4 5 2
1 5 9
3 4 12
5 9 17
4 20 12
4 9 32
18 12 49
17 14 23
7 20 12
14 9 32
9 12 7
12 18 87
10 11 43
12 7 1
13 9 12
9 12 12
17 12 1
18 12 23
6 7 12
18 19 2
19 2 13
15 18 34
5 10 31
11 13 9
```

4.2 Putting Coordinates

In our data collection from the IVT coordinates of the airports are also included. This coordinates are parsed and saved in the two vector files `x_coordinates.vec` and `y_coordinates.vec`.

Each line in these files describes a coordinate for the vertex with the corresponding number. Executing the command *Operatios>Vectors>Put Coordinate* for each .vec file will set the coordinates.

4.3 Computing Graph Metrics

In order to compute graph metrics the corresponding graph should be read in Pajek. (*File>Network>Read)*

Indegree:
Net>Partitions>Degree>Input
After executing this command a partition file with the ending .clu listing the Indegree of each vertex in the corresponding line can be saved. *File>Partition>Save*

Outdegree:
Net>Partitions>Degree>Output
After executing this command a partition file with the ending .clu listing the Outdegree of each vertex in the corresponding line can be saved. *File>Partition>Save*

Average distance among reachable pairs and most distant vertices:
Net>Paths between 2 Vertices>Distribution of Distances>From All Vertices
After executing this command a vector file with the ending .vec listing the amount of pairs with a specific distance can be saved. The distance is computed disregarding the line values, only the number of hops is counted.

Diameter:
Net>Paths between 2 Vertices>Diameter
Notice that the diameter is defined as the longest shortest path between two vertices.

Shortest path between 2 Vertices
Net>Paths between 2 Vertices>One Shortest or *All Shortest*
With the command above one shortest path or all shortest path between two vertices can be computed. Even the line (arc) values can be considered in the computation of the shortest path. You have to type in the start and end vertices using the vertex number or label. After executing this command a network containing only the vertices and arcs of the shortest path or paths and a partition containing the vertices of the shortest path or paths in one class and the rest of the vertices in another class will be generated.

Distance from/to one vertex to/from all other vertices
Net>k-Neighbours>Input/Output
This command will compute the distance from/to one vertex to/from all other vertices and create a partition of classes containing the distances between one vertex and all other vertices.

Distribution of line values
Info>Network>General
This command lists line values and the corresponding line connections in the form ZRH.IST
Info>Network>Line Values
Identifying the number of clusters or intervals of line values a distribution of line values is listed on the Report window.

5 Parsing and Generating Network Files

This chapter explains sketchily how to solve the issue of transforming the data collections from the IVT and Eurocontrol into Pajek compatible .net files. For a detailed comprehension it is recommended to have a look at the commented C++ codes on the enclosed CD.

5.1 Transforming the Data Collection from IVT

The Figure 5-1 shows step for step which processes have been done on the data collection from the IVT in order to transform it into a Pajek file, which can be worked on. Each square represents a step. Squares labeled with a C++ file contain an abstract pseudocode which describes what the code executes. For detailed description please open the C++ file on the CD and read the commands. Squares labeled with Word Pad or Pajek describe steps wich has been made in these programs.

5.2 Transforming the Data Collection from Eurocontrol

Eurocontrol delivered a set of daily flight schedules of the whole November 2007. All the airports are made anonymous and there is no airport list available. The C++ file compiled program of `eurocontrol.cpp` is looking through the whole flight schedule and extracting an airport list which is stored in **Vertices* format to *eurocontrol.net.* After that all the flight schedules are again analyzed and an arcs list representing air flights is constructed. The result is the *eurocontrol.net* file with a list of vertices and arcs. For a detailed explanation please look at the command on eurocontrol.cpp.
The *eurocontrol.net* file can be used for further analysis on the data collection from Eurocontrol in Pajek.

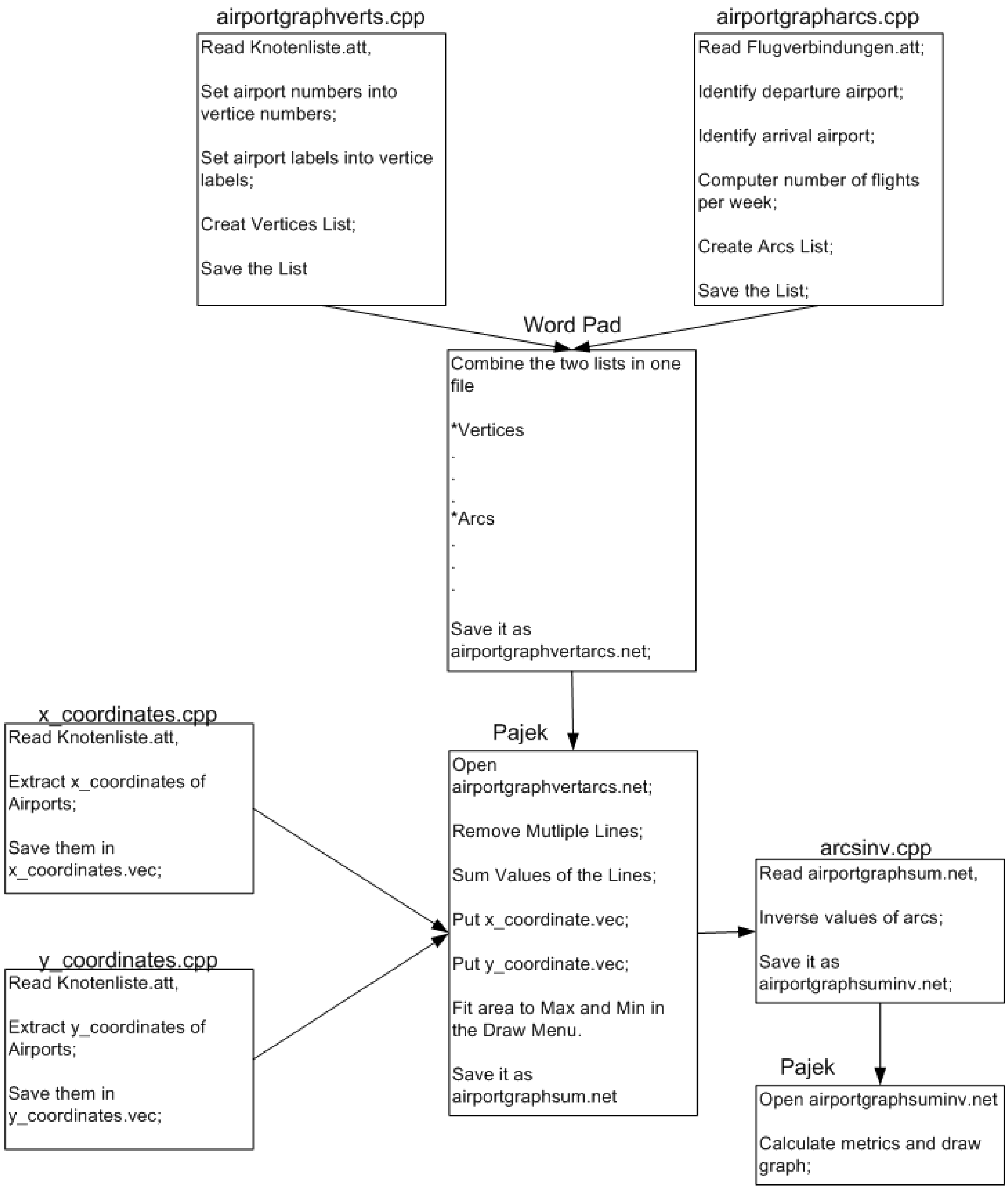

Figure 5-1: Transforming Data Collection from IVT

6 European Air Traffic

After transforming the data collection from the IVT with the processes described in chapter 5 it can be worked on the European Air Traffic Network using Pajek.
In this chapter the results using the opportunities of Pajek described in Chapter 4 are presented.

6.1 The Graph

In Pajek after opening the `airportgraphsuminv.net` file (*[Main]File>Network>Read*) it can be let draw with the clicking *[Main]Draw>Draw*.
The Graphes are illustrated in the Appendix A because of their size. It is recommended to have a look at the Figures opening them at the Computer. Figure A-1 represents the European Air Traffic Network with the arcs weighted by number of flights per week. There are a lot of airports which are not connected with other airports.

6.2 Indegree

After computing the indegree partition the distribution of the indegree is computed with the command *[Main]Info>Partition*
A distribution list can be found in the file `Input Degree Partition.txt` .
It is remarkable that 55.6 % of the airports have an input degree of zero, which indicates no approaching airplanes. Amsterdam with 104, Munich with 103 and Frankfurt with 101 are the most approached airports in Europe. Zurich with an indegree of 72 occupies the 17th position.
Figure 6-1 illustrates the indegree distribution. (In the appendix B a bigger size of figure 6-1 can be found.). The amount of airports belonging to a fixed degree decreases when the related degree increases.

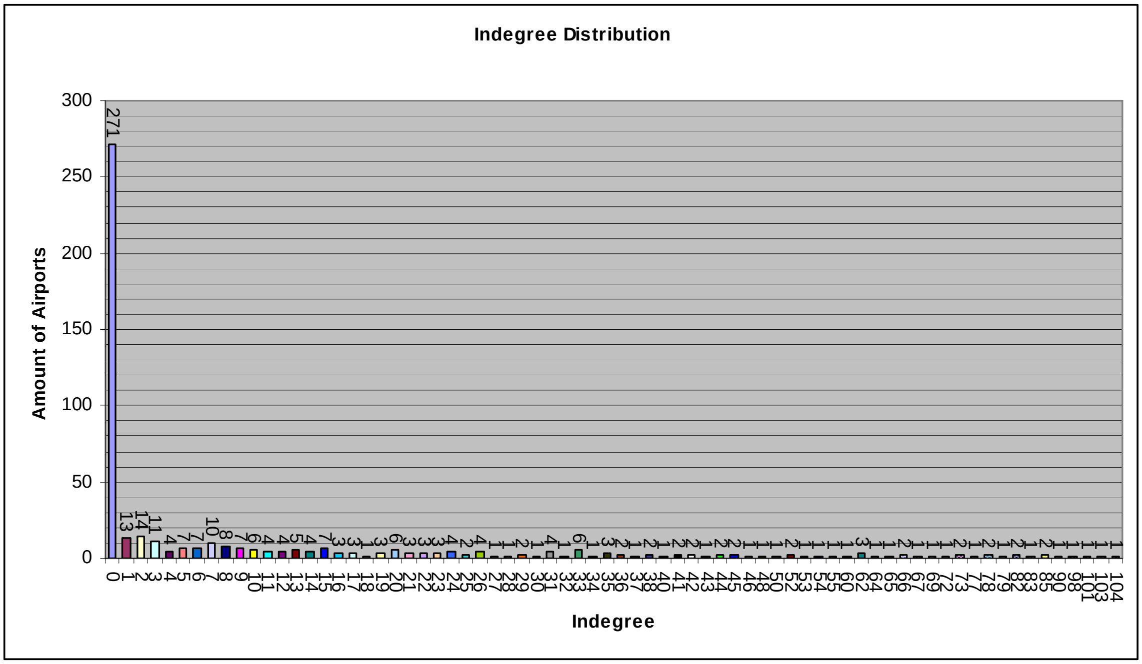

Figure 6-1: Indegree Distribution Amount of Airports

Figure 6-2 shows the cumulated percentage of airports with increasing indegrees. The logarithmic shape of the curve is conspicuous.

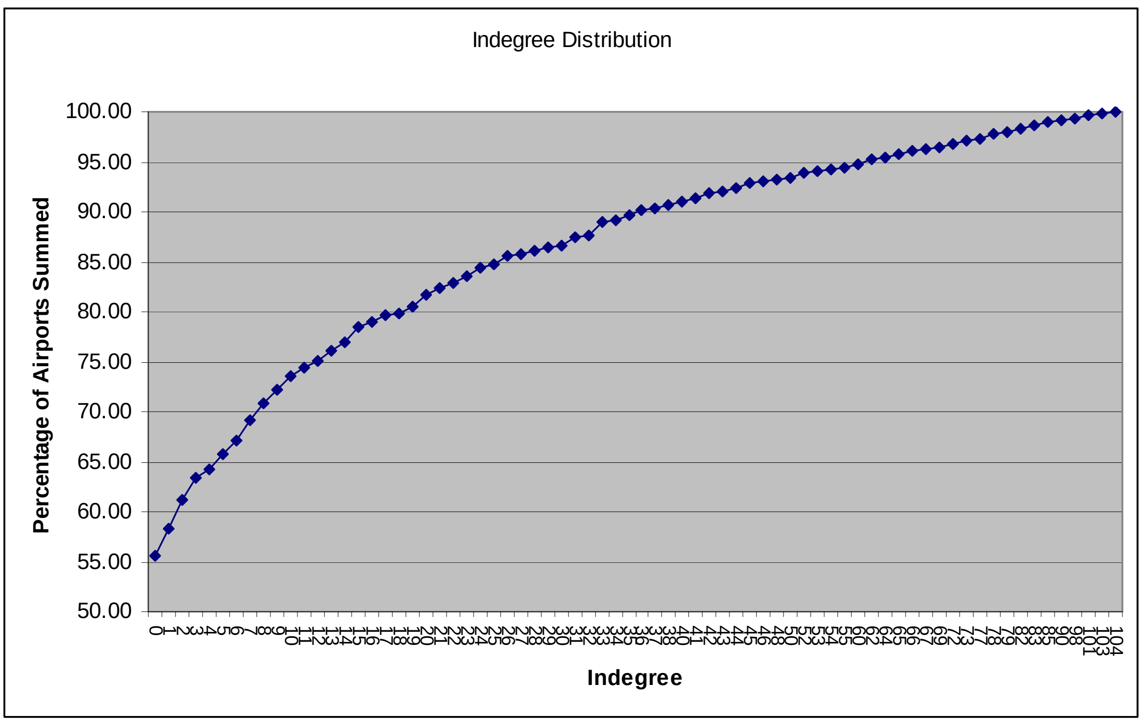

Figure 6-2: Cumulated Indegree Distribution as Percentage

7.8 Outdegree

A distribution list can be found in the file `Output Degree Partition.txt` . Similar to the statistics of the indegree 55.6 % of the airports have an output degree of zero, which indicates no departing airplanes. Amsterdam with 103, Munich with 102 and Frankfurt with 101 are the most departed airports in Europe. Zurich with an outdegree of 72 occupies again the 17th position.
Figure A-4 illustrates the outdegree distribution graphically.

The characteristics of the figures 6-3 and 6-4 are similar to the figures of the indegree distribution. The logarithmic shape is again detectable.

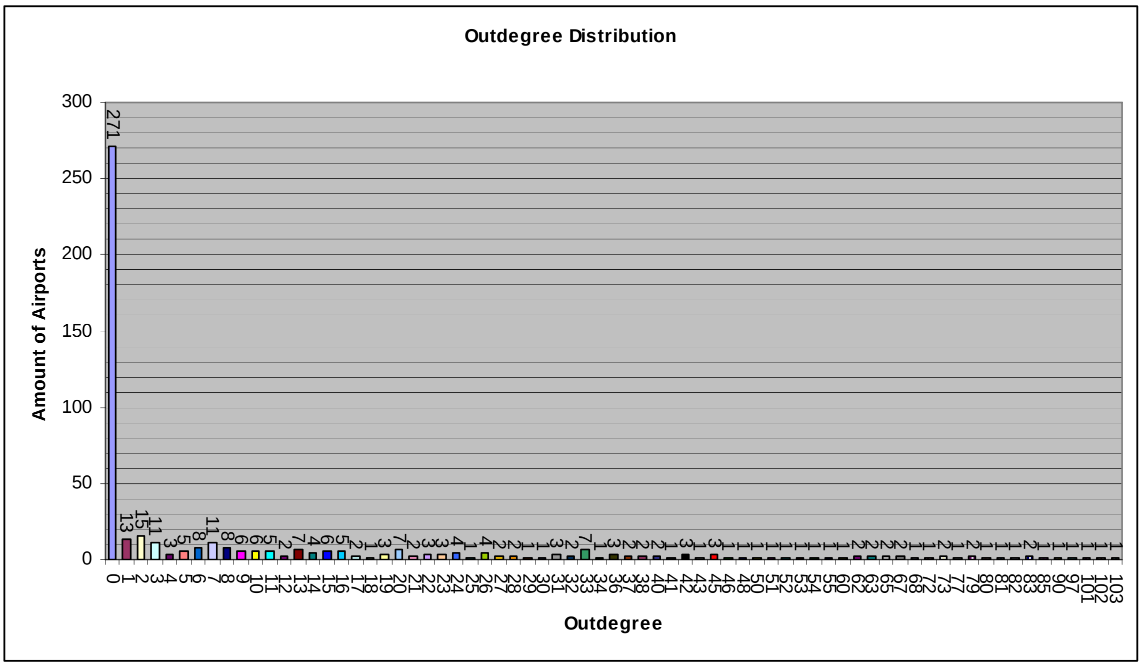

Figure 6-3: Outdegree Distribution Amount of Airports

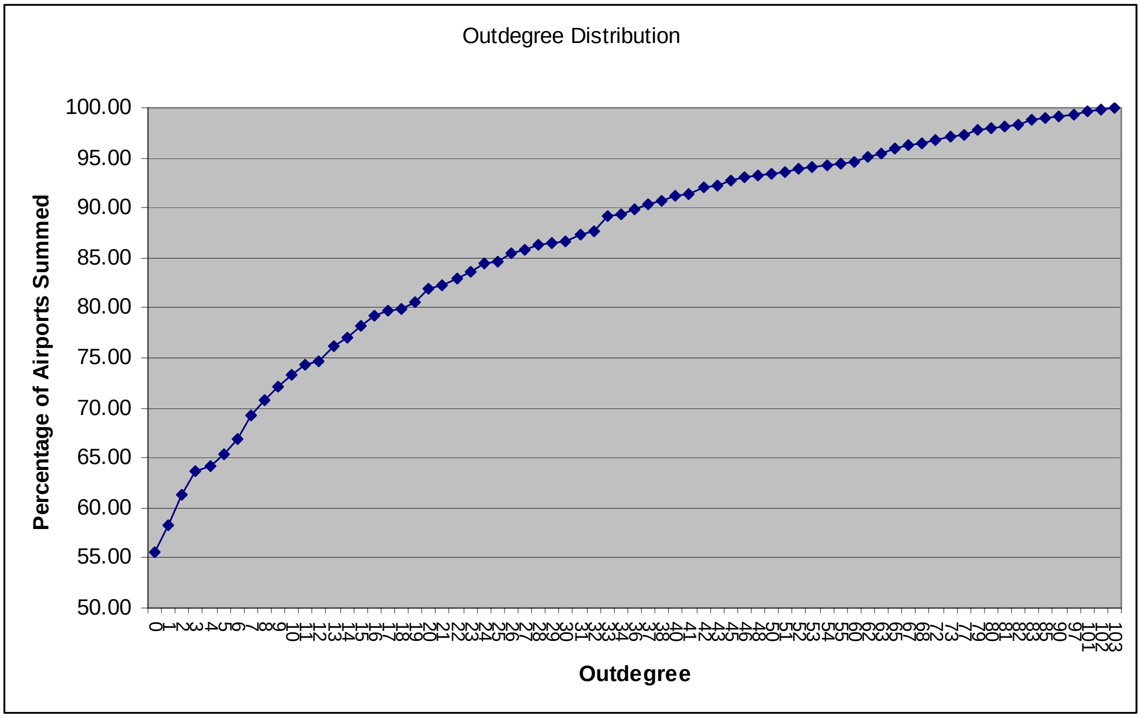

Figure 6-4: Cumulated Outdegree Distribution as Percentage

7.9 Distribution of Distances

There are in total 190242 pairs of Airports which are not connected through a flight.

Distance	Amount of Pairs
1	5227
2	28709
3	12338
4	166

Table 2: Distribution of Distances

The average distance among reachable pairs amounts to 2.16027.

The diameter has a value of 4. The distance between the airports OUL (Oulu in Finnland) and CND (Constanta in Romania) is one representant for the Diameter.

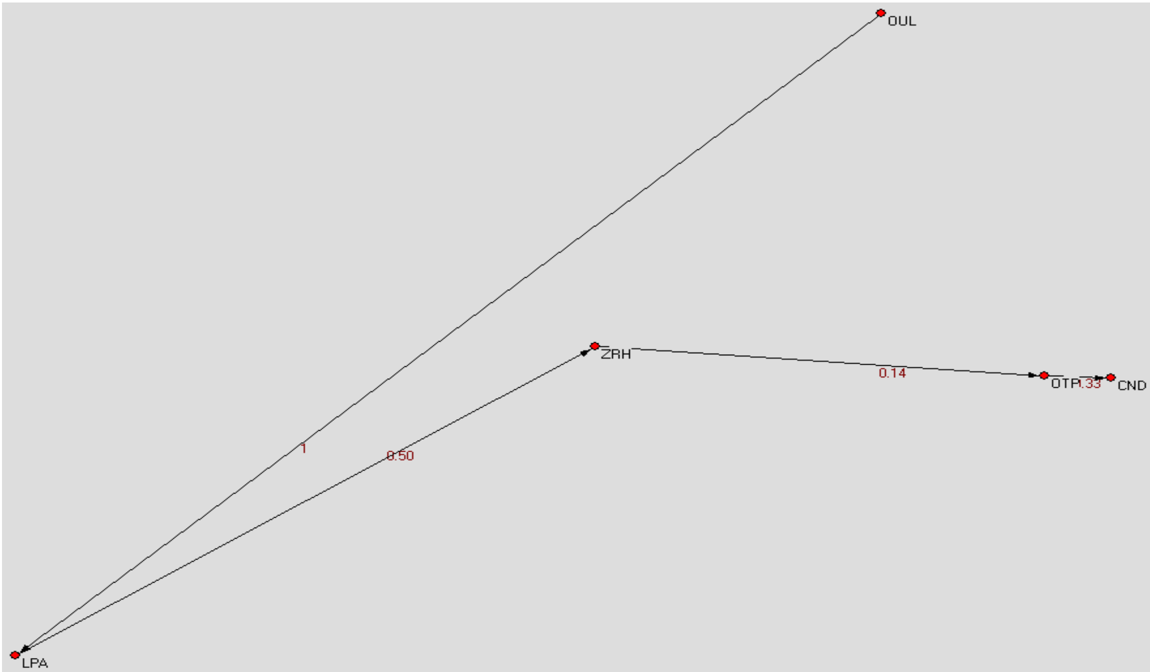

Figure 6-5: Diameter OUL to CND

Considering the values on line during the computation of the shortest path an amount of 5 hops is obtained from OUL to CND. The line values are the inversed number of flights between the two airports. The computation of a shortest path in Pajek indicates the path with the most frequent air flights from one airport to an other airport.
The sum of the line values is 0,4.

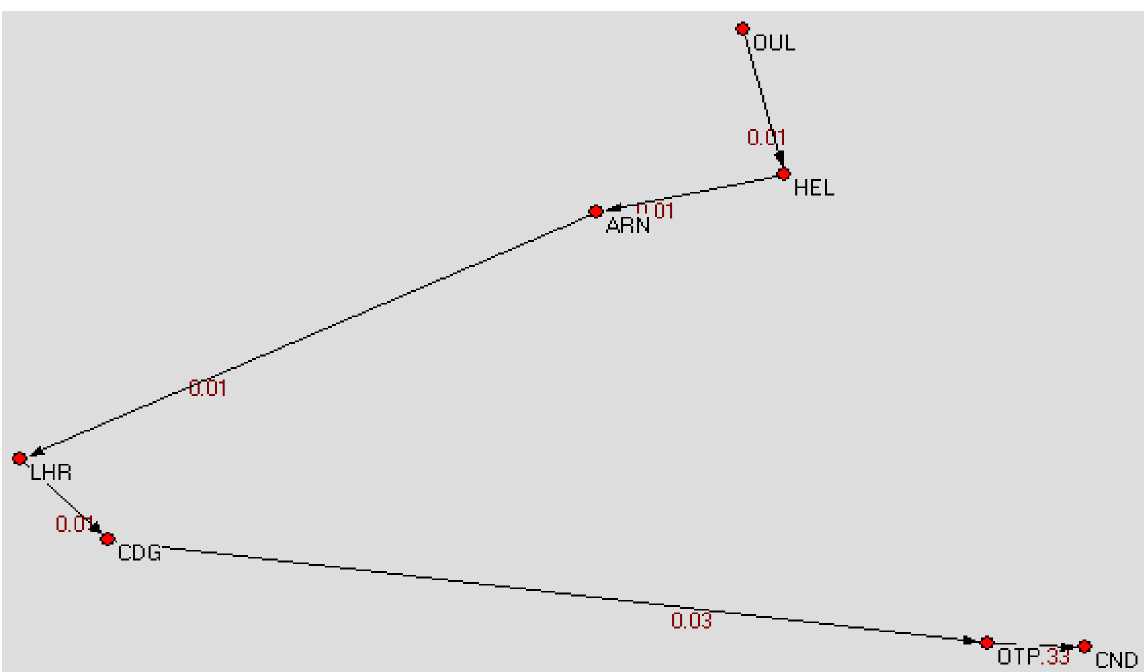

Figure 6-6: Shortest Path from OUL to CND considering line values

7.10 Distribution of Distances from Zurich

Frequency distribution of cluster numbers:

Cluster	Freq	Freq%	Valid%	CumFreq	CumFreq%	CumValid%	Representative
0	1	0.2053	0.4630	1	0.2053	0.4630	ZRH
1	72	14.7844	33.3333	73	14.9897	33.7963	HEL
2	140	28.7474	64.8148	213	43.7372	98.6111	OUL
3	3	0.6160	1.3889	216	44.3532	100.0000	LRH

Above a snap shot of the report Window in Pajek after creating a k-Neighpours-Input-Partition and visualizing the Informations for this Partition is shown.
Cluster 0 is Zurich. The 2^{nd} column Freq is indication the amount of members of Cluster 1, 2 and 3. The members of Cluster 1, 2, respectively 3 are in one, two respectively three hops reachable from Zurich.

7.11 Distribution of Distances to Zurich

Frequency distribution of cluster numbers:

Cluster	Freq	Freq%	Valid%	CumFreq	CumFreq%	CumValid%	Representative
0	1	0.2053	0.4630	1	0.2053	0.4630	ZRH
1	72	14.7844	33.3333	73	14.9897	33.7963	HEL
2	140	28.7474	64.8148	213	43.7372	98.6111	OUL
3	3	0.6160	1.3889	216	44.3532	100.0000	LRH

A snap shot of the report Window in Pajek after creating a k-Neighpours-Output-Partition and visualizing the Informations for this Partition is shown.
Cluster 0 is Zurich. The 2^{nd} column Freq is indication the amount of members of Cluster 1, 2 and 3. The members of Cluster 1, 2, respectively 3 arrive in one, two respectively three hops in Zurich.

7.12 Line Values

The most frequent air flight with 514 flights per week is from Barcelona to Madrid. It is followed with 505 flights per week by the connection from Madrid to Barcelona. The 390 flights from Monaco to Nice follow the previous.

The distribution of the line values to the airports are illustrated because of the high amount of the lines in two figures in the appendix B.

Again the logarithmic shape of the cumulated distributions curve stands out.

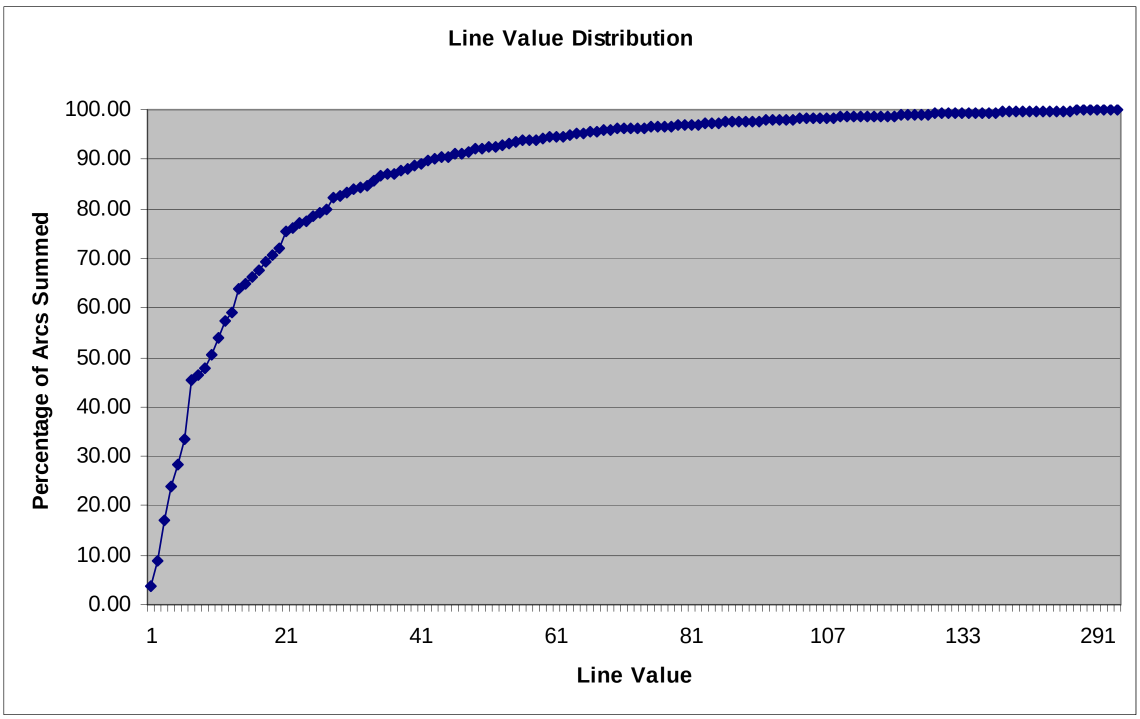

Figure 6-7: Cumulated Line Value Distribution as Percentage

7 Conclusion and Outlook

This chapter contains the conclusion of this thesis. Additionally the contributions and an outlook on possible future works are presented.

7.1 Conclusion

In this thesis the static characteristics of the air traffic network over Europe are analyzed and so on a fundament for further dynamical statistics research is build.

A flight schedule and a flight record build the data collections which are parsed and transformed into a common Pajek [8] network file format.

In Pajek, software to analyze and illustrate large networks, static characteristics like indegree, outdegree and line value distributions are calculated and plotted.

In analyzing the distributions we find out whether the network is random or scale-free.

The distribution figures in chapter 6, Appendix A and B are showing a shape which indicates a power law distribution. The power law says that large is rare and small is common.

Therefore it can be concluded that the European Air Traffic Network is scale free.

7.2 Contributions

The contributions of this semester thesis to design the air traffic network as a backbone for DTN Networks:

- Acquirement of a flight schedule and record of the European Air Traffic
- A parser and transformer of this data collections into Pajek Network Files
- Static statistics of the European Air Traffic Network

7.3 Outlook

The data collections in this semester thesis are covering the European Air Traffic. In order to enable a global delay tolerant network an acquirement of a global data collection should be possible.

In this semester thesis the scope satisfied with analyzing static statistics. Both data collections include departure and arrival times of flights. In future researches the dynamic statistical characteristics of the European Air Traffic could be obtained and used to optimize a delay tolerant network using the air traffic as a backbone.

Furthermore the flight records of Eurocontrol could be more useful for statistical research if they are better identified. A differentiation of publicly available and not accessible flights could be done. A record should be closer to reality than a flight schedule and build a better research fundament for delay tolerant networking.

A Draws of Pajek

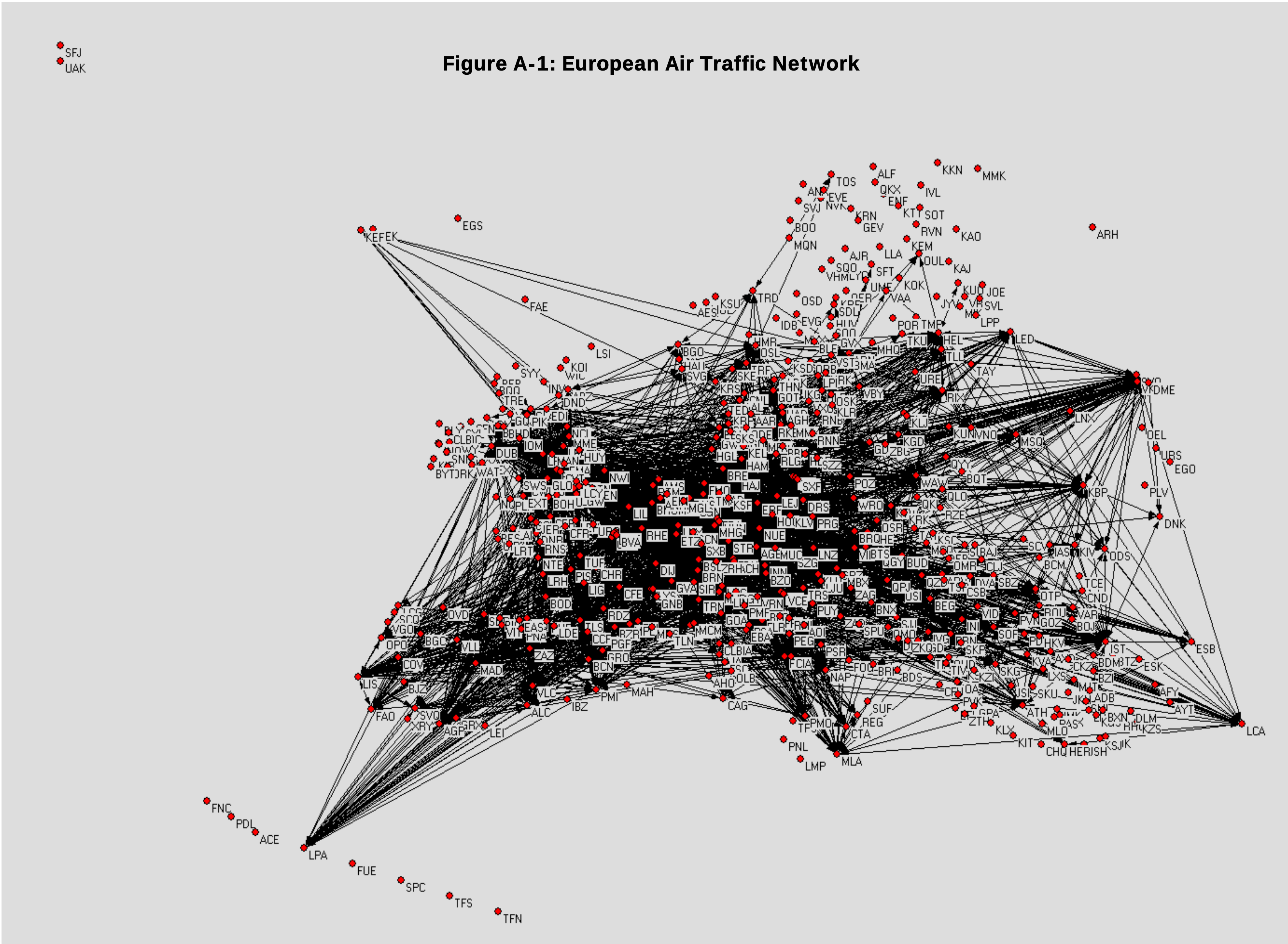

Figure A-1: European Air Traffic Network

Figure A-2: European Air Traffic Network without Arcs

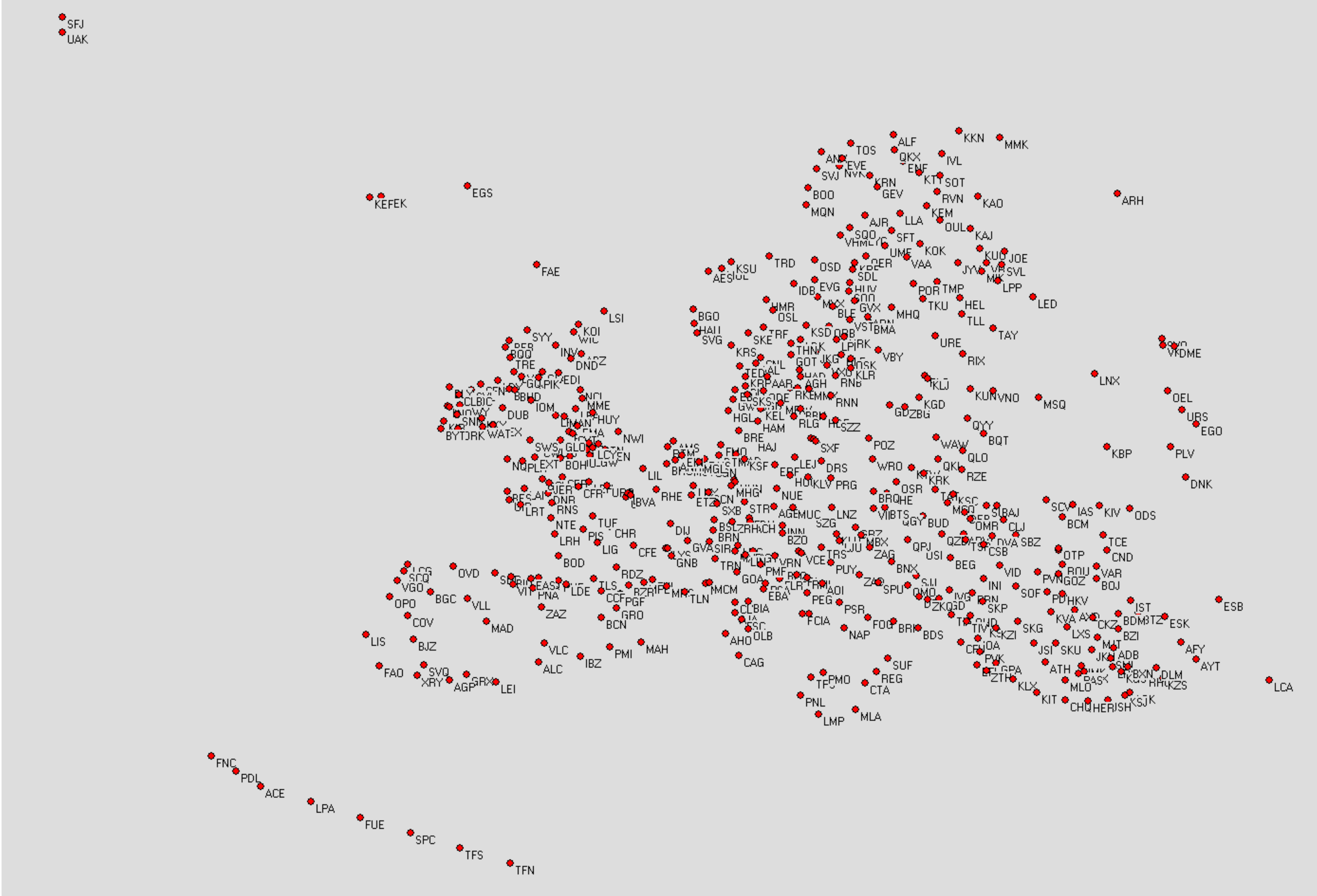

Figure A-3: Indegree Distribution of Airports

Figure A-4: Outdegree Distribution of Airports

B Distribution Figures IVT

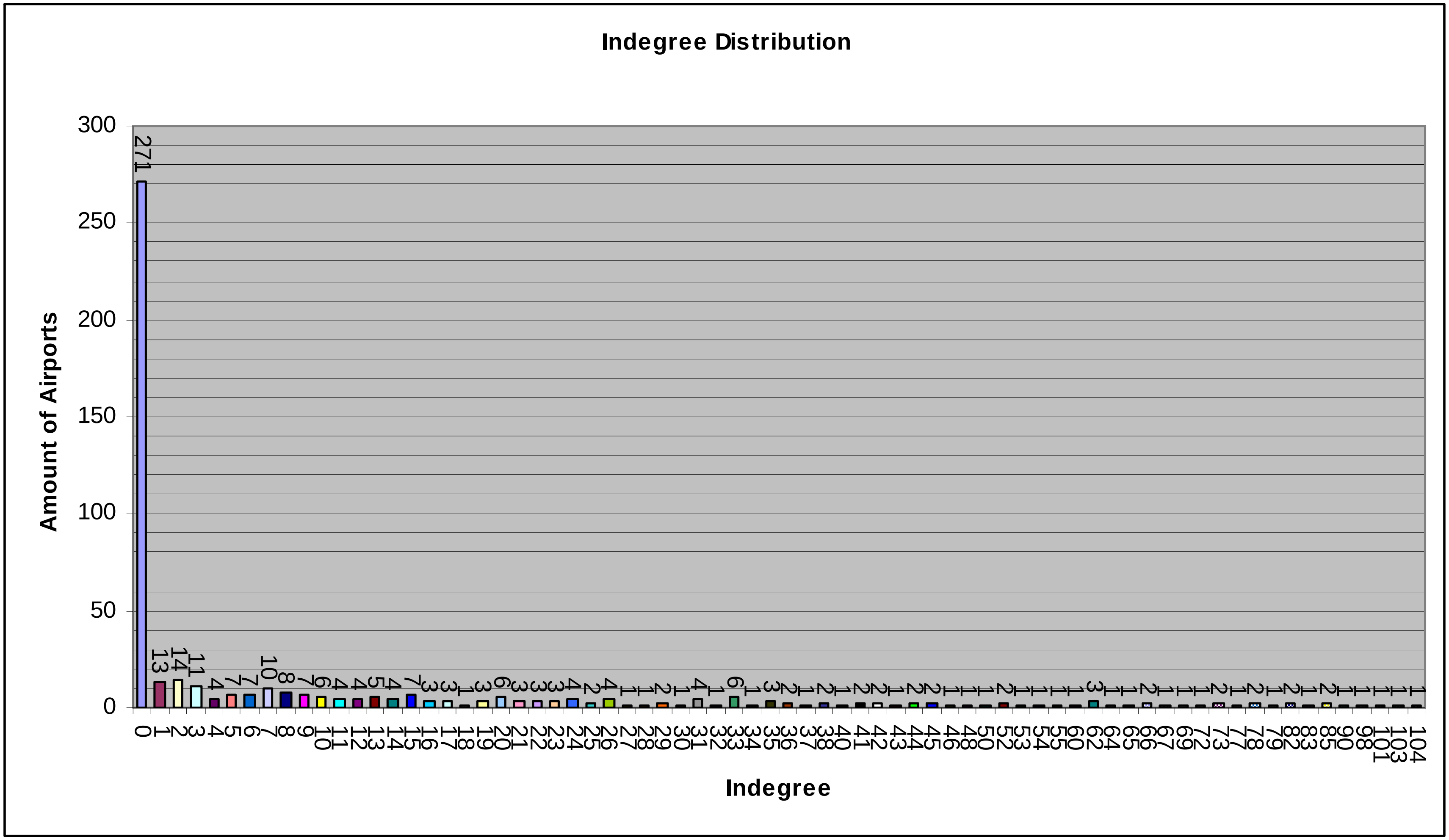

Figure B-1: Indegree Distribution Amount of Airports

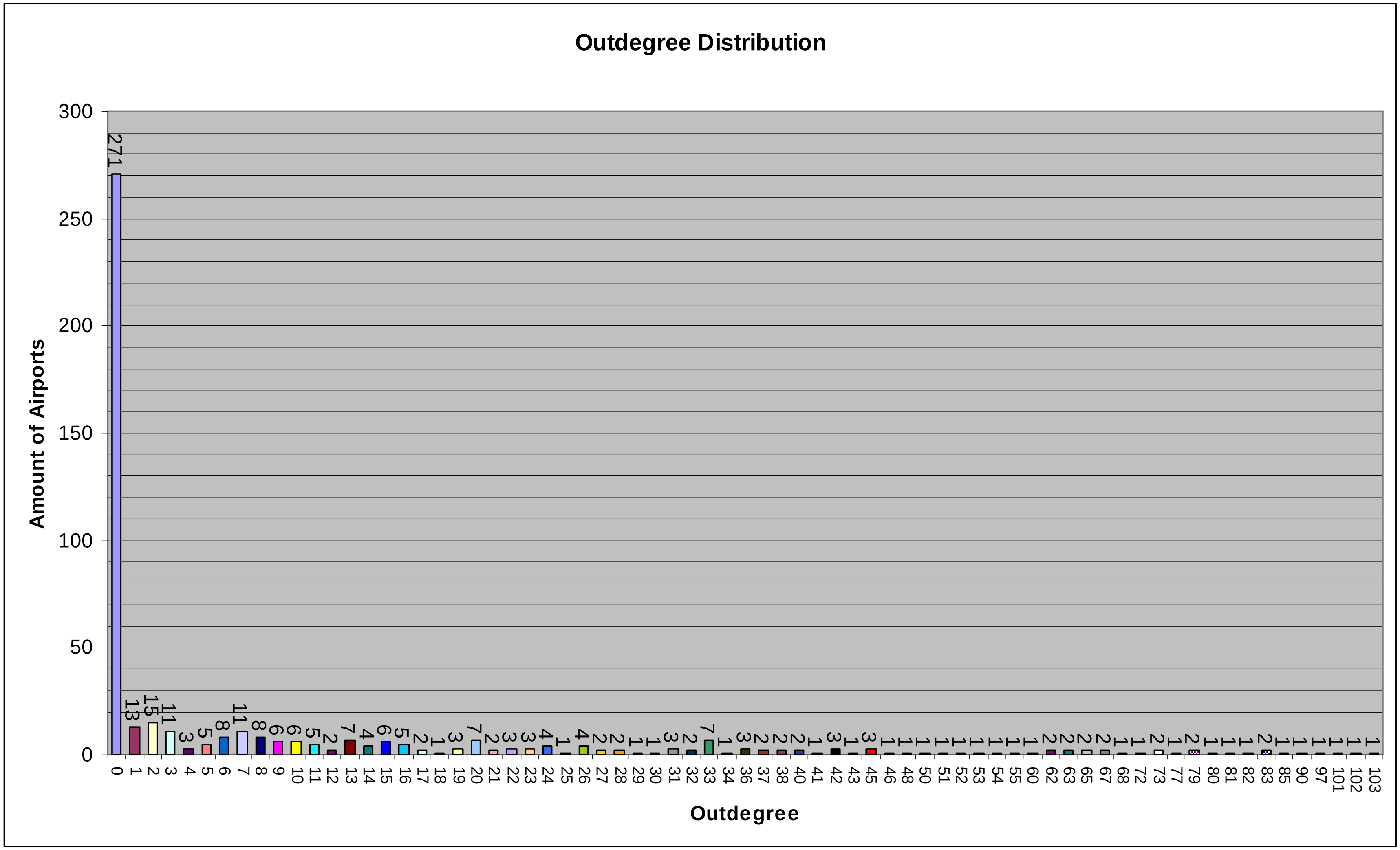

Figure B-2: Outdegree Distribution Amount of Airports

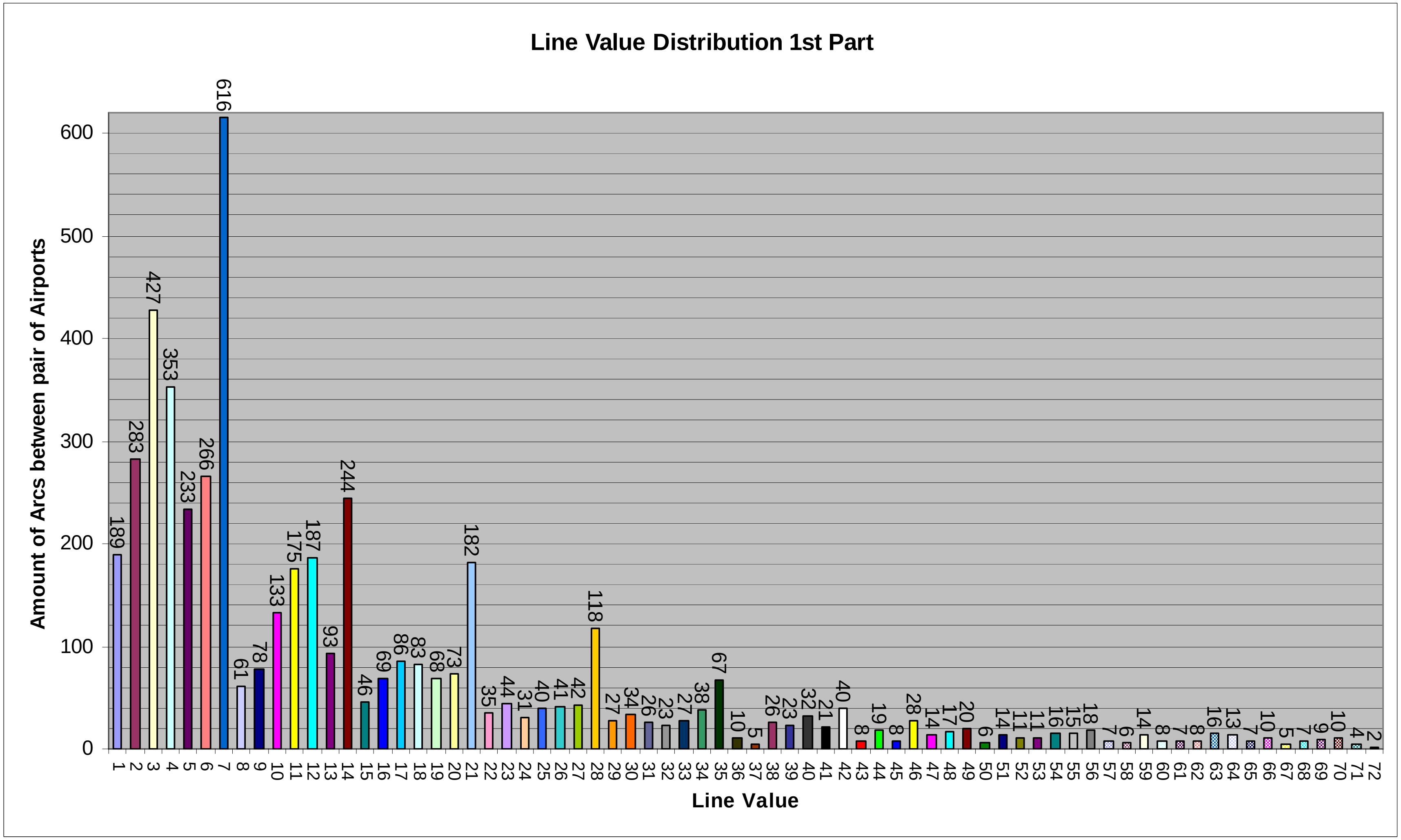

Figure B-3: Line Value Distribution 1st Part

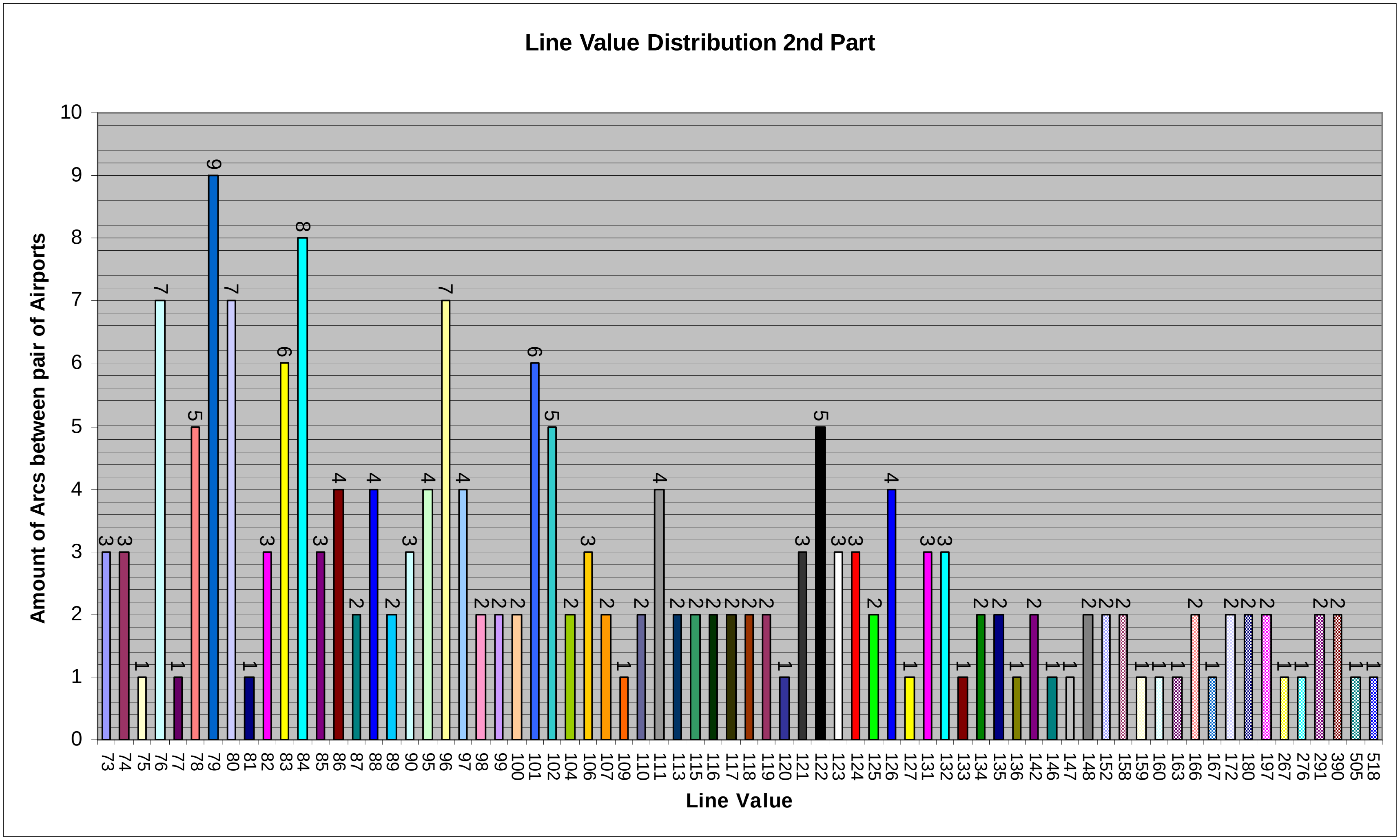

Figure B-4: Line Value Distribution 2nd Part

C Distribution Figures Eurocontrol

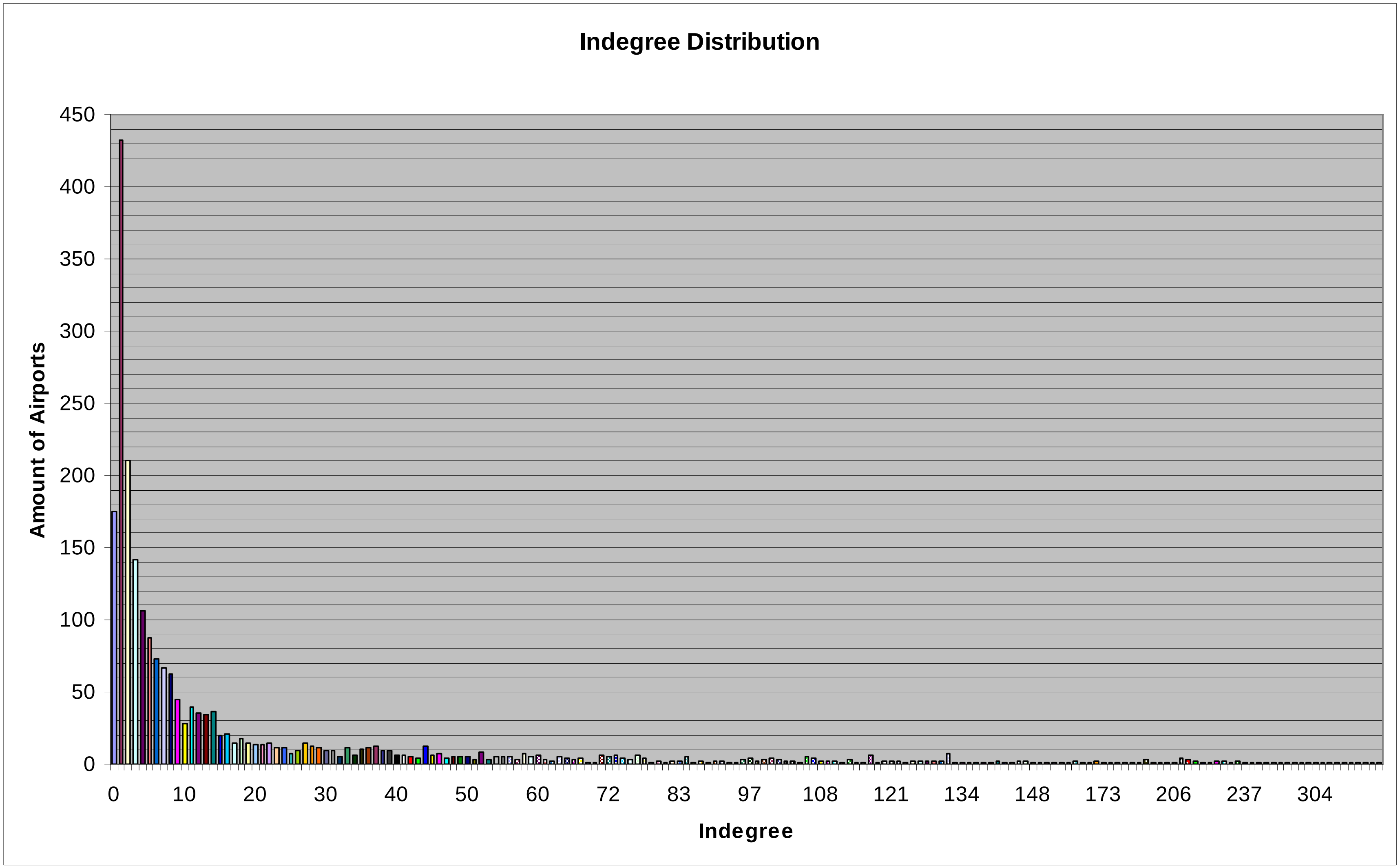

Figure C-1: Indegree Distribution Amount of Airports

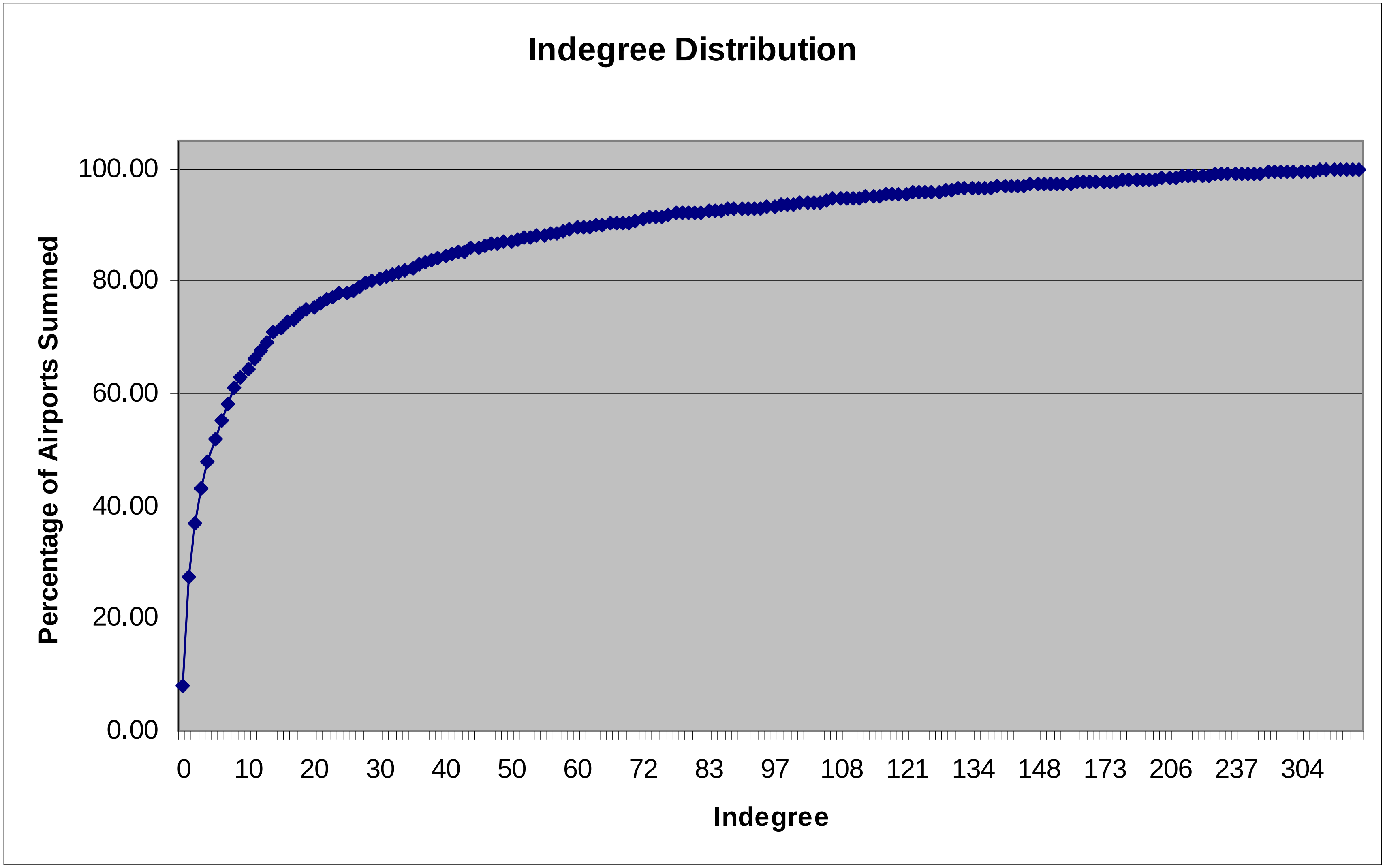

Figure C-2: Cumulated Indegree Distribution as Percentage

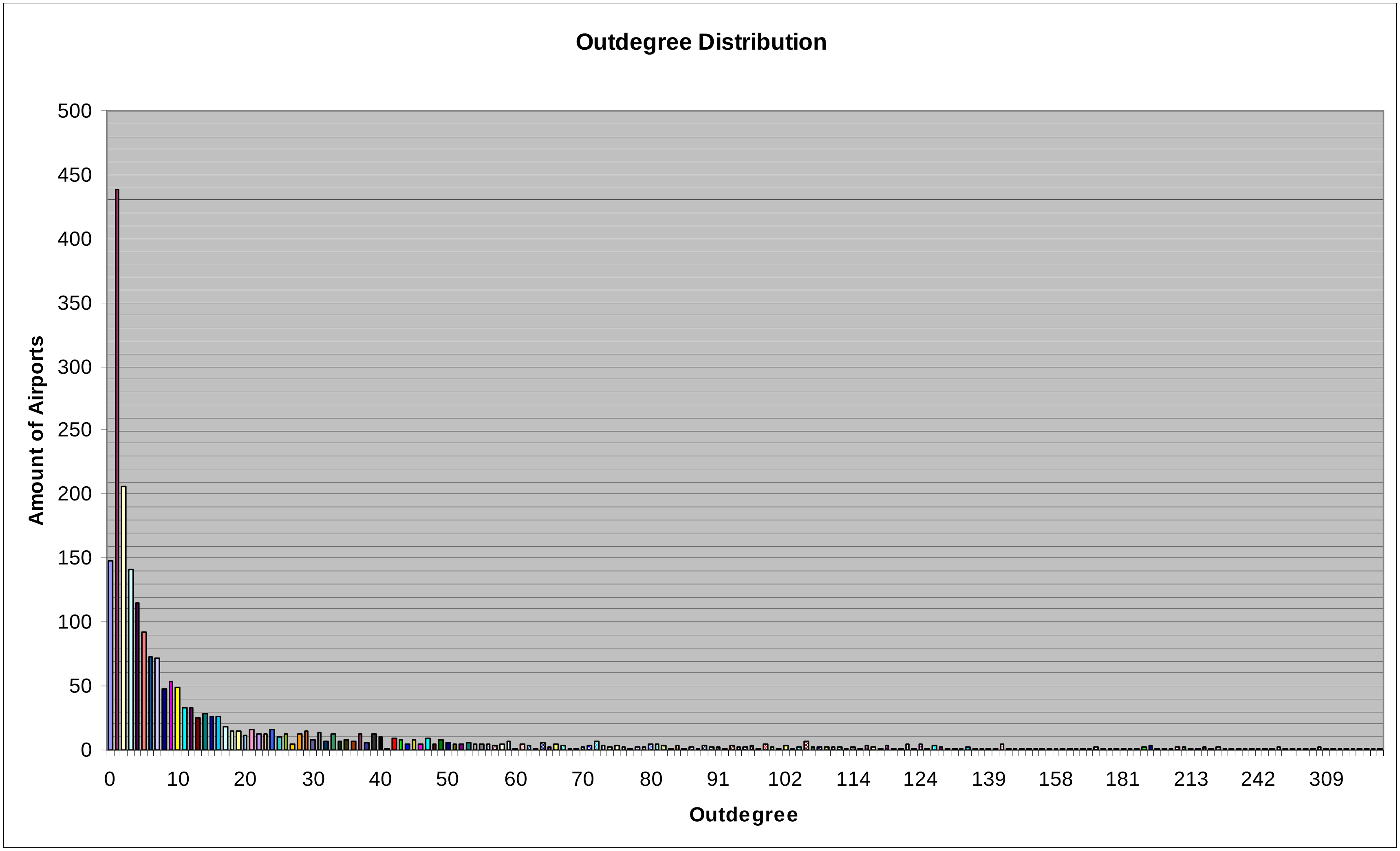

Figure C-3: Outdegree Distribution Amount of Airports

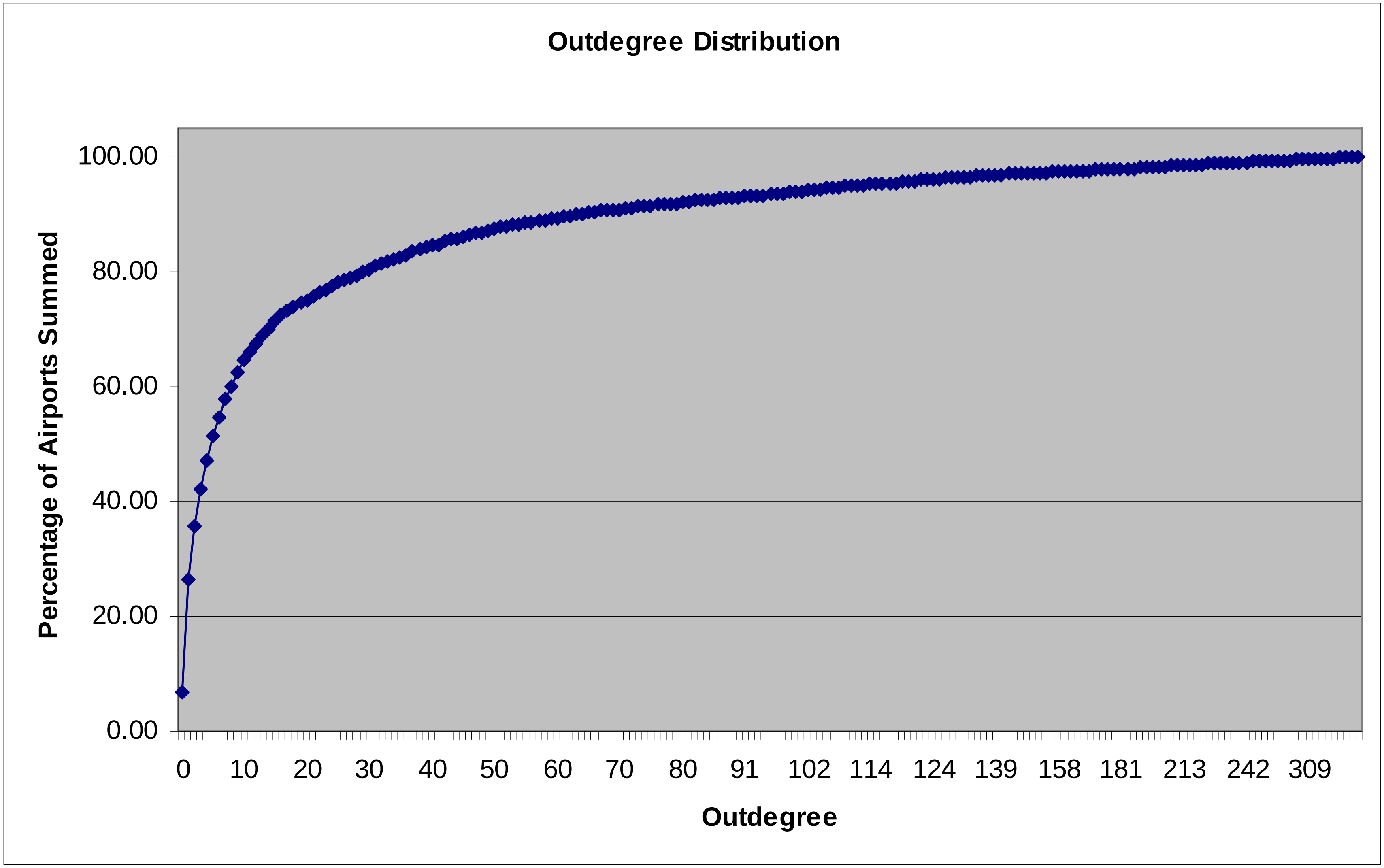

Figure C-4: Cumulated Outdegree Distribution as Percentage

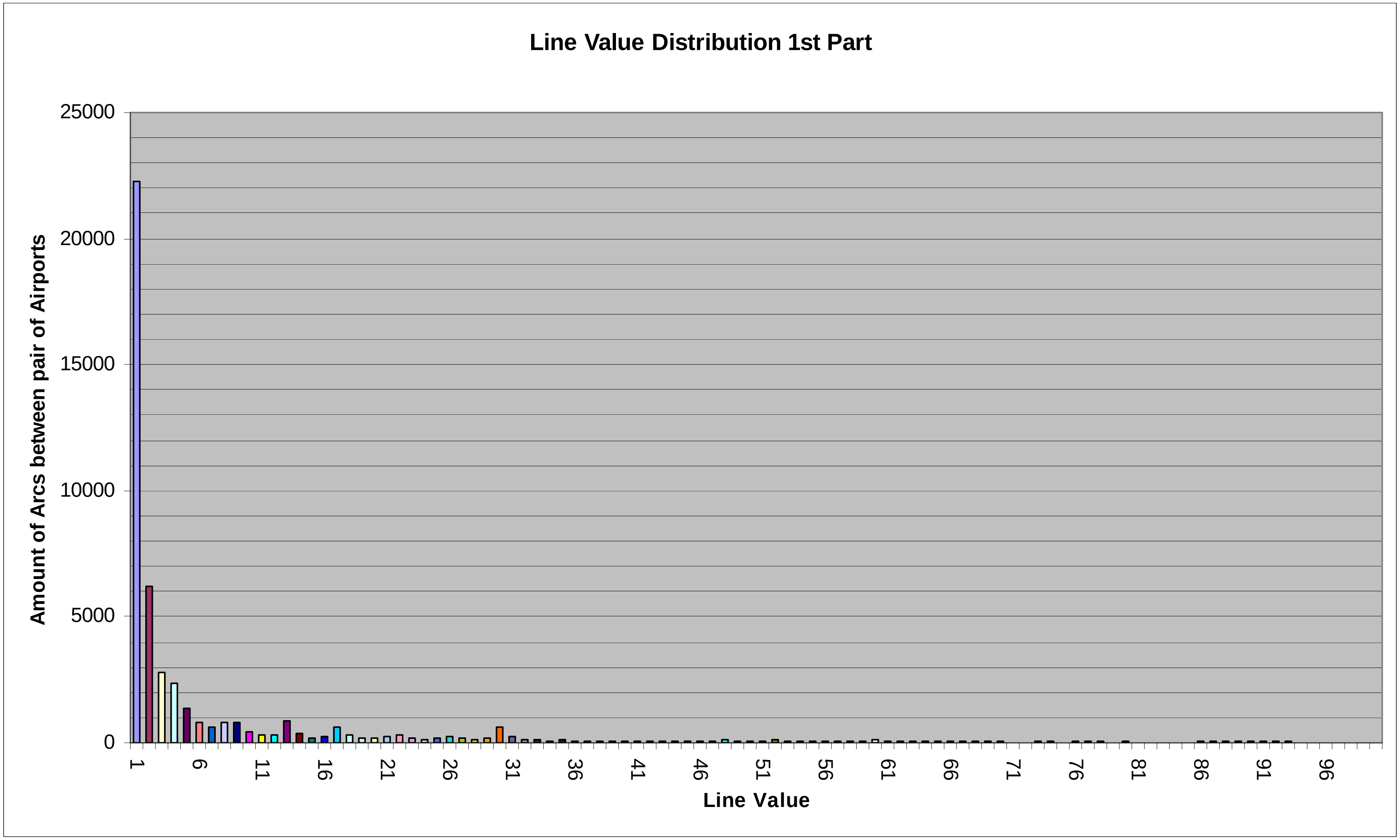

Figure C-5: Line Value Distribution 1st Part

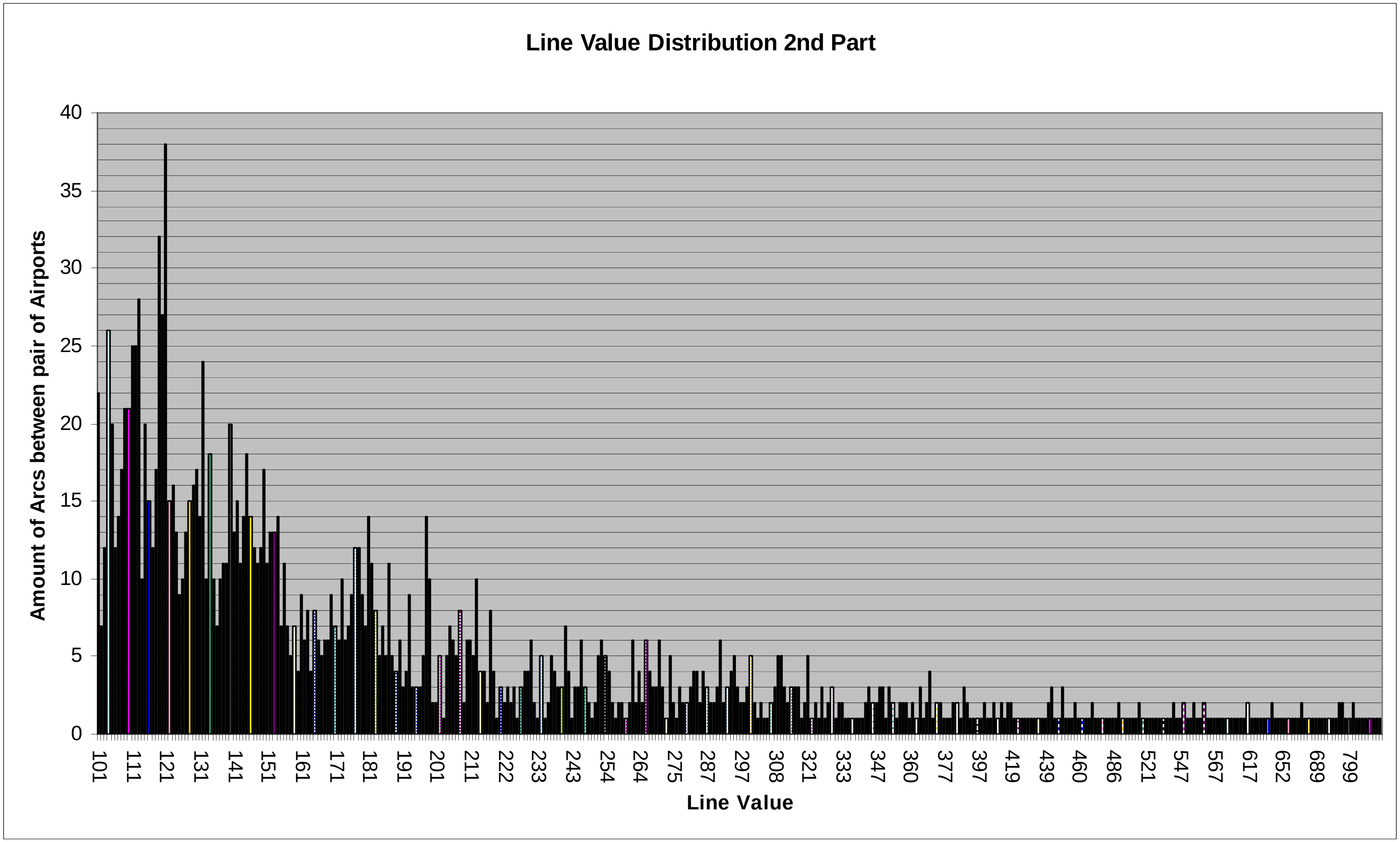

Figure C-6: Line Value Distribution 2nd Part

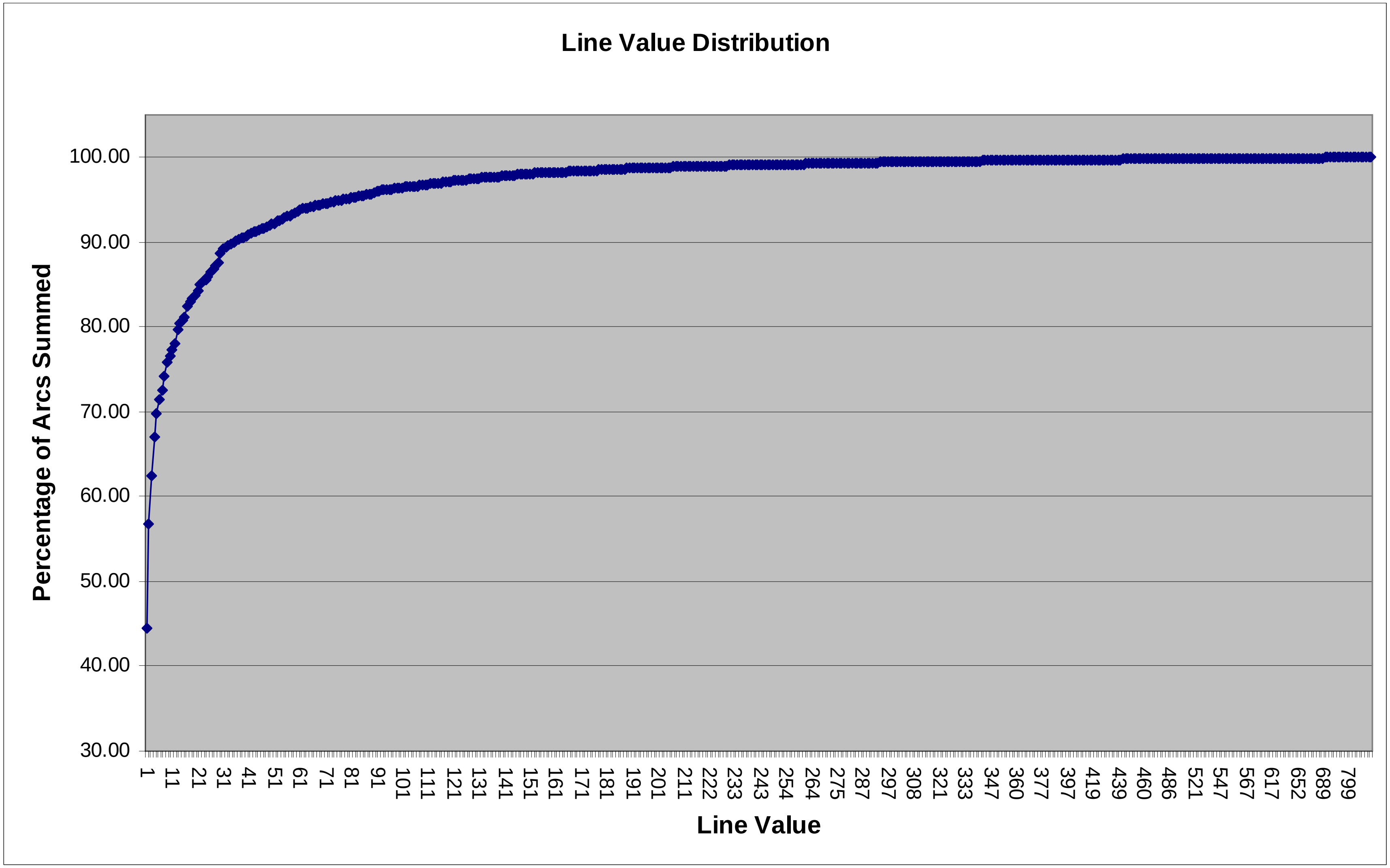

Figure C-7: Cumulated Line Value Distribution as Percentage

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