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ABSTRACT

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Abstract

The modern computer technology makes it possible to nowadays calculate even more complex equations and make larger models than was possible just a few decades ago. This can also be seen in solving difficult transportation problems, like route choice, and in the modeling of traffic flows and traffic assignment. In addition to having faster computers, also the amount of information available has increased considerably in the past few decades. Because of these reasons, it is good to know in detail about what kind of information is available as well as it's important to start summarizing the vast information base. The purpose of this study is thereby to first take a look at what has been studied in mathematical and methodological transportation research between 1983–2007 and how the focus point of research has shifted during those years. Secondly the thesis also give an overview of what kinds of methods are available in traffic flow and traffic equilibrium studies, which were the most researched topics according to this thesis.

The first part of the study was conducted by categorizing the articles which had been published in the journal *Transportation Research part B: Methodological* between 1983–2007. The categorization was based on what the article had been about and then placed in one or several of the seven categories. After that the total amounts of studies in each category were calculated as well as the yearly totals for all categories. From the yearly totals it was then possible to calculate a trendline, which then showed how the focus of research had evolved.

The category which had the most articles written about was traffic flow and traffic equilibrium. It was also the only well classified category where a trendline was visible. The largest amounts of studies in traffic flow and traffic equilibrium were made in the 1990s. Before and after that the study amounts have been slightly smaller. The changes are however rather small, and even though there has been a slight downwards trend in traffic flow and traffic equilibrium studies after the 1990s, it has still been the most studied topic year after year, a few exceptions excluded. Thereby one can say that the focus point of research hasn't shifted much. The same topics which were studied in the 1980s are still valid, the only difference being that the models and methods have evolved.

In the end of the thesis, there is a short literary review of the methods, which are used in traffic flow and traffic equilibrium studies. Its purpose is to give an initial overview on what kinds of methods there are in traffic flow and traffic equilibrium studies and in which situations the methods are applicable.

Key words	Traffic, Traffic flow, Traffic Equilibrium, Traffic Assignment, Transportation, Traffic networks, Propagation of research
Further information	

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TIIVISTELMÄ

- [X] Pro gradu -tutkielma
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Tiivistelmä

Tietokoneiden nopea kehittyminen mahdollistaa nykyisin entistä monimutkaisempien laskutoimitusten suorittamisen sekä entistä monimutkaisempien mallien kehittämisen. Tämä on havaittavissa myös erilaisten kuljetusongelmien (kuten reitinvalinnan) ratkaisussa sekä liikenteen ja liikenneverkkojen mallintamisessa. Tietokonetehojen lisäksi, myös saatavilla olevan informaation määrä on kasvanut olennaisesti viimeisten vuosikymmenien aikana. Näistä syistä johtuen on hyvä olla tarkemmin selvillä siitä, minkälaista tietoa on saatavilla sekä tiivistää olemassa olevaa tietoa helpommin lähestyttävään pakettiin. Tämä tutkielma pyrkiikin aluksi katsastamaan mitä kuljetuksiin liittyvässä metodologisessa ja matemaattisessa tutkimuksessa on vuosien 1983–2004 aikana tutkittu ja miten tutkimuksen painopiste on siirtynyt vuosien saatossa. Toisekseen tutkimus pyrkii antamaan yleiskuvan tutkituimmaksi havaitusta aiheesta, eli liikenne virroista ja liikenteen jakaumasta.
Tutkimuksen ensimmäinen osa on suoritettu luokittelemalla *Transportation Research part B: Methodological* -lehdessä ilmestyneet artikkelit vuosilta 1983–2007 seitsemään eri kategoriaan sen perusteella, mitä aihetta artikkelit käsittelivät. Kukin artikkeli sijoitettiin joko yhteen tai useampaan kategoriaan. Sen jälkeen saadusta aineistosta laskettiin kuhunkin kategoriaan kuuluneiden artikkelien kokonaismäärät sekä kunkin kategorian vuosikohtaiset artikkelimäärät. Vuosikohtaisten määrien perusteella voitiin kullekin kategorialle laskea trendi, josta näkyy kategorian saaman huomion kehitys vuosien aikana.
Eniten tutkimusta oli saanut osakseen liikennevirtojen ja liikenteen jakauman tutkimus. Se oli myös ainoa varsinainen kategoria, jossa oli havaittavissa suhteellisen selkeä trendi. Määrällisesti sen tutkimuksen huippukausi ajoittui 90-luvun loppupuolelle, jota ennen ja jonka jälkeen tutkimusmäärät olivat hieman pienempiä. Muutokset eivät kuitenkaan ole olleet kovin radikaaleja, sillä muutamaa poikkeusta lukuun ottamatta liikennevirtojen ja liikenteen jakauman tutkimus oli aina kaikkein tutkituin aihe. Voikin sanoa, että tutkimusten painopiste ei ole juurikaan muuttunut vuosien varrella, kunkin alan tutkimus on vain mennyt eteenpäin.
Tutkimuksen lopussa on myös kirjallisuuskatsaus liikennevirtojen ja liikenteen jakauman mallintamisen metodeihin. Sen tarkoituksena on antaa alustava käsitys siitä, mitä eri metodeja on käytettävissä ja mihin niitä voi käyttää, sekä mitä alalla parhaillaan tutkitaan.

Asiasanat	Kuljetus, Liikenne, Liikenneverkot, Liikennevirta, Liikenteen jakauma, Tutkimuksen kehitys
Muita tietoja	

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Emphasis on traffic flow and traffic equilibrium problems

Master´s Thesis
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List of Abbreviations

ATIS - Advanced Travel Information System
CA - Cellular Automata
LWR - Lighthill–Whitham–Richards
OLS - Ordinary least squares estimate
OD - Origin-Destination
OV - Optimal velocity
TSP - Travelling Salesman Problem

1 INTRODUCTION

1.1 Background to the study

We currently live in a world where change is very rapid and information is available abundantly. It has been said that today a person is exposed to more information in one day than an 18th century citizen was exposed to in his entire life. But as information is so widely available, it is not an asset before it is converted into intelligence and knowledge. After that conversion, information becomes an important source of wealth. (Corbin, 2002, 1–5)

Since information is so widely available and it is time consuming to go through thousands of pages of research, it can be seen important to summarize some of the information into a more compact form to be converted from plain information to knowledge. But in order to know what to summarize, one should know what is being studied at the moment.

Thereby the question of what is currently being studied is also an interesting topic of research. For example in transportation modeling, the Delphi study made by The Institute of Transport Studies at Sydney University in 1995 saw activity modeling as the most important issue for the next ten years and in that study, equilibrium procedures were left at 10th place in importance. (Hensher & Button, 2000, 5–7) Still, the dynamic user equilibrium has been one of the most studied topics in recent years according to Gentile, Meschini and Papola (2007, 1114–1115). In addition to that, rising technologies such as Intelligent Transportation Systems require complex models and algorithms, which may also have an effect on what is currently being studied. (see e.g. Bierlaire, 2006, 287–300)

Even if all people claimed that their topic of study has gained popularity among researchers, none of them might be wrong. The total amount of research in all has increased quite a lot. At least the Transportation Research Part B: Methodological journal's size has increased dramatically indicating that the total amount of research may have also been increased. In 1997 the journal had approximately 500 pages and 6 issues came out per year and currently (in 2007) it had 10 issues per year with over 1100 pages of studies. (ScienceDirect, 2008a) In other words, the amount of research published in that journal which is concentrated on Transportation research methodology has more than doubled within the past 10 years and thereby it is possible that route choice research, traffic equilibrium research, network planning research etc., may have all simultaneously increased their popularity in terms of total amount of papers published.

Therefore it is now very interesting and useful to take a look at what actually is being currently researched. Has the increase in the amount of studies spread equally among the topics or has some topic taken more space from the others?

1.2 Purpose of the study

The objective of this study is twofold. First to study the trends of transportation methodology research; what topics are currently being studied and how has the division between the different topics evolved in 25 years (1983–2007).

After determining what is the most widely researched topic, the second objective is to give an overview of that topic, so that it is easier for the reader to get a grasp at what kind of information and methods are available nowadays in that field of study. Also some possibilities for further study in that field are indicated.

1.3 Limitations

This study is limited to only methodological studies of transportation literature. Thereby it can not be used to determine what is studied in Logistics in general and even many aspects of transportation research, such as environmental research and practical studies, are being overlooked.

Also the analysis on what has been researched in the field of Transportation methodology is limited to one publication only, the Transportation Research Part B: Methodological. Therefore the study on what has been researched and how the focus point of research has shifted should be seen as only a very rough guideline to what is being studied.

However, the proposed classification of topics created in section 3.3, can be used in other Transportation themed journals as well. If the same classification of research areas was to be used in analyzing other Transportation magazines, then the results from this study could be combined with the results received from the other study, resulting in a more thorough and accurate view on the development of Transportation research in general.

1.4 Structure of this Thesis

The remainder of this study is structured so that section 2 gives a brief overview of the history and early stages of various aspects in transportation research.

Sections 3 and 4 are reserved for studying the development of transportation methodology. First, in section 3, the research methods used in this study are explained and justified. In section 4 the study is conducted by classifying articles from Transportation Research Part B: Methodology -journal and the results are shown. The data used in section 4 can be found from Appendix 1.

Section 5 will take a slightly closer look at the nearby-history and current state of traffic flow and traffic equilibrium research, since they were the fields of study most in need of summarization according to section 4. In the end section 6 includes the final conclusions of the study, suggests some possibilities for further research and serves as the summary of this thesis.

2 HISTORY OF TRANSPORTATION STUDY

2.1 General

Transportation has been an issue for thousands of years for example in the form of sea travel. Even the ancient Egyptians were able to build ships of some sort and Sumerians in southern Mesopotamia built ships with keels and ribs already around 3000 BC. Phoenicians are known to have travelled around Africa by sea as early as circa 600 BC, and from a European point of view, the age of discovery in the late Middle Ages and early Modern Era are an important milestone in the modern global sea fare. (Hakala, 1990b, 432)

Maps have also been around at least for a few millennia already as the earliest known Babylonian map was made around 2500 BC on a clay tablet. Longitude and latitude found their way on maps ca. 200 BC, which is the basis for modern cartography. (Hakala, 1990a, 87)

As even magnetism was discovered by the Chinese before anno Domini and compasses were in use some centuries later, it is needless to say that the basic principles for transportation research have been around for very long. (Hakala, 1990a, 357–358)

2.2 Route Choice

2.2.1 Travelling salesman problem and graph theory

Also the roots for modern transportation route choice problems date back several centuries. For example a need for a solution to a contemporary route choice problem, the travelling salesman problem (TSP), was voiced in the 15th century in the United Kingdom, where judges and lawyers needed to travel from a population center to another during specified times of the year. (Applegate, Bixby, Chvátal & Cook, 2007, 1–18)

Although there weren't any profound mathematical solutions to the problem yet, the interest to the problem and the importance of it grew in the 19th century. In 1832 a book "*Der Handlungsreisende*" was published for travelling salesmen in Germany and included several good routes for salesmen in Germany and Switzerland. In the United

States lawyers and preachers travelled from town to town and required good routes and also the armada of travelling salesmen grew in the USA up to approximately 350,000 persons by the end of the 19th century. And these are just some examples of the importance of the travelling salesman problem before any mathematical solutions were offered. (Applegate et al., 2007, 1–18)

From a mathematical point of view, the groundwork for graph theory and thereby for e.g. the TSP was done by a Swiss mathematician Leonhard Euler in 1735 when he solved a puzzle of the Königsberg's Bridges. The problem was to find a path which crosses all the seven bridges of Königsberg and then returns to the point of origin. In 1759 Euler also solved the Knights tour problem[1], a problem that had been mentioned already in the 9th century Arabic literature. Euler's mathematical solution to it can be seen as an important step towards solving the TSP. (Alexandersson, 2006, 567–570) (Applegate et al., 2007, 8–10)

A new milestone towards the TSP was made in 1859 when Sir William Hamilton introduced a solution, now known as the Hamiltonian circuit, which creates a path that crosses each node in a graph (or network) exactly once and comes back to its origin. Hamilton was interested in classic geography and in the dodecahedron, so his initial tour followed dodecahedron's geometric edges. One possible tour along dodecahedron's edges is seen in figure 1 (Kalita, 2005, 1430–1432) (Applegate et al., 2007, 18–20)

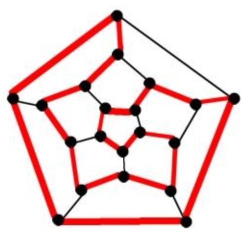

Figure 1: Example of a Hamiltonian Circuit in a dodecahedron; modeled according to Weisstein, 2008

The next big step from the Hamiltonian circuit is then the travelling salesman problem itself. Karl Menger is often credited as the first mathematician to mention the actual TSP as he did it at a mathematicians' colloquium in Vienna 1930, though at that time he called it *Das Botenproblem* (the messenger problem). He was interested in finding the shortest path for a postman or travelers who need to take a tour and come back to the point of origin, while visiting all the other necessary nodes. (Applegate et

[1] Creating a path following the rules of chess where the knight visits each square on the chess board exactly once.

al., 2007, 11–12)

After Menger's initial discussion of the problem, several other mathematicians discussed it. However, the first papers containing actual mathematical answers to the problem were published in the late 1940's. The other paper was done by Eli S. Marks and the other was written by M.N. Ghosh. However they referred to the problem as neither the messenger problem nor the TSP, but instead they were concerned by travelling farmers. (Applegate et al., 2007, 11–12)

After the initial solutions, the TSP in its various forms has been a topic of research among mathematicians. In 1940s and '50s school bus routings were one of the topics of discussion by e.g. Merrill Flood and Albert Tucker. In 1954 Dantzig, Fulkerson & Johnson made a famous 49 city tour solution. In 1959 Beardwood, Halton and Hammersley published a famous paper which calculates the estimate of the length of the optimal route. In early '60s the TSP became a hot topic after Procter & Gamble made a competition where the person to plan the shortest 33-city TSP route was awarded 10,000$ (won by Gerald Thompson). And in 1962 Held and Karp made a TSP algorithm that is still considered as the best-known guarantee on the running time of a general solution method for the problem. (Applegate et al., 2007, 11–18, 50–52)

In 1971 a variant of traveling salesman problem emerged when Wilson introduced the dial-a-ride problem. It is a version of TSP where there are pick-up and drop-off points on the tour as well as can have time-windows and maximum ride-time constraints, which makes the dial-a-ride problem harder than the regular TSP. (Fabri & Recht, 2006, 336) (Healey & Moll, 1995, 83–86)

The TSP is an NP-hard problem, so there are polynomial times answers and also the original travelling salesman problem is still a topic of research among mathematicians today. Even the question whether a good algorithm[2] for the TSP exists or not is a matter of discussion. If someone proves that there isn't such an answer or finds a good answer, he or she would be rewarded with 1,000,000$ from the Clay Mathematics Institute. The amount of cities to be incorporated in the tour can always be made greater to make the problem more difficult so that it takes too long to calculate the route even with modern computers and for example in 2006 a route for 85,600 cities was made. One can also set additional limits, such as time- or capacity constrains to the tour, force multiple visits or apply the problem to a new setting such as for manufacturing robots to make the problem harder and to keep the discussion alive. (Applegate et al., 2007, 44–56) (Gutin & Punnen, 2002, 7–11, 14–19) (Healey & Moll, 1995, 83–86)

[2] "Precise criterion for a method to be called a *good algorithm*. To be in this category the algorithm should have a guarantee $f(n)$ that is a polynomial function of the problem size n, that is, for large values of n, the algorithm should run in time at most Kn^c for some constant numbers K and c." (Applegate et al., 2007, 48)

2.2.2 Shortest path problem

The shortest path problem is also an old network optimization problem, which tries to find the lowest cost path (or route) from a pre-determined starting point to a pre-determined ending point. Some initial studies on how to choose a route (even in a congested network) were done by Kohl already in 1840s and in the 1920s by Pigou and Knight. (Santos, Coutinho-Rodrigues & Current, 2007, 756–757) (Boyce, Mahmassani & Nagurney, 2005, 87)

The first efficient solutions to the shortest path problem were made in 1959 by Dijkstra and in 1960 by Whiting and Hillier. Among others pioneering work in the late 1950s and early 1960s was made by e.g. Dantzig, Minty, Ford and Fulkerson to name a few. When it comes to finding second best routes, the earliest known good algorithm for this purpose was introduced by Hoffman and Pavley also in 1959. (Dreyfus, 1969, 395–412)

The shortest path problem is still a topic of interest. The problem can be made more complex with adding different kinds of constraints to the path, for example the path is forced to include certain nodes or make time limitations in visiting some nodes. Adding such constraints generally makes the shortest path problem NP-hard. In the constrained shortest path problem, Saksena and Kumar can be credited as one of the pioneers. (Santos et al., 2007, 756–757) (Dreyfus, 1969, 408–410)

2.2.3 Transportation problem

The roots of the transportation problem[3] date back to the 18th century when Gaspard Monge published his memoire about the most economical way of earth-moving in 1781. The problem was further studied by Appell in the late 19th century and a major contribution was made by L.V. Kantorovich on his paper "*On the transfer of masses*" published in 1942. There he transformed the non-linear problem by Monge into a linear one in the search of the optimal solution and lowest cost. Thereby the problem is sometimes called as the Monge-Kantorovich problem. (Feyel & Üstünel, 2004, 347–351, 384)

The year 1942 can be referred as the year when the transportation problem was born. Though the study itself was done in the late 1930s, the publication was delayed due the

[3] "A programming problem that is concerned with the optimal pattern of the distribution of goods from several points of origin to several different destinations, with the specified requirements at each destination." (Sci-Tech Dictionary, 2003)

Soviet censorship policies regarding articles about economics. Kantorovich also continued to study his theory and published articles co-written with his pupils M.K. Gavurin and G. Sh. Rubinshtein in the late 1940s and -50s, though again the study itself was done much earlier and the publications were delayed by the Soviet procedures. And in mid-1950s Kantorovich was able to hold lectures about the topic and popularized his formerly hard-to-get theories. (Vershik, 2006, 1410–1417)

Since then the transportation problem study has continued in various ways. For example the minimum cost flow problem known as the Hitchcock transportation problem is a popular topic of study in the footsteps of Monge and Kantorovich, which originated also in the 1950's. It is a minimum cost flow problem where all the suppliers are on one side of a bipartite graph and all the consumers on the other side. (Dubuc, Kagabo & Marcotte, 1999, 141–147) (Brenner, 2008, 1–4) Other further enhancements of the transportation problem include, for example, the cases where the distances (or costs) are uncertain (see e.g. Bai, Mao & Lu, 2004, 219–224) and the case where there is also a fixed cost in every transportation, which makes the transportation problem NP-hard. (Kowalski & Lev, 2008, 913–917)

2.3 Traffic flow

Hundred years ago in 1908 Ford introduced a car called Model T, which was the first truly mass-produced car and one of the success stories of its time and over 15 million pieces in total was produced. (Gardner, 2008, 84) Before Ford traffic problems were small and isolated so they didn't raise much interest. (Gazis, 2002, 69)

During the 1920s and 1930s researchers mainly in the UK, Germany and in the USA began trying to estimate the capacities of roads. The estimation attempts led to the introduction of first traffic speed–volume relationship models. Determining who exactly was the first one to publish his studies is hard, but one solid contender would be Schaar whose study saw the daylight in 1925. It took into consideration such variables as the speed, vehicle length, drivers' reaction times, friction coefficient and gravity acceleration. (Del Castillo & Benítez, 1995, 373–374)

A completely different approach to speed-density relationships was initiated by Greenshields, who in 1935 made no assumptions of the drivers' behavior and obtained his speed–density relations by fitting his models to actual observed traffic data. His linear model included only maximum traffic speed, traffic density and the maximum traffic density. His studies were then later on continued by e.g. Greenberg (1959), Underwood (1961) and Drake et al. (1967) when traffic modeling was a more popular topic. (Del Castillo et al. 1995, 373–374)

But after the little initial interest in traffic modeling in the early 20th century, the mass-production of cars brought the traffic problems on surface and by the mid-20th century traffic problems were big and craved for more attention. By 1950 several scientist with various backgrounds attempted to model traffic and find answers to the arisen problems. (Gazis, 2002, 69)

The traffic flow studies could be divided into microscopic and macroscopic studies from very early on. Reuschel (1950) and Pipes (1953) were among notable pioneers in traffic modeling on the microscopic side as their initial models described cars' movements in detail and the relation of the lead car and the following car and their speeds. (Gazis, 2002, 69)

On the macroscopic side a fluid mechanist by the name of Lighthill together with Whitham modeled traffic as a fluid-like continuum in 1955. They measuring traffic flow in cars per hour and traffic density in cars per mile and were able to even model shock waves in traffic, though only those which happen widely in time as in when traffic shifts from one steady-state pattern to another one which has a different density and flow. (Gazis, 2002, 69)

In 1956 General Motors hired a new research executive, Larry Hafstad, who wanted to make General Motors' research lab also a leader in basic sciences. One person whom GM hired was Robert Herman who teamed up with Elliott Montroll, who already had been interested in traffic flow theories. Together Montroll and Herman made investigations on car-following models which were similar in concept as Reuschel's and Pipes' model, but had meaningful mathematical differences[4]. Montroll and Herman were able to test their models on GM's test track and Chandler was brought into the team. The test methods might have been primitive, but it's notable that their published results in 1958 have served as the foundations of microscopic theories as of today and even after almost 50 years their investigations still stand the test of time and are considered as a breakthrough in car-following understanding. It should be noted though that at the same time in 1958 also Kometani and Sasaki published in Japan, independently from the GM studies, a very similar theory to that of Chandler's et al. (Gazis, 2002, 69–70) (Newell, 2002, 175) (Holland, 1998, 142)

In all the late 1950s and early 1960s were very hectic times for traffic modeling theories. In late 1950s Webster studied optimal traffic light settings. In 1959 Herman published a study concerning a platoon of cars following one another and traffic flow's stability by asking what happens when a front car makes some sort of maneuver and thereby sends a signal which then passes from one car to another. (Gazis, 2002, 70–74)

Influenced by the past studies, in the 1960s Herman began research with Prigogine

[4] Explained in some detail in Gazis, 2002, page 70

on kinetic traffic flow theory which is somewhere in between microscopic and macroscopic theories in its scope. (Nelson & Raney, 1999, 298–302)

Speed–density relation-wise in the 1960s Prigogine's and Herman's kinetic theories were one new source. In 1961 Newell and Franklin independently formulated the first exponential speed–density curves, which were then referenced twice (in 1966 and 1971) before mysteriously disappearing from traffic flow literature. In 1965 Edie and Baverez studied the propagation of stop–start waves in Holland Tunnel, the same year Dörfler studied the dynamics of stopped platoons at traffic lights and still in 1965 Franklin published his studies of traffic jam densities. In 1967 Pipes derived a new family of speed–density curves from existing car-following models and as mentioned, in the late 1960s Underwood and Drake improved the speed–density relation studies made by Greenshields in the 1930s. (Del Castillo et al. 1995, 373–388)

After a very vivid period of study in the 1960s, the interest towards the traffic flow study decreased noticeably in the 1970s. Early 1970s still saw several important studies being published. The two-fluid theory for traffic flows in towns was introduced by Prigogine and Herman in 1971 and still in 1971 Prigogine and Herman published a highway traffic flow model linked to Boltzman's equations of the kinetic theory of gases. The Boltzman-like gas kinetic theory was able to fill a lot of gaps in traffic flow modeling. The kinetic flow theories were also further improved by Phillips in the late 1970s. After the 1970s the flow of completely new traffic flow model ideas has reduced and time has been spent in reworking and refining old procedures. (Nelson et al. 1999, 299–302) (Gazis, 2002, 72–74) (Newell, 2002, 174, 177)

2.4 Traffic equilibrium

Traffic equilibrium study aims to assign routes from various origins to various destinations in urban networks and choosing such routes for cars that the travel time is minimized. In that vein, the study has its roots in both traffic flow theories and in route choice problems, but one could say that specific traffic equilibrium study began after the network flow theories were developed for various uses. (Boyce et al., 2005, 87–88) (Gazis, 2002, 73–74)

In 1951 Beckmann, McGuire and Winsten began their study on network equilibrium and were one of the pioneers of the equilibrium study and they developed a cost-minimizing model for flows in a congested network, now called as system optimum flows. The same year also Nash published his equilibrium model. Other very notable pioneer in traffic equilibrium studies is Wardrop. In 1952 he published his famous two principles in assigning traffic to a network. His principles was that either the travel time is optimized in an individual level or then on a system level so that the total travel time for all passengers is minimized and in the 1960s Dafermos and Sparrow started calling the Wardrop's principles as user-optimal and system-optimal models, terms which are still used to describe equilibrium models. Wardrop's principles are considered as the starting point of development of modern traffic assignment theories. (Boyce et al., 2005, 86–89) (Gazis, 2002, 73–74)

When listing notable contributions to traffic equilibrium study in the 1950s, one shouldn't forget that the Frank and Wolfe algorithm was introduced to solve linear optimization problems in 1956 though to the traffic equilibrium context it was introduced in the 1960s. (Boyce, LeBlanc & Chon, 1988, 163)

In 1961 the traffic equilibrium models were combined with the problem of road tolls and congestion pricing by Walters. It's a topic of study which still is an important part of equilibrium studies. One should however note that road tolls itself in networks were already researched in the 1920s by e.g. Pigou. (Boyce et al., 2005, 89–91)

The 1960s also saw the advent of multi-criteria equilibrium models, where travelers faced different criteria in their route selection such as travel time and monetary cost. The first ones to introduce such models were Quandt in 1967 and Schneider in 1968. After that, in the late 70s and early 80s, Dial and Dafermos made some notable contributions to the multi-criteria model.[5] (Nagurney & Dong, 2002, 445–447)

In the early 1970s more elaborate cost schemes were introduced for the routes in the equilibrium models. In Dafermos' studies, the route cost was able to be calculated differently for different users and thereby allowing the equilibrium models to become multi-user class models. In the 1980s elasticity of demand was emphasized more. (Boyce et al., 2005, 91–93)

The 1970s was also the decade when dynamic[6] traffic assignment models were introduced by Yagar in 1971. Merchant and Nemhauser are often credited as the first to consider dynamic route choices over general networks in 1978. They studied especially the dynamic system optimal equilibrium model. Also the introduction of logit models to traffic assignment models happened in 1971 by Dial and in 1977 Daganzo and Sheffi proposed the use of probit models, which can be seen as the foundation of stochastic route choice models in traffic equilibrium. (Boyce et al., 2005, 92–93) (Boyce et al., 1988, 177–178) (Gazis, 2002, 73–74)

During the last decade, one of the most active topics in transportation modeling has been within-day Dynamic Traffic Assignment. That is traffic assignment problems

[5] A table of what different contributions were made to the multi-criteria models can be found in Nagurney & Dong, 2002, page 447

[6] Where the amount of traffic changes as a function of time and traffic assignment is thereby time-dependent (Gazis, 2002, 74)

where at different times of day the traffic demand varies as it incorporates peoples' departure time preferences. Static analysis is often thought to be an improper way to model congested networks. (Gentile et al., 2007, 1114–1115) Also the advent of advanced travel information systems (ATIS) has created new problems for traffic assignment models. (see e.g. Huang & Li, 2007, 1464–1477)

2.5 Other

2.5.1 Logit models

Choice models are used in various different contexts and not only in logistics. However they are useful also in various transportational aspects like in estimating traffic flows (see e.g. Castillo, Menéndez & Sánchez-Cambronero, 2008, 482–509) and in modeling peoples' transportation mode choices (see e.g. Lo, Yip & Wan, 2004, 251–272). Thereby a short recap in logit model history is in order also in this context.

The introduction of powerful computers and advances in econometric estimation has made it possible and practical to nowadays have very general and wide logit models. However multinomial and nested logit models have been the workhorses in the analysis of discrete choices in travel behavior for a few decades. (Dios Ortúzar, 2001, 213–216)

In other uses logit models are very old inventions. For example a widely used choice model, multinomial logit model, was first introduced in biology by Fechner already in 1860. As choice models they became popular as late as in the 1970s, though Luce's psychological studies in 1959 utilizing the multinomial logit model are also at times cited as predecessors in the study of choice modeling without forgetting that logit type structures in product share models were widely applied already in the 1960s. (De Palma & Lefevre, 1983, 103–108) (Dios Ortúzar, 2001, 213–216) (Manrai, 1995, 1–3)

The current form of nested logit models used in choice modeling was introduced in the early 1970s by Ben-Akiva and Manheim. D. McFadden played an important part in creating the nested logit model in the early 1970s as well and he is also generally cited as the creator of the nested logit model. In the latter part of the 1970s, heavily influenced by Ben-Akiva's work, H.C.W.L. Williams made several important contributions to the nested logit model. (Dios Ortúzar, 2001, 213–216)

In 1977 Williams also proposed a new kind of logit model, Cross Correlated logit. Though the new logit model has not proven practical, the study itself laid the basis for Monte Carlo simulations, which Williams and Dios Ortúzar undertook to assess misspecification problems. Also multinomial logit models were used in the 1970s. (Dios Ortúzar, 2001, 213–216) (Gruca, Sudharsan, 1991, 480–482)

Nowadays the nested- and multinomial logit models are still in much use as well as new improved logit models have been introduced to for example better suit the challenges of the modern era of information technology (see e.g. Bierlaire, 2006, 287–300). In addition to logit models there are also probit models, which were first introduced by C. Bliss in 1934 as a probit model in biological research, though again the roots of the probit technique itself can be found in the late 1800s. (McCulloch, 2000, 1320–1321)

2.5.2 GPS

The global positioning system (GPS) is one of the recently emerged technologies in transportation, which have enabled businesses to manage their transportation fleet more efficiently. Combined with other wireless technologies and efficient computer programs, GPS can nowadays save lots of work, help in costing calculations and help one's business in several ways. (Kruse, 1998, 38–41) As an emerging technology several uses for GPS technology are still in the works, one of the latest and most active topics being the incorporation of GPS into mobile phones and creating more value that way (see e.g. Salz, 2008, 25).

But though the GPS itself is quite a modern tool (released for civilian use in 1993) and is currently actively expanding in its uses, it still has roots in the 1950s when William Guier and George Weiffenbach started tracking the Soviet satellite Sputnik's signal after its launch in 1957. Then they were asked by Frank McClure to develop a positioning system based on the satellite's signal. As Guier, Weiffenbach and McClure found the operation feasible; with Richard Kershner they designed a positioning system called the Transit Navigational System. (Cho, 2004, 88) (Lesea, 1997, 18)

In 1960 the first Transit satellite was launched into orbit first providing service to the US military submarines and ships. In 1967 the system was opened to civilian ships and surveyors, who soon became the majority of the users. After that, the Transit system was shut down in 1996 as it had been gradually replaced by the GPS, which provided more satellites and thereby better service and was released by the military for civilian use in 1993. (Cho, 2004, 88) (Lesea, 1997, 18)

3 METHODS OF RESEARCH

3.1 General discussion of the methods used in this study

Olkkonen (1993, 64–67) states that it is important to keep the scope of the study narrow enough that one can focus to the relevant issues. As the computerization and advent of more efficient computers has enabled very complex mathematical models to be made (see e.g. Dios Ortúzar, 2001, 213) it is interesting to specialize on that area of transportation studies (transportation research methodology).

As the primary interest is in how the transportation research methodology has developed, the journal chosen for the first part of the study is Transportation Research Part B: Methodological. It is a viable choice since the journal has specialized on all methodological aspects of transportation study as well as on the aspects which require mathematical analysis (ScienceDirect, 2008a)

3.2 Meta-analysis

As the goal of the first part of this thesis is to study how the transportation methodology research has developed over time, the first research method one should look at is meta-analysis. Like this thesis' first part, meta-analysis also studies on how science has developed by the means of an intensive literary review. Meta-analysis is highly quantitative method, which (according to Wolf) B. Green and J. Hall have found to be an efficient way to summarize large literatures. (Wolf, 1986, 10–11, 53–56)

Meta-analysis doesn't prejudge nor exclude studies for being somehow inferior to other studies making meta-analysis a more objective method than traditional literature reviews. Thereby stronger conclusions can be reached by statistical reviews than by reviews based on subjective impressions. (Wolf, 1986, 10–11, 53–56)

However, unlike in this thesis, meta-analysis' primary goal is to construct a theory based on findings from former researches. In other words, it lists several studies which research the same topic and their results are being compared in order to combine the results of all the previous studies to get a more accurate view of the situation. (Hunter – Schmidt, 2004, 3–5) This thesis is only concentrated on finding out what has been the focus of transportation research and how the focus has changed over the past 25 years. Thereby regular meta-analysis can't be completely utilized.

3.3 Statistical methods

Statistical methods play an important part in the first part of this thesis. As mentioned in paragraph 3.2, statistical methods yield strong and objective conclusions when doing extensive literary reviews. (Wolf, 1986, 54–55)

To see where the focus point of transportation methodology research has been, the first step is to calculate the total number of studies in each category for the entire 25 year span of the study. The total amount of articles in each category tells us what has been studied and in which category a summary is most badly needed.

The second point of interest is to see how the focus point of transportation research has shifted over the 25 years. To achieve that, the yearly totals are needed. Because the amount of issues and the total amount of articles varies from year to year, the yearly totals of each category have to be converted into yearly percentages. I.e. how big of a percentage of the year's articles have dealt which category.

From the yearly percentages one can then calculate a regressionline, which tells the trend of how the focus point has evolved. The regressionline is calculated separately for each category using the method of ordinary least-squares estimate (OLS). The result of calculating OLS is a formula like: $\hat{Y}=\alpha+\beta X$. For this study, especially the slope, which is the variable β, is interesting since it tells the trend of where the research focus has been shifting. Once the variable α is also calculated, then in principle one can estimate the amount of studies in the future, with the given formula. (Gujarati, 2003, 15, 58–65). However, in this case the estimate might not be always accurate especially for years far in the future. In this study, Excel's functions were used to calculate the regressionline.[7]

The regressionline in itself isn't enough since it can give erroneous results. It is important to measure how accurate the regressionline is. The correlation coefficient is a good tool for analyzing how much linear regression there is (the strength of linear regression) between the year and the amount of studies conducted. (Gujarati, 2003, 23–24)

Also the coefficient of determination (R^2) was calculated using Excel. It indicates the regressionline's goodness of fit and tells us how much of the fluctuation in the amount of studies performed in each category in each year can be explained by the year. (Gujarati, 2003, 81–87) (Dougherty, 2002, 65–68)

Of course the linear regression only shows the linear relationship between the variables. For other kinds of relationships there are also for example polynomial regression models, which were used whenever deemed necessary. The polynomial

[7] For a detailed guide on how to calculate OLS manually and how it works in principle, see for example Gujarati, 2003, 58–92

regressionlines can also be easily calculated with Excel. (Gujarati, 2003, 226–229)

3.4 Categories

3.4.1 Selecting the categories

The first task in conducting a large literary review is familiarizing oneself to the topic by going through as wide range of related material as possible. (Olkkonen, 1993, 66) While reading the material, I also collected notes on what were the topics of the studies I read. That then resulted in a list of dozens of different categories many of which were very similar in nature. For example several different, but very similar and related route choice problems like Dial-a-ride problem[8] and travelling salesman problem[9] were listed as categories.

However using such an extensive list of variables as the basis of this research would haveve been very inconvenient. A massive list of variables would have also made it very hard to get a good overall picture of what the trends in transportation research are, if several similar studies were all classified in their own categories.

Also since many of the variables on the extensive list were so closely related it could have created problematic situations when classifying the articles. Olkkonen suggests that generally in a research it is good to have a relatively small amount of terms – or in this case categories – and that they are all clearly defined. (Olkkonen, 1993, 76–78)

For the above mentioned reasons the variables were combined into a smaller amount of more clearly defined categories. Since no universal categorizing method specifically made for Transportation research was found, a new categorizing system was created. The category selections were based mainly on clues given by the researchers on what their study topics were close of or in some cases similarities in what kind of use the results were good for. The next paragraph both explains the variables as well as gives more specifics on how the combining of the categories were made.

[8] See for example Healy & Moll (1995, 83–104)
[9] See for example Cordeau & Laporte (2003, 579–594)

3.4.2 Categories explained

First, table 1 summarizes, what the different categories are and what kinds of questions the categories contain. The first column titled "#" refers to the letter which is used of each category in the classification study found in Appendix 1. After the table, there are more detailed explanations and reasons why the categories were formed as they are. Also some category specific criticism is offered.

Table 1: Categories explained

#	Category name	Example problems of the different categories
A	Route choice optimizing	-Shortest path algorithms -Travelling salesman problem -Dial-a-ride problem
B	Other optimizing	-Scheduling -Vehicle usage optimization and optimal seat allocation -Optimal vehicle and batch sizes
C	Traffic flow and traffic equilibrium	-Traffic assignment -Traffic flow models -Car following and queuing models
D	Network planning	-Planning complete and partial transportation networks -Planning where to build new links and where to do maintenance work. -Controlling traffic (e.g. traffic signals and road tolls)
E	Human behavior and future prediction	-Discrete choice models -Origin-Destination matrix calculations and estimations -Socio- and geographical OD matrix estimations
F	Technology	-Positioning- and advanced travel information systems -Computing efficiency -Inter-vehicle communication
G	Other	-Economics -Other issues

3.4.2.1 Route choice optimizing

Route choice optimizing contains route selection algorithms from the point of view of a single company or a traveler. Big portion of the articles deal with the complex Pareto optimal problems such as different iterations of the classic travelling salesman problem and its close relative, dial-a-ride problem. Of course in addition to that there are several other route choice problems for both trucks and other types of vehicles.

Route choice optimization is often very closely related to traffic equilibrium problems as the optimal route may often depend on how the traffic is assigned on different routes e.g. in congestion situations and user optimal traffic equilibrium problems depend on users finding the shortest path (see e.g. Jang, Ran & Choi, 2005, 593–620) Thereby the main difference between the two classes is often the point of view; whether the problem is examined from the system perspective or from the individual perspective. Of course there are also studies that clearly can be classified in both categories.

3.4.2.2 Other optimizing

Other optimizing contains lots of scheduling related studies and also airline seat allocation studies (see e.g. Wang & Wang, 2007, 410–425). There were also a few economic order quantity studies and other logistics related optimization studies.

3.4.2.3 Traffic flow and equilibrium problems

As already mentioned, the traffic equilibrium problems are closely related to route choice problems. Especially user optimal solutions to traffic equilibrium can be classified in either category or often to both categories. In addition to route choice problems, network planning is a very close relative to this class. Many of the network planning methods utilize both traffic flow models and traffic equilibrium models (e.g. Daganzo, 2007, 49–62).

Traffic flow is often an inseparable part of equilibrium models (see e.g. Friesz & Mookherjee, 2006, 207–208) and therefore these two classes were combined. In many cases it would have been very difficult to separate these two classes though they are definitely somewhat different aspects of transportation study. Still, trying to separate the studies might have resulted in some erroneous results, so it was best to keep them together. As already mentioned it is best to keep the different categories and terms as clearly defined as possible. (Olkkonen, 1993, 76–78)

3.4.2.4 Network planning

As mentioned network planning is closely related to traffic flows and equilibrium problems. Very often the equilibrium or traffic flow problems are an inseparable part of network planning. (see e.g. Daganzo, 2007, 49–62).

Network planning category consists of all the planning related articles ranging from planning the whole network and new additions to the network (see e.g. Gao, Wu & Sun, 2005, 479–495) to controlling the traffic e.g. via traffic signals or road tolls (see e.g. Jiang, Li & Shamo, 2006, 543–562). The planning can be for example planning of traffic networks (roads or public transportation) or planning new locations for production plants etc. Naturally for example bus network planning is also closely related to route choice optimizing and studies can again be classified in multiple categories.

3.4.2.5 Human behavior and future prediction

This category contains all studies which deal with human behavior, discrete choice models, social- and spatial interactions as well as Origin-Destination (OD) matrix estimations. In short it consists of studies which have some human element involved.

Perhaps the biggest group of studies in this group is all the different discrete choice models for example for transportation mode choice. The choice models vary from logit and probit models to stated preference queries. Related articles, such as studies of Monte Carlo algorithm which is often used in logit and probit choice studies, are also classified in this category.

Somewhat an equally large group is studies utilizing socio-demographic and spatial data for example for estimating traffic and product flows between different places and estimating OD matrixes. Calculating OD matrixes from hard data, such as traffic amounts on different roads, is of course somewhat different method as many others in this category, but it is still included as it gives similar data as for example the OD estimations from spatial data.

The studies in this category were often utilized with the studies in the "Traffic flow and equilibrium problems" -category and thereby may be classified in two (or more) categories.

3.4.2.6 Technology

The technology category differs a bit from the others. First of all, in 1996 technological innovations got its own Transportation research journal (Part E), which surely may affect the category's score in this study. Also, more often than in other categories, technology related articles were closely related to other categories and thereby classified in multiple categories.

The biggest concern however is that whether an article should be classified as technology related or not is more subjective than the classifications in other categories. The general guideline in this study has been that articles with heavy emphasis on intelligent technologies such as positioning systems, computers and data processing and transmitting were classified in the technology category. However studies utilizing less intelligent technology such as regular traffic lights and traffic cameras or traffic volume calculating machines were not included.

For the abovementioned reasons, the results of the technology category should be taken with some skepticism. However, having the technology category included didn't affect the other categories in any way, because it was allowed to classify articles in multiple categories, so there was no harm in having the category included. Only the category "Other" could have had some more articles, but that category is even less informative than the technology category.

It is important to remember however that computerization and other technological breakthroughs are ongoing revolutions in transportation. (Koskinen, Koskinen, Markkula, Mattson, Ollikainen, Sarjanen & Vinnari, 1997, 440–442) Therefore it is interesting to see does it show clearly in this study's results even though the category has its deficiencies. So one can say that all the strengths and weaknesses considered, having a technology category has the possibility of giving interesting results, especially since it has no negative effect on the results from the other categories.

3.4.2.7 Other

One prominent class of studies in this category, which in retrospect might have been an interesting class of its own, was economical issues. In general however the category "other" consists of all the studies, which didn't fit in the more clearly specified categories. However, in order to keep the classification as consistent as possible, it was possible for an article to be classified in any of the categories alongside the "other" category. E.g. Adler & Smilowitz (2007, 394–409) consists of both highly economical aspects and it also deals with creating airline networks, so it was classified under both “other” and “network planning”.

3.4.3 Classifying the articles

Primarily all the classifications were made based on what the researcher or researchers had stated as their main goal on their study or what they thought their main result was. Especially if neither the goal nor the primary result were stated on the study, then the classification was based on what seemed to be the most intensively discussed topic in the study.

Since the categories are very closely related and some studies overlapped several categories, the studies had to be allowed to be categorized in as many categories as deemed necessary. And it leaves less room for subjective decisions the likes of in which category I find the study to be more fitting, if the researchers have stated that it studies two or more different areas. Thereby allowing the study to be placed in several categories helps to preserve the objectivity of the study, but still it is possible to see the trends. For example when someone creates a traffic equilibrium model and then solves the shortest route problem for it (route optimization & traffic equilibrium) or creates a route selection model for GPS coordinator purposes (technology & route optimization) it is logical to put the studies in several categories.

4 THE DEVELOPMENT OF TRANSPORTATION REASEARCH METHODOLOGY STUDY (1983–2007)

4.1 Totals

Between 1983 and 2007 there were total of 988 articles in the Transportation Research Part: B, Methodological, which were classified. This chapter is dedicated to reviewing the results of the classification process made for this study. The classification itself is located in Appendix 1. All of the numerical results in this chapter are based solely on that classification study.

Before going into detailed information about how the focus between the different categories has evolved, it is good to look at the bigger picture. The category totals, both absolute amounts and percentages, can be seen from table 2.

Table 2: Article amount totals

Category	**Total amount of articles**	**% of all articles**
Route choice optimization	91	9.2 %
Other optimization	126	12.8 %
Traffic equilibrium & traffic flow	394	39.9 %
Network planning	193	19.5 %
Behavior and future prediction	274	27.7 %
Technology	25	2.5 %
Other	96	9.7 %

As can be seen from table 2, the most studied topic was traffic equilibrium and traffic flow problems. It amounted to 394 articles, which is nearly 40% of the total amount of articles. The next most active topics were behavior and future prediction followed by network planning. Technology was left far behind others. That can be partially explained by the fact that there is another Transportation Research magazine dedicated to emerging technologies, but that is discussed in more detail later on.

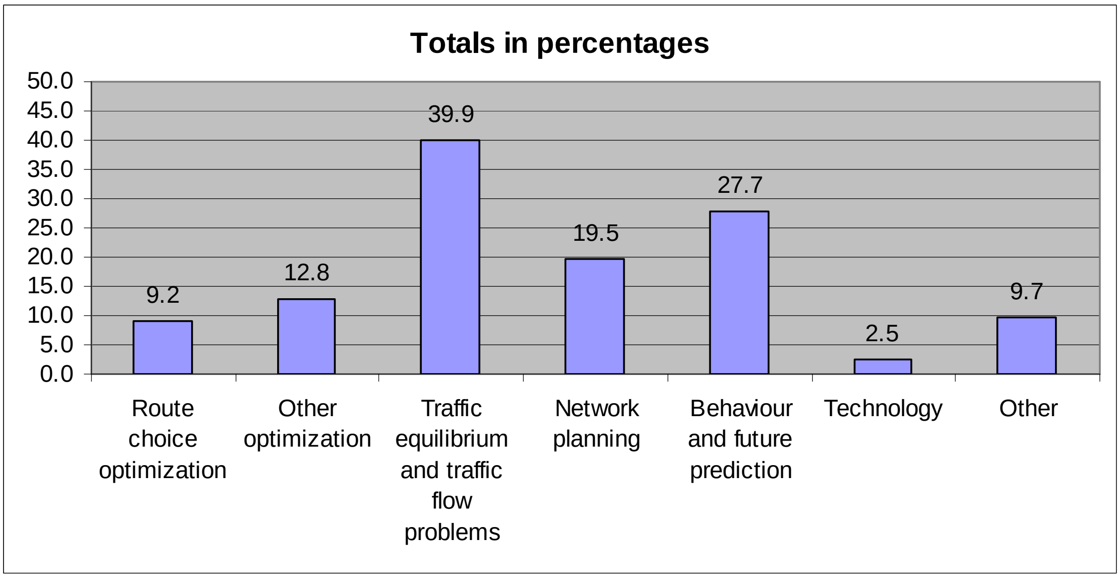

Figure 2: Category-totals in percentages

From the chart it is perhaps even easier to notice how clearly the three top categories have dominated the studies. It can also be seen from figure 2 that traffic equilibrium and traffic flow problems has been quite clearly the most studied topic in Transportation Research Part B, while the technology category is barely even seen.

When looking at either table 1 or figure 2, one should remember that the total percentage is not 100%. As several of the articles were categorized in two or more different categories, the total amount of classifications exceeds the total amount of articles. Still, the maximum for each category is of course 100%.

As the overall view is now known, the next paragraphs are dedicated to the detailed study of how the individual categories have developed over time and thereby, how the study focus has developed during the 25 years, which was this study's timeframe. Also, when applicable, the next paragraphs try to offer some explanations to either the shifts in focus or to the overall situation of the category.

4.2 Route choice optimization

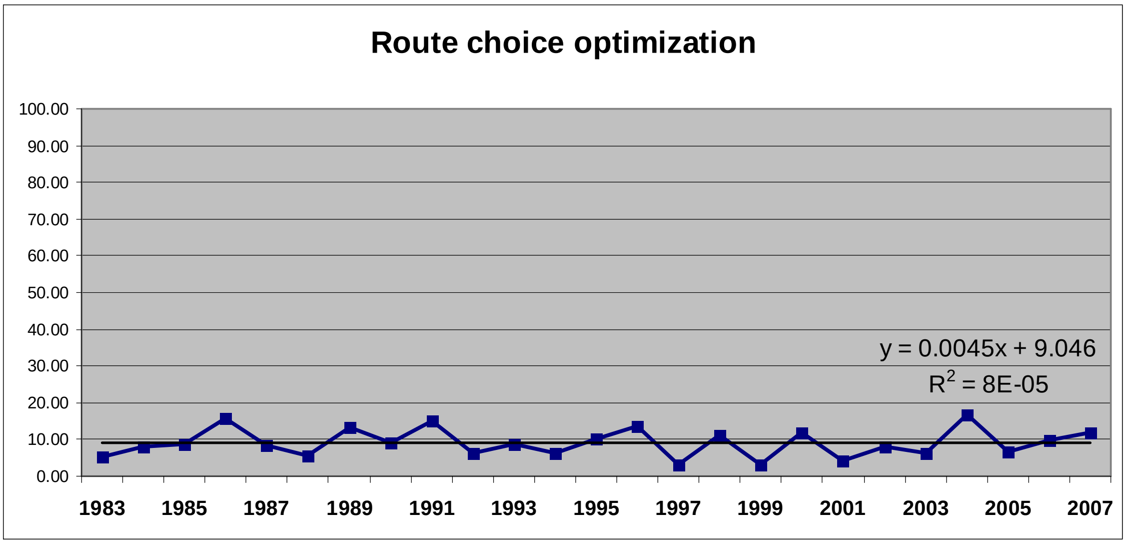

Figure 3: The development of the amount of route choice optimization study

As can be seen from figure 3 the amount of route choice optimization study has been quite stabile between 1983 and 2007. The trendline is almost level as the slope is only 0.0045. It means that, although there is some fluctuation in the study amounts between the years, there is no significant trend towards neither of the directions, up nor down. The amount of route choice optimization has remained constantly around its total average percentage 9.2%.

The correlation coefficient is only 0.01, meaning that there is no statistically meaningful linear correlation between the year and the study amounts. Naturally the regressionline can't be used to predict the future study amounts either as the goodness of fit is considerably less than 1%. In other words, the year explains less than 1% of the fluctuation in the study amounts. However the stability can be clearly seen from the graph.

4.3 Other optimization

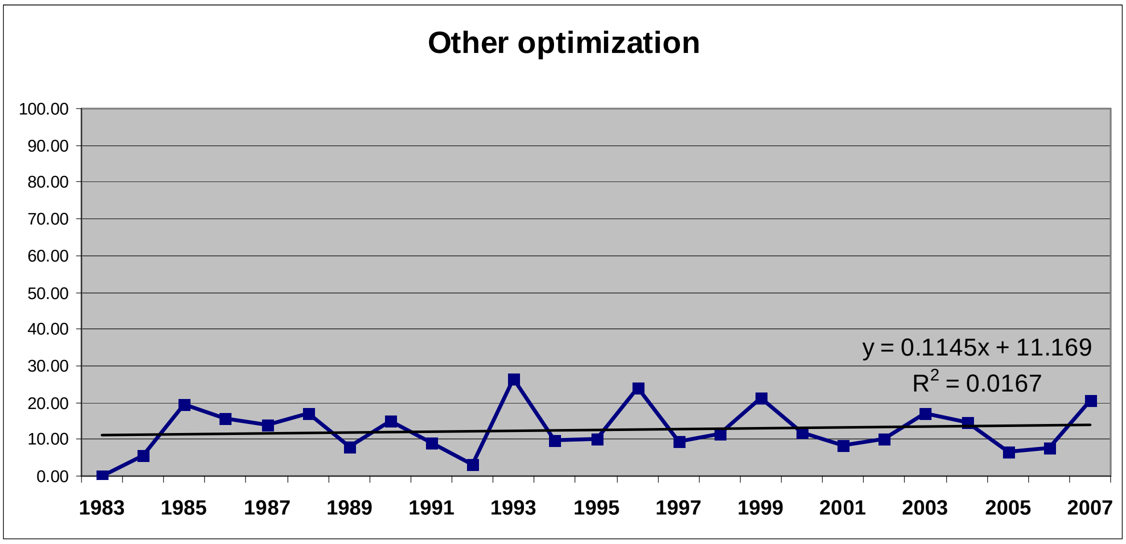

Figure 4: The development of the amount of other optimization study

Also other optimization study has no clearly visible upwards or downwards trend as can be seen in figure 4. The yearly fluctuations are quite heavy. For example the second lowest point (3.2%) was measured in 1992 and the highest point (26.5%) the next year in 1993 after which the amount fell down to 9.7%, which is again lower than the average 12.8%.

The fluctuations may be partially explained by the editors' choices to put similar articles close to each other. However the statistically insignificant correlation (0.13) and goodness of fit (0.017) indicate that the year itself has not much significance when estimating how much studies will be conducted each year.

4.4 Traffic equilibrium and traffic flow problems

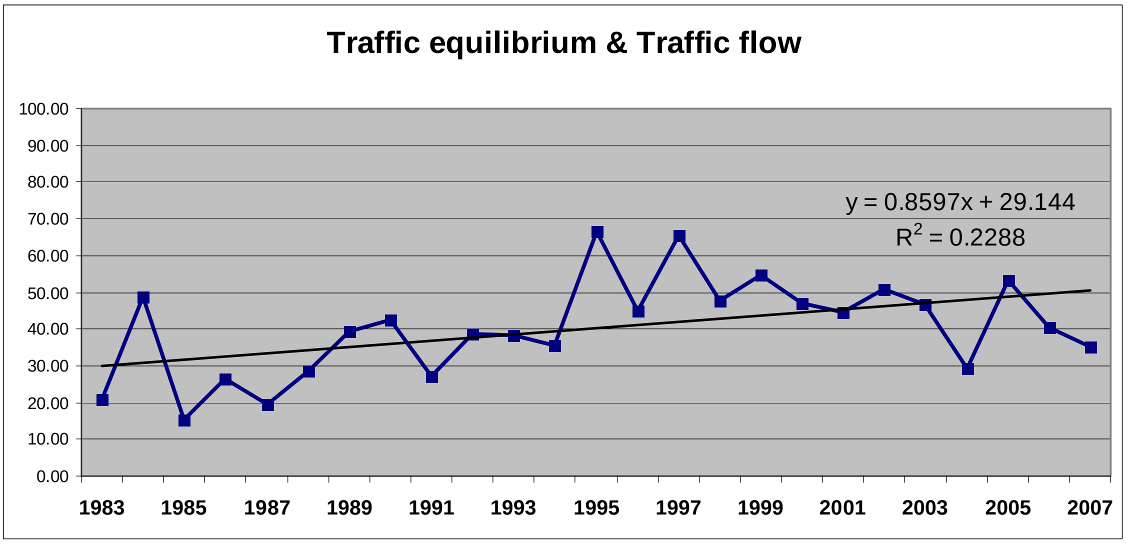

Figure 5: The development of the amount of traffic equilibrium and traffic flow study

The traffic equilibrium and traffic flow study has a clearer upwards trend than the other categories, the correlation is at 0.48, meaning that some linear correlation can be measured, but again the yearly fluctuations are quite high. From figure 5, it can be seen that the peak years were in the 90's and the last few years were again slightly less active. Thereby a polynomial trendline may be more appropriate measure of the overall trend and development of the focus point as seen in figure 6.

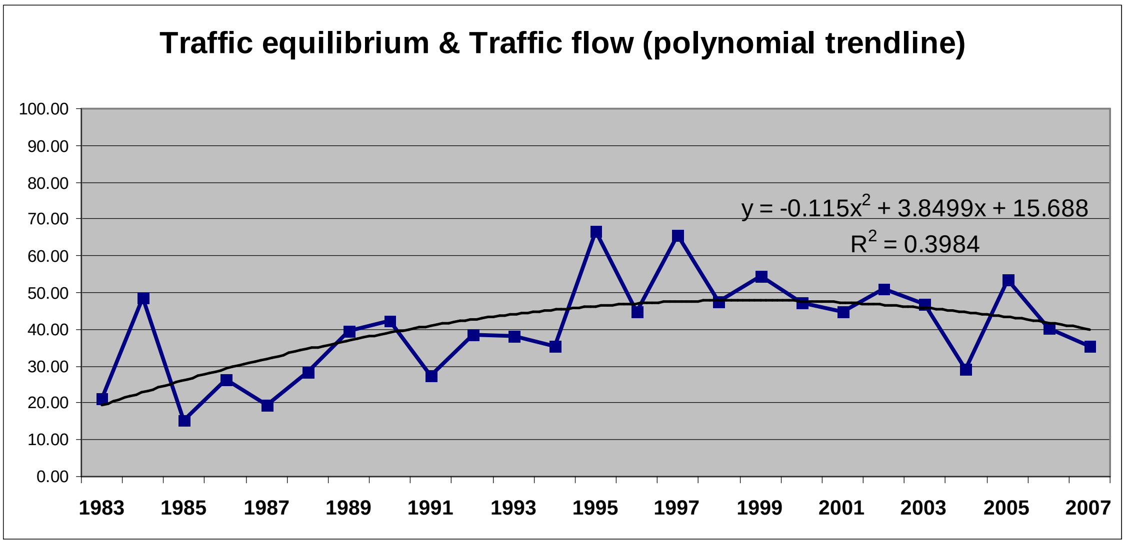

Figure 6: The development of the amount of traffic equilibrium and traffic flow study with polynomial trendline

The goodness of fit almost doubles from 23% to 40% when the polynomial trendline is taken into use compared to the linear trendline. It can also be clearly seen that the polynomial trendline fits the graph better than the linear trendline. It means that rather than the study amounts having constantly risen, the study amounts rose for some extent from the beginning, but peaked at the late 90's and has since been in a slight decline.

This behavior can be also supported by the results of the Delphi study conducted by The Institute of Transport Studies at Sydney University in 1995, where they identified key themes and asked participants to evaluate the most important issues over the next 10 years. In that study activity modeling was seen as the most important overall and equilibrium procedures were left at 10th place. (Referenced by Hensher & Button, 2000, 5–7).

4.5 Network planning

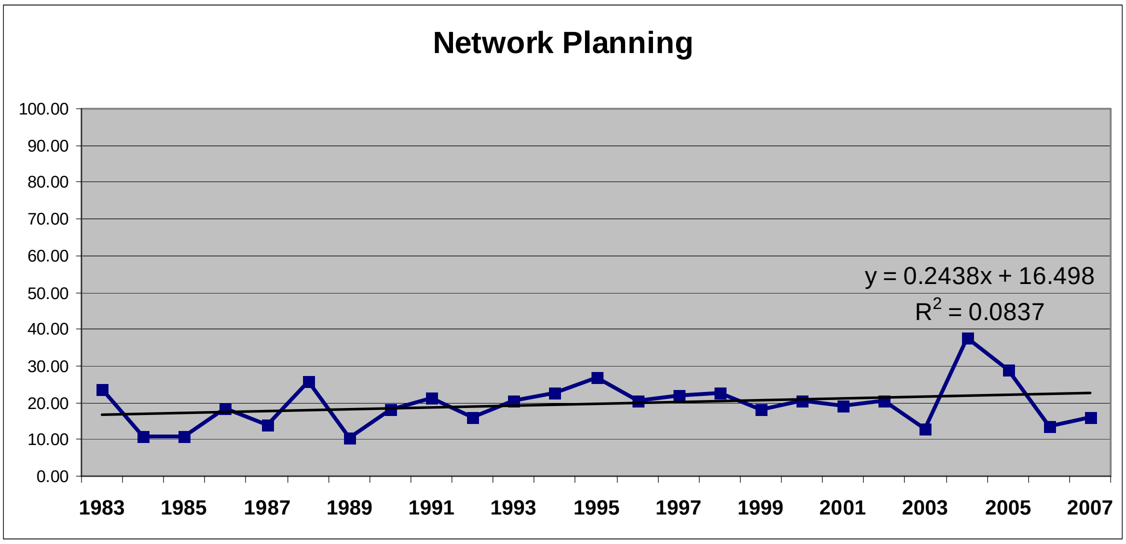

Figure 7: The development of the amount of network planning study

Network planning has also fluctuated quite steadily at around its average value of 19.5%. There is a slight upwards trend as the trendline slope is 0.24, but partially that is just a result of a very high peak in 2004 and 2005, after which the situation leveled. The peak during 2004 and 2005 is spread across several issues so there is no simple reason explaining the behavior (such as having a theme issue could be).

The correlation is statistically insignificant at only 0.29. Also the goodness of fit of the linear trendline is low, just about 8%, so again in this case the general yearly fluctuations can't be well estimated with the regression equation. With the exception of having the peak in 2004/5, the study amounts have been quite stabile around its 19.5% average.

4.6 Behavior and future prediction

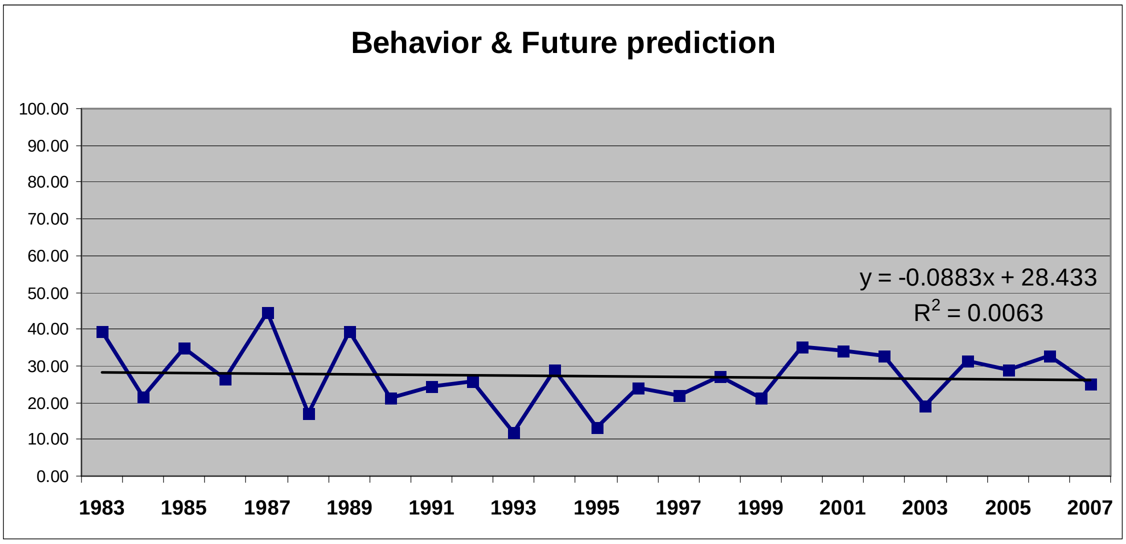

Figure 8: The development of the amount of behavior and future prediction study

Also the category "behavior and future prediction" has stayed quite steadily around its average, 27.7%. The trendline is actually slightly negative, which is kind of surprising if compared to the Delphi researcher's results where activity modeling and topped the importance list followed by stated preference/choice and location based choice models (Referenced by Hensher & Button, 2000, 5–7).

However, as mentioned, the trendline's slope is only slightly negative, its correlation is statistically insignificant (-0.08) and its goodness of fit is also statistically insignificant 0.6%. Therefore the reasonable conclusion would be that, again, the year when studies were conducted plays a very insignificant role in determining how much studies were made and it can be seen that apart from year-by-year variation, the overall percentage of behavior and future prediction studies has remained quite stable. In figure 9, the situation is looked through a polynomial trendline.

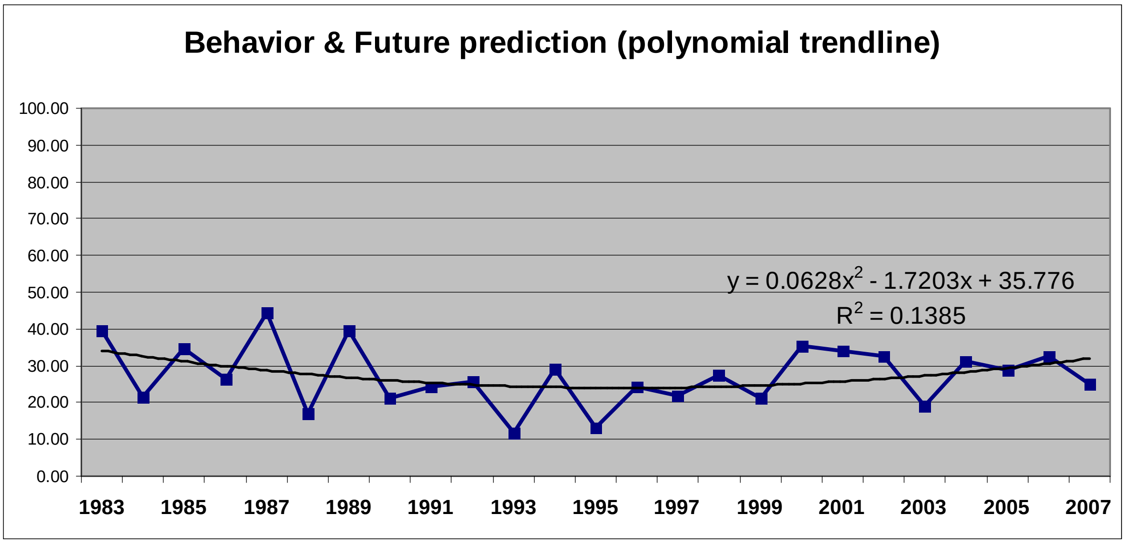

Figure 9: The development of the amount of behavior and future prediction study with polynomial trendline

Although from figure 9 one can see that the polynomial trendline seems to fit the Behavior & Future prediction graph better than the linear trendline, the goodness of fit is still just at 13.9%. So the trendline is not much use in predicting the future development of this class, however the 13.9% is significantly better than the 0.6% received from the linear trendline. Also one could note that the polynomial trendline indicates that the amount of studies might be on the rise unlike the lesser fit linear trendline. However, even 13.9% goodness of fit doesn't hold much significance statistically.

4.7 Technology

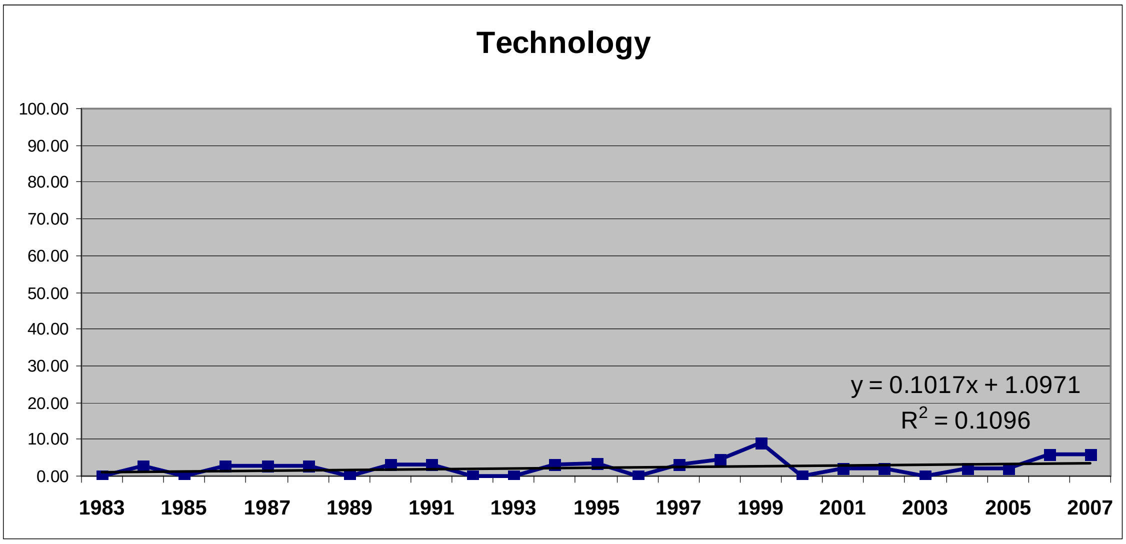

Figure 10: The development of the amount of technology study

Also in technology, the main conclusion is that the study amounts have been quite stable. There is a slight upwards trend (slope 0.1), but even though the correlation (0.33) and the goodness of fit, 11%, are better than in most categories they are still statistically quite insignificant. It can be noted though, that the last two years, 2006 and 2007, scored over 5% and were the highest values after 1999's peak at 9%. And even though the 1999's peak clearly stands out from the other years, it has to be noted that when the study amounts are so low as they are in technology's case, it doesn't take much to have a peak. In 1999 there were still only 3 studies (out of 34) which were about technology. In addition to that, they were all also classified in at least one other category as can be seen from appendix 1.

But as mentioned in the methodology chapter, especially this category has to be reviewed somewhat critically as it is so often closely related to other studies, such as route choice optimization with GPS, so the line between classifying and not classifying some study into technology is very thin. However it can be noted that there was no specific upwards trend visible as one might have subjectively assumed for example because of the it-boom beginning in the late 90's. An important notice is though that after 1996 there has also been a Transportation Research journal Part C dedicated to Emerging technologies. (ScienceDirect, 2008b)

4.8 Other

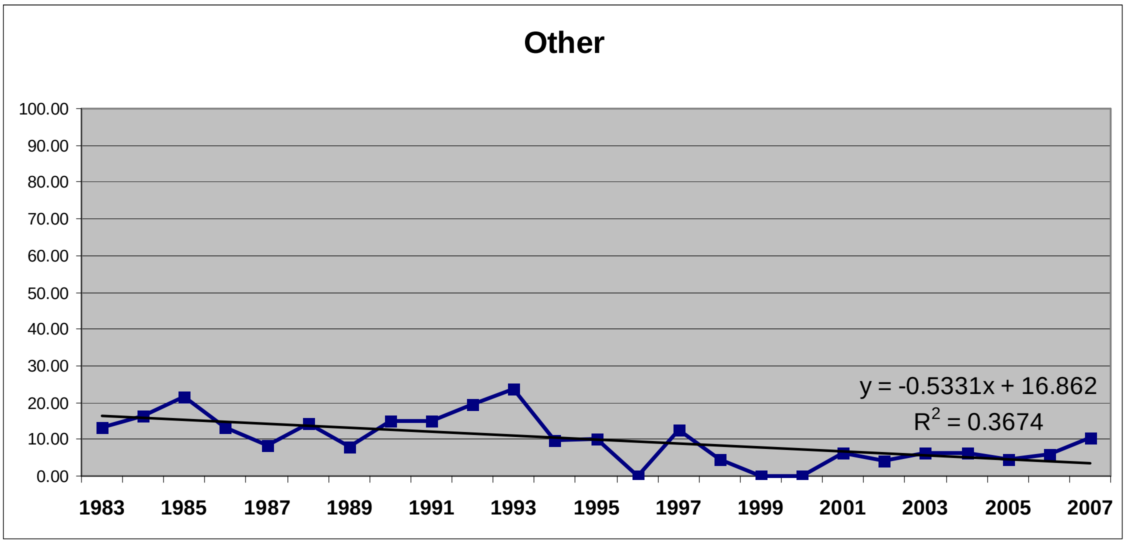

Figure 11: The development of the amount of other study

In the other category, there is a quite clear decline as the slope is -0.5 and the correlation is at a statistically meaningful level (-0.61). The goodness of fit is not that high, but better than in most of the other cases (37%). The overall average is 9.7% and one can see that in the latter part of the study, the amount of other studies has constantly been either under the average or only very slightly above it.

One plausible explanation for that could be the fact that at the beginning of the study period (in 1983) there was only two different Transportation Research journals, parts A (Policy and Practice) and B (Methodological). In 1993 Part C (Emerging Technologies) was introduced, Part D (Transport and Environment) was introduced in 1996 and after that also parts E and F have become in operation. (ScienceDirect, 2008b). That may have enabled part B (Methodological) to be more dedicated to its area of specialization.

4.9 Overall conclusions

Overall no significant trends towards any direction were observed. In almost all of the categories the yearly research amounts fluctuated fairly much from year to year. One plausible cause for that may be that quite often in one journal there were several related studies, which of course can have some impact on the yearly values. There were also some theme issues dedicated to certain kind of study. Although there weren't many of those, in some cases they may have also had an impact on one specific year's scores.

However as the total amount of articles was as high as 988, single theme issues haven't made much of an impact in the total scores.

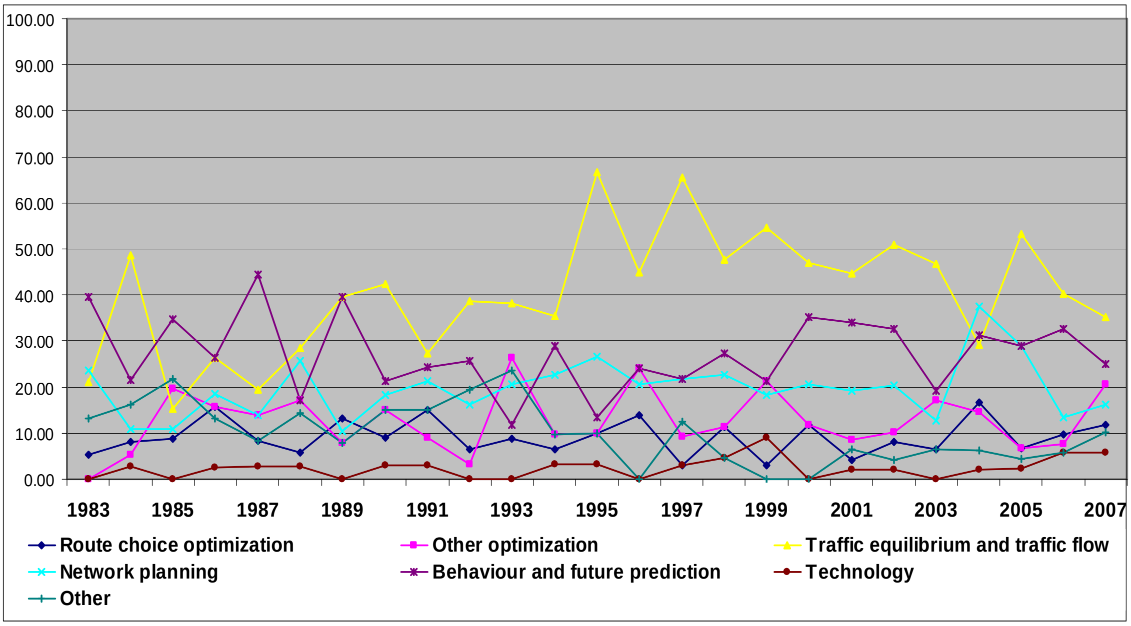

Figure 12: Year-by-year comparison of the study focus points

From figure 12 one can also quite easily see that there have been no significant changes between the different classes in the long run. Yearly variations are quite high in most of the classes, so on given years the order between the categories is different, but the situation has then normalized. The only longer lasting and clear difference are the traffic equilibrium and traffic flow studies' peaks in the latter part of the 1990's.

As stated in chapter 1, one purpose of this part was to show, which category is in the most need for a summary of which kind of methods are available, what are they good for and what criticism is there of the different methods. The quite clearly most studied topic in Transportation Research Part B: Methodological was traffic equilibrium and traffic flow problems, so that is the obvious choice for the overview, which will be covered in the next chapter.

5 TRAFFIC EQUILIBRIUM AND TRAFFIC FLOW PROBLEMS

5.1 Traffic flow

5.1.1 General

Traffic flow theories try to mathematically describe the interactions between vehicles, drivers and infrastructures. Since the traffic flow as a topic of study became active already in mid- 20th century and it has been researched by various kinds of scientists, the traffic flow problem has gathered a notable amount of different types of models, with their own strengths and weaknesses. As the traffic flow problem is so complex, there is no ultimate best solution available. (Leclercq & Moutari, 2007, 918–919) (Gazis, 2002, 69)

5.1.2 Microscopic, Macroscopic or Hybrid

Traffic flow models can be divided between macroscopic models and microscopic models depending on how detailed their point of view is. Microscopic models see the vehicles at an individual level, how the individual vehicles interact with each other and with the environment. The macroscopic view however doesn’t pay such attention to individual vehicles, but rather examines the overall traffic stream, its speed, concentration and so on. The traffic is seen as a fluid-like entity in the macroscopic view. (Leclercq et al., 2007, 918–919)

Because the microscopic models examine the traffic in such detail, they are inefficient in modeling very large networks. The more cars there are on the network, the slower it is to compute it with a microscopic model. Since macroscopic modeling looks at vehicles collectively (their collective speed, density etc.) the amount of cars in the network doesn’t affect the macro-models’ computation time. Thereby for example computing traveling wave solutions on a straight road might take the microscopic model 4 hours to calculate where as the macroscopic model might be ready in just a matter of seconds. Thereby macroscopic models can be said to be more suitable for real-time traffic simulations than microscopic models. (Leclercq et al. 2007, 918–919) (Jiang & Wu, 2003, 85–87)

However, the computational efficiency of the macroscopic models comes with a price. Since it is broader in its view, the macroscopic model can’t describe an individual vehicle’s behavior or pinpoint its position or trajectory. It can’t give the details as well as the microscopic model can. (Leclercq et al. 2007, 918–919)

In addition to purely microscopic or macroscopic models, nowadays there are also different kinds of hybrid models available or in the works. The hybrid models try to benefit from the good traits of both microscopic and macroscopic models and one can either simulate the model more coarsely or in more detail, whichever is needed more. (Leclercq et al. 2007, 919)

One way of creating a hybrid model is to just simulate traffic according to a macroscopic model where only global variables are needed and simulate microscopically the parts where a more detailed simulation is needed. For example simulate all the junctions microscopically and at the same time simulate the network macroscopically and thus providing a hybrid model. (see e.g. Tolba, Lefebvre, Thomas & El Moudni, 2005, 407–436)

Another hybrid approach is called the mesoscopic model. In mesoscopic models, vehicles are combined into bigger entities such as clusters or platoons and thereby there are some precision and behavior aspects included in the models or individual cars are examined in a macroscopic environment. Still, the amount of vehicles isn’t as big as it would be if all vehicles were modeled independently nor is the precision of modeling as good as in microscopic models. For example gas-kinetic models and cluster models among others are called mesoscopic models. (Hoogendoorn & Bovy, 2001, 317–336) (Leclerq et al., 2007, 919–922) (Woensel & Vandaele, 2007, 438–439)

However, mesoscopic models are also more complex and heavier to calculate than macroscopic models. Thereby both microscopic and mesoscopic are better in modeling and simulating sections of roads and not complete networks. (Woensel et al., 2007, 438–439)

5.1.3 Car following models

As mentioned in chapter 2, car following models were among the first solutions for traffic flow modeling in the early 1950's. Traditionally car following models try to describe individual drivers in an interacting traffic flow without changing lanes. The movement of each individual car is normally calculated by its speed and the distance to the next vehicle. (Gong, Liu & Wang, 2008, 2597–2598) (Holland, 1998, 141)

Though the earliest models are from the 1950's, there is still interest in car following models. Since some of them can efficiently model traffic jam creation, they are very useful for example in traffic control in the battle against congestion and in intelligent transport systems as well as in search for traffic safety improvements. (Yu & Shi, 2008, 550–553) (Zhao & Gao, 2006, 513–520)

One example of a recent car-following model which has already had many extensions and modifications since its release in 1995 is the optimal velocity (OV) model. The original model describes the traffic jam formation and reveals a simple linear mechanism behind the transition from freely flowing traffic to congested traffic. (Yu et al., 2008, 550–553) For a more comprehensive list of different car following models, see e.g. Brackstone & McDonald (1999, 181–196).

There are of course shortfalls in conventional car following models. One is for example that the models assume that the vehicles travel in the middle of the lane and there is no overtaking. However in real life traffic situations cars usually are not located in the center of their lane and the behavior of the cars on the other lanes affect the drivers as well. That problem has also been incorporated in some models. (Gunay, 2007, 722–735)

Also since lane changes are prohibited in the regular car following models, there are of course also lane changing models made for car following models. (see e.g. Laval & Leclercq, 2008, 511–522)

5.1.4 Cellular Automata

Cellular automata (CA) traffic flow model is a rather recent addition to the microscopic simulating of traffic flows as it was introduced for this use in 1992 by Nagel and Schreckenberg. Since 1992 there have been significant advances and additions to the CA model, one example being a recent CELLSIM-simulation model based on CA and car-following principles. (Lárraga, Río & Alvarez-lcaza, 2005, 63–74) (Spyropoulou, 2007, 175–190)

Cellular Automata model originates from physics and the research of particle behavior. In CA the network is represented as a string of cells, which are either empty or have one vehicle in them and vehicles are represented as particles which go (or hop) from one cell to another, creating the traffic flow. As all the vehicles are individual particles, the CA model is a microscopic one. However the particle hopping model used in cellular automata is rather efficient in computational time, so it can model even rather complex traffic networks and new research often aims for adding the complexity or accuracy of the model without compromising the computational efficiency. (Lárraga et al., 2005, 63–74) (Spyropoulou, 2007, 175–190)

The Cellular automata model is usually used to model complex urban traffic networks and is used in traffic simulations. It can simulate different types of vehicles or even pedestrians and railways as well as traffic where different types of vehicles (e-g-motorcycles and cars) are using the same network in different ways as the motorcycles can fit to spaces where regular cars can't. In addition to that, CA can be used to simulate also lane changes and be used as a tool in traffic signal optimization, though that hasn't been thoroughly studied yet. (Spyropoulou, 2007, 175–178)

However further studies are needed to make the CA models more accurate, realistic and to verify results. Especially traffic signals on CA models could use some more research. (Spyropoulou, 2007, 175–190)

5.1.5 Fluid dynamic traffic flow model

Fluid dynamic models are macroscopic traffic flow models. They describe traffic flows like the traffic was something similar to fluids. The most prominent fluid dynamic model is the "‘Lighthill–Whitham–Richards" (LWR) model, which is the starting point of fluid-dynamic modeling. Even the early fluid dynamic models grasped well many of the basic phenomena of traffic, such as traffic's waves and their propagation, but of course the original LWR-model has seen improvements and has also spawned studies, which are, for example, dedicated to studying traffic waves (see e.g. Zhang, 2000, 583–603). (Gazis, 2002, 69–70)

The fluid dynamic models are concerned with the overall picture of the traffic flow. They describe the flows' movements, speeds and concentration (traffic density), but they can't be used to model vehicles on individual levels. Therefore the macroscopic models are computationally very efficient and can be used to describe the traffic flows even in big networks and one can run very large simulations with fluid dynamic models because of their efficiency. However, traffic flow phenomena are very complex and even if efficient, the fluid dynamic models may not be able to grasp all the complex traffic phenomena. (Leclercq et al., 2007, 918–919) (Cho & Lo, 2002, 342–345)

Currently some see that combining microscopic models with macroscopic fluid dynamic models (hybrid models), is one of the most promising ways to model traffic flows. Also second order traffic flow models, which combine two different equations, are based on fluid dynamics. (Leclercq et al., 2007, 918–919)

5.1.6 Second order traffic flow models

Second order traffic flow models were originally introduced in 1971 by Payne. The second (or higher order) traffic flow models were designed to complement the fluid-dynamic traffic flow models and be able to address such issues as stop–start waves in long queues, which can't be described by regular fluid dynamic models and higher order models also enable modeling of multi-class traffic. Initially the models had such problems as negative speed cars and information travelling faster than any cars and the models were therefore harshly criticized. (Goatin, 2006, 287–290) (Logghe & Immers, 2008, 523–524)

In 2000 Aw and Rascle (2000, 916–938) literally claim to have resurrected the second order traffic flow models by tackling the problem of negative speeds and several other issues related to former second order models. Though it was an important step forward, it still had its problems, especially in situations when traffic density is near zero. Also the maximum speed on empty roads depended on initial data, which is wrong. (Goatin, 2006, 287–290)

Second order traffic models are comprised of two different equations. The first one is dedicated on the conservation of mass and the second one describes the (macroscopic) traffic flow by modeling the drivers' reaction to the traffic densities ahead creating the traffic flow phenomena such as traffic waves. The second order models are often more influenced by fluid dynamics (hydrodynamic second order models) and less by gas-kinetics. However higher-order models based on gas-kinetics do also exist (see e.g. Schiavo, 2002, 607–622). (Rascle, 2002, 581–582) (Lebacque, Mammar & Haj-Salem, 2007, 710–712) (Aw & Rascle, 2000, 916–922)

The second order models aim to describe the non-equilibrium features of traffic flow better than the single-order ones (like gas-kinetic flow models). They can also be better than single order models in describing congested flows than single-order models are. However in low-traffic, free-flow situations the single-order models (like LWR) create better results. The second order models also still need further research to for example serve better the interests of traffic management problems. (Lebacque et al. 2007, 710–711) (Goatin, 2006, 288–289, 301)

5.1.7 Gas-kinetic traffic flow model

Gas-kinetic models have also evolved from the fluid dynamic models to their own group of models called mesoscopic models. The gas-kinetic models utilize the boltzmann equation, which is used to describes fluids' properties in the large domain by examining the statistics of motion of a single particle in the fluid and is applied e.g. in study of gas dynamics. In traffic flow modeling, gas-kinetic models usually describe individual particles' (vehicles') behavior at low detail level and are interested in the dynamics of speed distributions. I.e. Cars travel in their desired speed until a slower car comes in their way and then the faster car tries to overtake it when given the chance. (Cho et al. 2002, 345–350) (Hoogendoorn & Bovy, 2001, 318–321) (Gazis, 2002, 73)

In addition to just describing individual cars, gas-dynamic models have been developed to also be able to handle the vehicles as platoons. Actually the first models were criticized for having all cars behaving individually, because it is a chaotic situation. In reality not all driver behaviors are individual; they are somewhat dependent on the traffic situation and other vehicles' behavior. Also if there is a bigger group (platoon) of slower vehicles, then given the chance a faster vehicle would rather pass the whole platoon at once and not pass every vehicle individually like the initial models assumed. (Hoogendoorn et al., 2001, 318–321) The gas-dynamic traffic flow model is in other ways versatile as well. It enables scientists to model e.g. multiple driver classes, lane changing and light traffic situations, which are hard to impossible to model with e.g. regular fluid dynamic models. (Gazis, 2002, 73)

Also depending on the model and its complexity, the gas-kinetic models can be made more realistic by adding variables for the individual behavior. Different environments and different countries have their own distinctions, which can be modeled into the gas-kinetic models as it allows different kinds of driver and vehicle classes. Of course such additions make the models more complex and thereby slower to compute, which is one of the down-sides compared to simpler macroscopic models. Especially when modeling larger networks, mesoscopic models are often too inefficient to compute. (Schiavo, 2002, 607–614, 622) (Woensel et al., 2007, 438–439)

5.1.8 Other

Other methods to simulate traffic flows include e.g. the 3-phase theory mainly studied by Boris Kerner. The main idea behind the three-phase traffic theory is that, unlike some other models suggest, there are actually three phases in traffic flow. Instead of just congestion and free-flow, Kerner suggests the traffic to be divided into free flow, synchronized flow and wide moving jam. (see e.g. Kerner, 2004, 379–440)

Pedestrian flows are also a viable topic of study. Good model for pedestrian flows would be useful in, for example, urban planning and land use. However modeling pedestrians is very hard, even collecting all kinds of data about pedestrian behavior is problematic. One way of collecting data is for example examining video recordings of pedestrians. But even with some knowledge of pedestrian behavior, creating a good mathematical model is very hard. (see e.g. Antonini, Bierlaire & Weber, 2006, 667–687)

Also there are various sub-problems in traffic flow modeling which can be studied. For example creating efficient lane changing models (see e.g. Sheu & Richie, 2001, 695–716) is a viable study. And many flow models also need good passenger-car equivalents, meaning how to convert larger trucks, motorcycles and other special vehicles into passenger cars to be used in traffic flow studies (see e.g. Al-Kaisy, Hall & Resiman 2002, 725–742).

5.2 Traffic equilibrium

5.2.1 General

Traffic assignment problem assigns origin-destination traffic flows to a traffic network and it consists basically of three parts, conservation of flow, route choice criteria and flow behavior model. (Jin, 2007, 32–33) (Carey & Subrahmanian, 2000, 157) Equilibrium models can be used to e.g. plan traffic control measures such as road tolls or optimize traffic signals (see e.g. Yang & Huang, 2004, 1–15 or Cipriani & Fusco, 2004, 569–583)

As mentioned in chapter 2.4, Wardrop published a paper in 1952 where he proposed two principles for traffic equilibrium problems. Either the routes are assigned so that the travelers minimize their travel time or the routes are assigned so that the total travel time for all travelers in the network is minimized. Nowadays the first principle is called user optimal assignment and the second one system optimal. The Wardrop principles can be said to be the starting point of development of modern traffic assignment theories. (Gazis, 2002, 74) (Boyce et al., 2005, 89)

Though the Wardrop's principles have been the corner-stones of traffic equilibrium studies and many studies can be categorized as either user optimal or system optimal, there are those that are just something in between the two classes. For example not all drivers always know which is the shortest or the least costing route for them or for the system, so they choose a route, which may not be optimal. And even if the drivers chose the optimal route, their preferences of what is optimal may also differ (see e.g. Huang et al., 2007, 1464–1477). Also sometimes there is some user optimal behavior and some system optimal behavior among the drivers, which create a mixed equilibrium. (see e.g. Yang, Zhang & Meng, 2007, 841–861)

One can also divide the traffic equilibrium models between discrete models and continuum models. The discrete modeling is usually used for detailed planning and analysis of transportation systems where as the continuum modeling is often used in when there is insufficient amount data available for a more accurate discrete model. Thereby continuum models are used more in the initial phase of planning and modeling and discrete models, when more accurate and detailed models are needed. (Ho, Wong & Loo, 2006, 651–653

Another way to divide equilibrium models has also been the division between static and dynamic traffic equilibrium models, but it has been said that the static case is already quite solved. The most commonly used method to solve equilibriums with fixed demand is the Frank-Wolfe algorithm[10], which can also be extended to other kinds of equilibriums. However, though there is no significant interest in the static equilibrium, there is still much work in extending the equilibrium models into dynamic environment, without forgetting the stochastic (and dynamic) models. (Hamdouch, Marcotte & Nguyen, 2004, 291) (Hensher et al., 2000, 177–178)

5.2.2 Dynamic & stochastic traffic assignment

Dynamic traffic assignment models time varying traffic flows on networks. In reality the demands on different routes vary depending on what time it is. For example in the morning there is rush hour traffic as people are travelling to work, but then at night the travel demand is much lighter. The static traffic assignment models can't be used to describe such problems, so dynamic models have to be taken into use albeit they are much more complex. (Friesz et al. 2006, 207–208) (Bellei, Gentile, Meschini & Papola, 2006, 1557–1558)

Since in the dynamic traffic assignment models the travel demands change depending on the time, the models thereby need some way to know peoples' departure choices. For that purpose, the dynamic traffic assignment models may use some sort of discrete choice model such as some variation of logit or probit choice models. Another way is to simply assign static demands for the different routes, for different times of day, but that solution can hardly be used in complex congested urban networks. (Bellei et al. 1557–1558)

The dynamic traffic assignment problem is a very complex one and there have been numerous papers written about it in the last few decades. For a very extensive list of dynamic traffic assignment related papers (hundreds of studies between 1973–2003), see e.g. Carey and Ge, 2003. But even though the research has been very active in the past, the problem is so complex that there is still work to be done in order to make more

[10] For information as to how the Frank-Wolfe algoithm works, see e.g. Hensher et al., 2000, 177–178

accurate models as no ideal model have so far surfaced. (Hamdouch et al. 2004, 291)

In regular dynamic models, it is assumed that the information of travel times is known. However in reality the travel times vary because of several reasons like incidents or luck with traffic lights. Because the travel times are partially unknown, it is reasonable to also measure the travel time reliability. (Shao, Lam & Tam, 2006, 173–174)

In reality travel time reliability is an important factor in peoples' travel behavior. In order to get improve reliability travelers may take different routes, which are thought to be 'safer' or they may choose to depart earlier, which then would affect the dynamic part of the model as in when the peak traffic is. Also different users take different sized risks as in will they get to their destination on time, making the behavioral aspects of the model more complicated when the route travel times are uncertain. (Shao et al., 2006, 173–176)

Also from a network planner's point of view (system optimal), it is good to take into consideration the behavioral aspects behind uncertain travel times and how people react to congested networks. For the planners there's another interesting uncertainty as well, which can be incorporated in a stochastic traffic assignment model, the uncertainty of traffic demand. Traffic demand is rarely perfectly known in advance and future demands can only be probabilistically estimated. If the network design is based on an estimation that is far off, then there might be a bad congestion spot or gridlock on some point of the network. (Waller & Ziliaskopoulos, 2006, 418–419) (Shao et al., 2006, 174)

As the causes of bad network design may be disastrous, it is good to be able to take into account the uncertainties in traffic demand and try to design networks, which aren't only efficient with the current traffic predictions, but also minimizes the risk uncertainties in demand. Thereby stochastic models are essential also in system optimal traffic assignment studies. (Waller et al., 2006, 418–419)

5.2.3 Multi-class, multi-criteria traffic assignment

In multi-criteria traffic assignment problems, the travel time is no longer the only criteria how travelers optimize their routes. The routes also have other costs or road tolls and travelers optimize their route choice in a traffic network by selecting the optimal combination of travel time and travel cost. If also multiple user classes are introduced into the traffic equilibrium problem, then all user classes have different preferences over how much they value the shortness of their travel time vs. how much they are willing to pay. (Yang et al., 2004, 1–6)

The multicriteria models can be used to for example determine optimal road pricing strategies. By optimally assigning the road tolls, the traffic flows become system optimal even though the road users choose their routes user optimally as the traffic flows can be controlled with increasing the road tolls on roads which otherwise would become congested. Therefore the multi-criteria models are useful in planning congestion pricing for a network. If the model is also a multi-class model, then in addition to being able to have different preferences as of how much their time is worth, to different classes (e.g. different kinds of vehicles) can be given different road toll prices when deemed necessary. (Zhang, Yang & Huang, 2008, 146–148) (Yang et al., 2004, 1–5)

It is also often of course impractical to collect road tolls on every road and therefore the otherwise optimal solution may be impractical to implement. In that case one can also use the multi-criteria models to find second best pricing solutions to the network at hand, by placing constraints such as where the tolls can be collected. (Han & Yang, 2008, 753–754)

Other criteria besides time and cost can be also set. For example in an urban setting the reliability of transportation time may be an issue. And accordingly, if there are multiple classes involved, then some appreciate the reliability more and some have higher tolerance for variations of time. And of course the reliability of travel time and differentiated user-classes between how tight their schedules are, affects the stochastic and dynamic traffic assignment problems as in when the travelers choose to depart and thereby also affecting the peak traffic hours. (Shao et al., 2006, 173–198)

5.2.4 Game theory

Traffic equilibrium principles and game theory have much in common, and traffic equilibrium problems can also be tackled as a game. The Nash equilibrium, where the equilibrium is formed as each 'player' (traveler) chooses their best route according to the choices of other players. It creates a user optimal equilibrium where all players are fully competitive. System optimal equilibrium is harder to accomplish using Nash equilibrium, but not impossible, then there is only one player who is in charge of all the route choices and all travelers are co-operative. (Yang et al. 2007, 841–844) (Correa, Schulz & Stier-Moses, 2004, 974)

In reality, both types of behavior exist. There is some co-operation between network users and some competition. That situation can also be modeled with a game theoretic approach. The there are several independent players who try to minimize their travelling time (or cost) and then there is one player who controls several users who in co-operation try to minimize the system travel costs. That way also a mixed equilibrium can be created. There can also be a third player (system optimal), who leads the game by first setting travel costs in a way that it tries to drive all the players into using system optimum paths. Then other players react to the system optimal player's given limitations and try to find their lowest cost routes. After that the system optimal player can again react to the choices the other players have made etc. (Yang et al., 2007, 841–852)

5.2.5 ATIS assignment

The growing amount of advanced travel information systems brings new problems to traffic assignment studies. First of all, efficient ATIS' have to be designed by creating mathematical models to simulate peoples' route choice behavior under different amounts of traffic information. Then that has to be incorporated into traffic assignment problems. (Henn & Ottomanelli, 2006, 1526–1528)

The fact that some people have information systems, such as GPSs, available creates another problem in traffic assignment as it divides the travelers into two new different user-classes. Others who have better knowledge of the traffic conditions, travel times as well as routes and those who have less knowledge. Thereby their route choices may differ at times, when the ones who have information systems available can avoid spots where there is congestion while the ones with less information might not able to avoid the congested parts of the network. Thereby the route choices of the group equipped with ATIS have to be modeled differently that group's choices which doesn't have ATIS equipped. (Huang et al., 2007, 1464–1466)

5.2.6 Other

Traffic assignment models aren't only good for modeling vehicular traffic; they can also be modified to be used for transit assignment modeling. Transit assignment aims to simulate how passengers are assigned to different public transportation routes. The problem is even more complicated than the regular traffic assignment problem is as in addition to having to deal with regular traffic network variables, transportation networks have to take into consideration e.g. transfers from one line to another and bus-stops and terminals etc. (see e.g. Nielsen, 2000, 377–402)

One method still worth mentioning is the use of neural network study (inspired from human neurons) in traffic assignment. Qiao, Yang and Lam (2001, 843–863) got quite impressive results with their neural network model compared to traditional mathematical models. Also e.g. Huang & Lam (2002, 272) suggests that further research should be done on neural network methods and genetic algorithms, which have remembering and learning capabilities.

6 CONCLUSIONS & SUMMARY

The basic principles for transportation study have been around for several Millennia. Maps and sea travel were invented thousands of years before Christ and also compasses as well as longitude and latitude have been around over a thousand years. Many modern transportation problems, like the travelling salesman problem, have their mathematical roots in the 18th Century. The beginning of mass production of cars in the early 20th century created a demand for traffic research and even such innovations as GPS have their roots in the 1950s. Thereby one can say that a significant research has been done for a long time and the amount of information still increases at an ever growing pace, making the total amount of information currently available for everyone quite staggering.

However information itself isn't worth much before it has been first converted into intelligence and knowledge. Only after that it becomes a true asset. A good starting point is always to know where you currently are, so in converting that information into intelligence it is good to first know in more detail, what kind of information is available.

Also since computers have evolved very quickly in the past few decades, enabling very complex mathematical models to be calculated, the purpose of this thesis was to study:

- What is currently being researched in the mathematical and methodological part of transportation studies and how the focus point of research has shifted during the past 25 years (1983–2007)?

The secondary objective was then to give a short overview of the topic, which had been under the most intensive research based on the results of the first part. I.e. to give an overview of traffic flow and traffic equilibrium studies.

In order to gain an objective view of the situation, the study was conducted in a heavily statistical manner inspired by meta-analytical studies. Articles on the journal 'Transportation Research Part B: Methodological' were classified in seven different categories (Route choice optimization; other optimization; traffic flow and traffic equilibrium; network planning; human behavior and future prediction; network design; and other) based on what the researchers thought their articles were about. (See Appendix 1)

Of course one should remember that this research was limited to a very specific branch of transportation research (the mathematical and methodological), so results don't directly show, what is studied in logistics or even in transportation in general. For that purpose, one should do further studies on different journals.

However, in the methodological research, the most studied topic proved to be traffic flow and traffic equilibrium followed by human behavior and future prediction with network planning holding the third place. That coincides with Gentile's et al. (2007, 1114–1115) views that dynamic traffic assignment has been one of the hottest topics in transport modeling for the past decade, but it somewhat contradicts the Delphi study's results from 1995, where activity modeling was seen as the most important topic of study for the next decade. (Hensher et al., 2000, 5–7)

Partially that can be explained by the fact that behavioral studies may have spread more evenly between the different parts of Transportation Research journal (e.g. especially into part F: Traffic psychology and behavior) than the traffic equilibrium studies have spread.

Also it should be noted that most of the categories are very much interrelated. All the categories have some sort of relation to the one another, which at times made selecting the correct category a bit tricky (although the categories were clearly defined). However the most difficult cases were allowed to be placed under several categories when deemed necessary.

Because of the reasons stated above, it would be interesting to see whether a similar study conducted in another magazine, which also specializes on the methodological side of transportation studies, would give the similar results. And also it would be quite interesting to know, how much the results would have differed if the selected journal had specialized into the practical side of transportation studies (e.g. Transportation Research part A: Policy and Practice).

But even if there are some limitations as to how accurate depiction the study gives of the current state of research activity, it does show how the focus point within Methodological studies has changed. Or as it happens, how the focus hasn't changed.

All the categories had quite high yearly fluctuation in the study activity, which can at least partially be explained with the fact that editors may have often wanted to put related studies in the same issue, making every issue a bit biased towards some category. However the total amount of articles classified in this study was 988, so in the long run it should eliminate the possible biases caused by individual magazines with several related studies. Despite that, the only categories showing signs of statistically significant trend were 'traffic flow and traffic equilibrium' and 'other'.

In traffic flow and traffic equilibrium studies, the amount of research increased in the beginning, peaked at 1990s and has since been in slight decline though it still has remained as the most active topic of research according to this study. The category other has declined since the 1980s, quite possibly due to the fact that more parts of Transportation Research journal have been published, enabling the Methodological part to concentrate on its core competence, which is the highly mathematical methodological studies.

The lack of significant trends in the study shows however that most of the issues which were studied in the eighties seem still relevant topics today, they just have evolved. For example in the traffic equilibrium studies, the study of the static problem may have ceased to create new research (Hamdouch et al. 2004, 291), but the within-day dynamic traffic assignment has then been one of the hottest topics in transport modeling for the past decade (Gentile et al. 2007, 1114–1115).

In addition to showing that the topics which were studied in the 1980s are still valid areas of research, this thesis has given a starting point into learning more about traffic flow and traffic equilibrium studies. Although the overview didn't go into specifics as in, how the models work, it provided information about what kinds of methods are available in general, and in what they can be used for. Also some further research possibilities have been mentioned.

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APPENDIX 1: THE CLASSIFICATIONS

Appendix 1 contains the study and categorizations behind the results in chapter 4. Table 3 contains the key to the categories used in the study.

Table 3: Study's categories listed

#	**Category**	**D**	Network planning
A	Route choice optimization	**E**	Human behavior and Future prediction
B	Other optimization	**F**	Technology
C	Traffic flow and Traffic equilibrium	**G**	Other

Article	Author(s)	page	Yr. / Vol.	Is.	**A**	**B**	**C**	**D**	**E**	**F**	**G**
A direct method for speeding up the...	Ali Mekky	1-11	1983 / 17	1	0	0	0	0	1	0	0
Discrete choice theory, information...	Alex Anas	13-23	1983 / 17	1	0	0	0	0	1	0	0
Transportation mode choice and cit...	D. Kahn	25-43	1983 / 17	1	0	0	0	0	1	0	0
On planning dissaturation control si...	Enrico Canuto et al.	45-54	1983 / 17	1	0	0	0	1	0	0	0
On the kinematics and quantum dyn..	Robert G. V. Baker	55-66	1983 / 17	1	0	0	1	0	0	0	0
Linear probit models: Statistical pro...	J. M. Sparmann et al.	67-86	1983 / 17	1	0	0	0	0	1	0	0
A performance assessment model f...	Dennis L. Kershner	89-106	1983 / 17	2	1	0	0	1	0	0	0
Comparison of macroscopic mode...	M. Papageorgiou et al.	107-116	1983 / 17	2	0	0	1	0	0	0	0
Estimating gravity model parameter...	Robert H. Gray et al.	117-131	1983 / 17	2	0	0	0	0	1	0	0
Analysis of an $O(N^2)$ heuristic for th...	Harilaos N. Psaraftis	133-145	1983 / 17	2	1	0	0	0	0	0	0
Transportation systems analysis: Ill...	Michael Florian et al.	147-153	1983 / 17	2	0	0	0	0	0	0	1
Equilibrium predictions in transporta..	J. E. Fernandez L. et al.	155-172	1983 / 17	2	0	0	1	0	0	0	0
The structure of intercity travel dem...	Tae H. Oum et al.	175-191	1983 / 17	3	0	0	0	0	1	0	0
A probability analysis of some spati...	P. K. Walsh et al.	193-200	1983 / 17	3	0	0	0	0	1	0	0
An approximate analytic model of s...	Mark S. Daskin et al.	201-219	1983 / 17	3	0	0	0	0	0	0	1
Bulk service queues with deviations...	Warren B. Powell	221-232	1983 / 17	3	0	0	1	0	0	0	0
Ridership estimation for short-rang...	A. H. Nickesen et al.	233-244	1983 / 17	3	0	0	0	0	1	0	0
A note on trip matrix estimation fro...	C. S. Fisk et al.	245-250	1983 / 17	3	0	0	0	0	1	0	0
A hierarchical control system for fre...	M Papageorgiou	251-261	1983 / 17	3	0	0	0	1	0	0	0
Cost allocation by uniform traffic re...	C. Hendrickson et al.	265-274	1983 / 17	4	0	0	0	1	0	0	0
Travel outcome and performance: T..	Randolph W. Hall	275-290	1983 / 17	4	0	0	0	1	0	0	0
The existence and calculation of tra...	M. J. Smith	291-303	1983 / 17	4	0	0	1	0	0	0	0
A model to assess cost and fuel sa...	George Kocur et al.	305-318	1983 / 17	4	0	0	0	0	0	0	1
Fully allocated costing in U.S. Regul..	Wayne K. Talley	319-331	1983 / 17	4	0	0	0	0	0	0	1
Some remarks on Wilson's gravity ...	Silviu Guiasu et al.	333-337	1983 / 17	4	0	0	0	0	1	0	0
Capacity at a signal-controlled junct...	B. G. Heydecker	341-357	1983 / 17	5	0	0	0	1	0	0	0
A note on the interpretation of the d...	B. G. Heydecker	359-364	1983 / 17	5	0	0	0	1	0	0	0
An algorithm for solving asymmetri...	M. J. Smith	365-371	1983 / 17	5	0	0	1	0	0	0	0
Analysis of equilibrium automobile ...	Charles F. Manski	373-389	1983 / 17	5	0	0	0	0	1	0	0
An improved algorithm for matchin...	Peter J. H. Shewey	391-397	1983 / 17	5	0	0	0	0	1	0	0
A stochastic passenger loading mo...	Warren B. Powell	399-410	1983 / 17	5	0	0	1	0	0	0	0
Multicriteria spatial price equilibrium...	Terry L. Friesz et al.	411-426	1983 / 17	5	0	0	0	1	0	0	0
A queueing system for airport buses	Ali Selvi et al.	427-434	1983 / 17	6	0	0	1	0	0	0	0
Inferences on trip matrices from obs..	M. J. Maher	435-447	1983 / 17	6	0	0	0	0	1	0	0
A combined land use-transportatio...	Tschangho John Kim	449-462	1983 / 17	6	0	0	0	1	0	0	0
Route choice and the value of com...	John F. McDonald	463-470	1983 / 17	6	0	0	0	0	1	0	0
A numerical investigation of the imp...	Warren Powell et al.	471-490	1983 / 17	6	0	0	0	0	0	0	1
A note on implicit consumer discou...	David L. Greene	491-499	1983 / 17	6	0	0	0	0	1	0	0
Dynamic prediction of traffic volum...	Iwao Okutani et al.	1-11	1984 / 18	1	0	0	1	0	0	0	0
The stability of stochastic equilibriu...	Joel L. Horowitz	13-28	1984 / 18	1	0	0	1	0	0	0	0
The impact of fare and gasoline pric...	G. H. K. Wang et al.	29-41	1984 / 18	1	0	0	0	0	1	0	0
A derived demand model of regiona...	David L. Greene	43-61	1984 / 18	1	0	0	0	0	0	0	1
Two alternative definitions of traffic...	M. J. Smith	63-65	1984 / 18	1	0	0	1	0	0	0	0
Incorporating trip chaining into analy..	Ryuichi Kitamura	67-81	1984 / 18	1	0	0	0	0	1	0	0
Latent structure in road systems	J. H. Johnson	87-100	1984 / 18	2	0	0	1	0	0	0	0
On some traffic equilibrium theory p...	Stella Dafermos et al.	101-110	1984 / 18	2	0	0	1	0	0	0	0
A note on the optimal control of an...	G. Guardabassi et al.	111-113	1984 / 18	2	0	0	0	1	0	0	0
A comparison of user-optimum ver...	Larry J. LeBlanc et al.	115-121	1984 / 18	2	0	0	1	0	0	0	0
Simplical decomposition of the asy...	S. Lawphongpanich et al	123-133	1984 / 18	2	0	0	1	0	0	0	0
The length of tours in zones of diffe...	Carlos F. Daganzo	135-145	1984 / 18	2	1	0	0	0	0	0	0
Control system design for an individ...	G. Improta et al.	147-167	1984 / 18	2	0	0	0	1	0	0	0
A modified Frank-Wolfe algorithm f...	Masao Fukushima	169-177	1984 / 18	2	0	0	1	0	0	0	0
A note on using Davidson's functio...	M. A. P. Taylor	181-199	1984 / 18	3	0	0	1	0	0	0	0
Estimating bus component failure di...	T. H. Maze et al.	201-208	1984 / 18	3	0	0	0	0	0	0	1

Article	Author(s)	page	Yr. / Vol.	Is.	A	B	C	D	E	F	G
Methods of determining choice pro...	M. G. Langdon	209-234	1984 / 18	3	0	0	0	0	1	0	0
On the dual approach to the traffic a..	Masao Fukushima	235-245	1984 / 18	3	0	0	1	0	0	0	0
Grade measurement with an instrum..	K. J. Rogers et al.	247-254	1984 / 18	3	0	0	0	0	0	0	1
A model of daily time allocation to d...	Ryuichi Kitamura	255-266	1984 / 18	3	0	0	0	0	1	0	0
A model for allocating car parking s...	S. K. Goyal et al.	267-269	1984 / 18	3	0	1	0	0	0	0	0
Analysis of the cost structure of an...	J. Berechman et al.	273-287	1984 / 18	4-5	0	0	0	0	0	0	1
Estimation of trip matrices from tra...	Ennio Cascetta	289-299	1984 / 18	4-5	0	0	0	0	1	0	0
Game theory and transportation sys...	C. S. Fisk	301-313	1984 / 18	4-5	0	0	1	1	0	0	0
Checkpoint dial-a-ride systems	Carlos F. Daganzo	315-327	1984 / 18	4-5	0	0	0	0	0	0	1
On the frequency of the perceived c...	Moshe F. Friedman	329-337	1984 / 18	4-5	0	0	0	0	0	0	1
Dynamic model of peak period con...	Moshe Ben-Akiva et al.	339-355	1984 / 18	4-5	0	0	1	0	0	0	0
Convex programming formulations...	Donald W. Hearn et al.	357-365	1984 / 18	4-5	1	0	0	0	0	0	0
The transferability of logit-based sh...	F. F. Saccomanno	367-375	1984 / 18	4-5	0	0	0	1	1	0	0
Multilane traffic flow dynamics: Som..	PG Michalopoulos et al.	377-395	1984 / 18	4-5	0	0	1	0	0	0	0
Testing of dynamic models for sign...	D. E. Beskos et al.	397-408	1984 / 18	4-5	0	0	1	0	0	0	0
Analysis of interrupted traffic flow b...	PG Michalopoulos et al.	409-421	1984 / 18	4-5	0	0	1	0	0	0	0
Spatial price equilibrium sensitivity a..	Gary S. Chao et al.	423-440	1984 / 18	6	0	0	0	0	1	0	0
An assignment principle for urban n...	S. B. Gershwin et al.	441-458	1984 / 18	6	0	0	1	0	1	0	0
Timekeeping control of an automat...	I. P. Milroy et al.	459-468	1984 / 18	6	0	1	0	0	0	1	0
Comparative tests of multimodal tr...	Anna B. Nagurney	469-485	1984 / 18	6	0	0	1	0	0	0	0
Truck backhauling on two terminal n..	William C. Jordan et al.	487-503	1984 / 18	6	1	0	0	0	0	0	0
Bus garage location planning with d...	T. H. Maze et al.	1-13	1985 / 19	1	0	1	0	1	0	0	0
Air conflict frequency calculations	Moshe F. Friedman	15-16	1985 / 19	1	0	1	0	0	0	0	0
Testing probabilistic discrete choice...	Joel L. Horowitz	17-38	1985 / 19	1	0	0	0	0	1	0	0
Passenger car units in saturation flo...	R. M. Kimber et al.	39-61	1985 / 19	1	0	0	1	1	0	0	0
Multicriteria ranking of air shuttle alt...	Dusan Teodorovic	63-72	1985 / 19	1	0	0	0	0	0	0	1
Cross subsidy in urban bus operatio..	H. C. W. L. Williams et a	73-79	1985 / 19	1	0	0	0	0	0	0	1
Derivation of delays by input-output...	P.G. Michalopoulos	80-81	1985 / 19	1	0	0	1	0	0	0	0
Large-scale network distribution of ...	T. S. Glickman et al.	85-94	1985 / 19	2	0	1	0	0	0	0	0
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A car-following theory for multiphas...	H.M. Zhang et al.	385-399	2005 / 39	5	0	0	1	0	0	0	0
A mass point vehicle scrappage mo...	Cynthia Chen et al.	401-415	2005 / 39	5	0	0	0	0	0	0	1
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Optimal location of intermodal freig...	Illia Racunica et al.	453-477	2005 / 39	5	0	0	0	1	0	0	0
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An extended branch-and-bound met...	Stéphane Rouillon	404-423	2006 / 40	5	0	1	0	0	0	0	0
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A frequency-based assignment mo...	M. Cepeda et al.	437-459	2006 / 40	6	0	0	1	0	0	0	0
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Dynamic yield management when ai...	Xiubin Wang et al.	563-576	2006 / 40	7	0	1	0	0	0	0	0
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