Urban Travel Forecasting: A 50 Year Retrospective

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About the authors

Huw Williams and I met in 1972 at the University of Leeds. We didn't look much like this 40 years ago.

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Actually, we looked more like this.

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Why write a Retrospective on Urban Travel Forecasting?

- By 2003, we had each spent 30 years or more conducting research in this field.
- The 50th anniversary of the origins of the travel forecasting field was approaching.
- Huw was taking his sabbatical, while I had just retired from the teaching faculty.
- And, it seemed like an interesting way to spend 2 or 3 years topping off our careers.

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- Now, 8 years later, we have each read extensively, consulted with our peers and written several hundred pages.
- Our manuscript remains incomplete, but we have largely accomplished what we intended at the outset.
- The invitation to present this Lecture in Hong Kong seemed like a fine place to try to summarize what we have learned.
- So, congratulations (or condolences) on attending the unveiling of our findings!

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Dimensions of our review

- Research and Practice
- Travel Behavior Models and Transportation Network Models
- United States and United Kingdom, and more generally Europe

With a concern for the:

- Constraints imposed by data and computers
- Roles played by the leading contributors

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Contents of the Lecture

- Emergence of the traditional approach – US
- Further development of the traditional approach – UK
- Integrated transportation network equilibrium models
- Travel forecasting with individual choice models
- Further extensions of the discrete choice approach
- Activity-based travel analysis and forecasting
- Tradition and innovation in US practice
- Tradition and innovation in UK practice
- Computing environment and forecasting software
- Achievements and current challenges

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Getting started – a look at the origins of terms

Traditional and evolving terminology of travel forecasting			
	Traditional	Evolving	Current
Definition of travel	Trip-based	Tour-based	Activity-based
Unit of observation	Zone-based	Individual-based	Individual/ Household
Network representation	Link-based	Route-based	Origin-based
Choice representation	Aggregate	Disaggregate	Individual
Solution procedure	Sequential	Integrated/ combined	Simulation

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Context of model formulation and use

- Forecasts for a future design year, relative to a base year;
- Tests of the impacts of alternative policies;
- Explanation and exploration of observed travel behavior;
- Design of model systems and evaluation frameworks, given current computational feasibility;
- Design of transportation networks and patterns of activity location (land use).

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Drivers of Change in Modeling

- 1950-1960s:
  - rapid increase in car ownership
  - population growth and urban decentralization
  - major road building, with declining transit use
- 1970-1980s:
  - environmental and financing restrictions
  - demand management
  - expanding rail transit systems
- 1990-2000s:
  - sustainability, non-motorized modes
- Developing regions now face these drivers of change all at once

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The Formative Era – Practice - US

- Surveys and inventories:
  household travel, land use, road & transit systems
- Data processing and reduction → models

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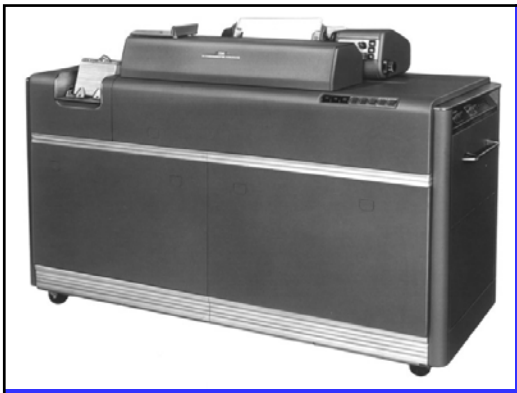

IBM 407 Accounting Machine

IBM 704 Computer

The Formative Era – Practice - US

- Surveys and inventories:
  household travel, land use, road & transit systems
- Data processing and reduction → models
- Representing travel through aggregation:
  (zones, 24 hour weekday, travel classes, ..)
- Partition of travel choices: frequency, O-D, route; no time of day, and often roads only
- Role of land use as the determinant of travel
- Early sequential procedure flowchart showing how to connect these 'steps'

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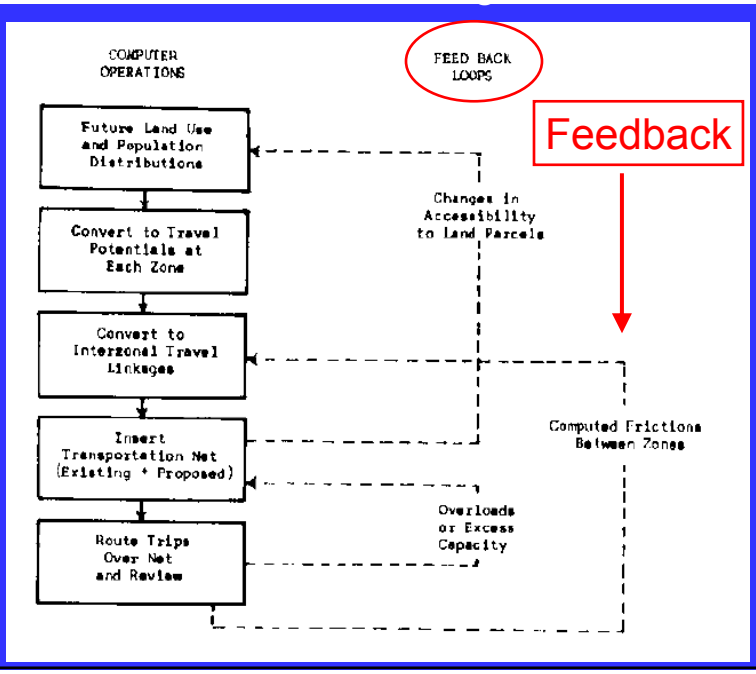
First known travel forecasting flowchart - 1957



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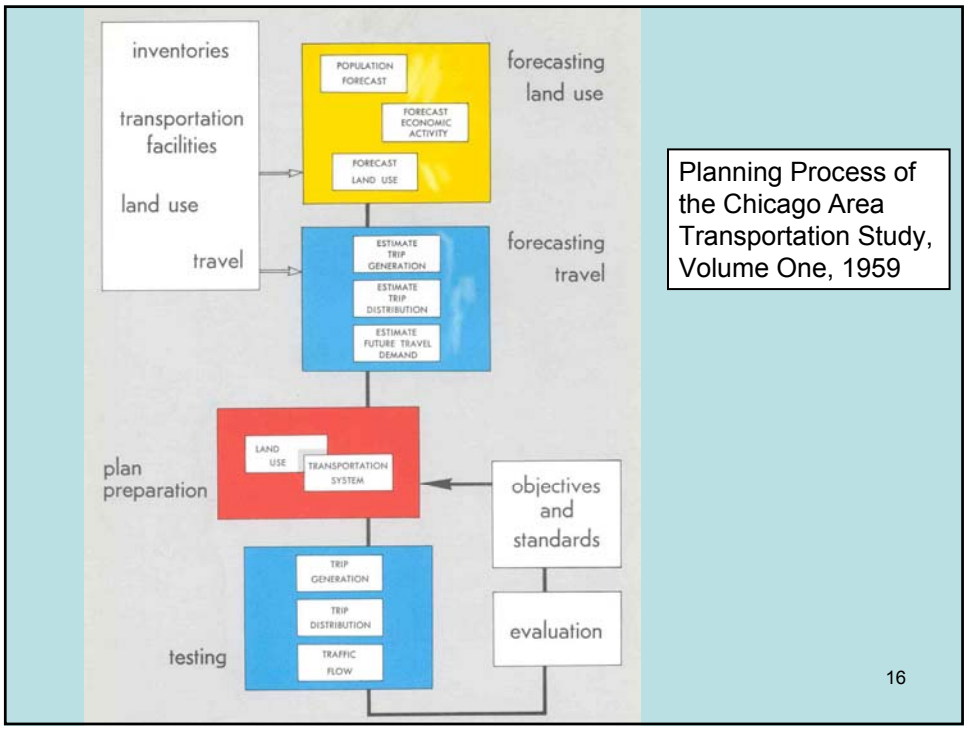

Planning Process of the Chicago Area Transportation Study, Volume One, 1959

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The Formative Era – Practice - US

- Early sequential procedure flowchart showing how to connect these 'steps'
- Demand – cost equilibrium intuitively solved with a simple feedback procedure
- Road network design:
  - expressway spacing formula
  - a strong orientation to road planning, with a secondary concern for transit

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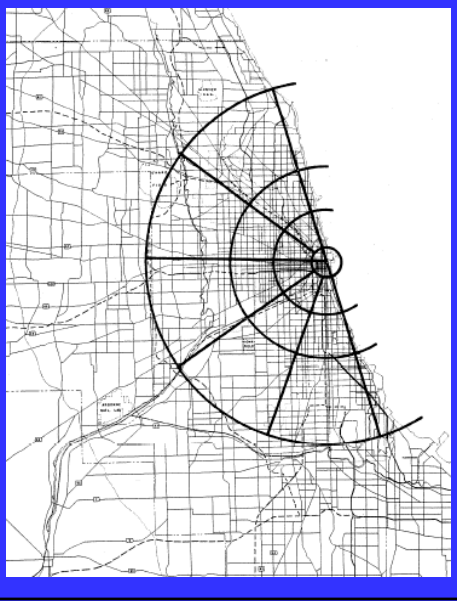
Ring – radial system



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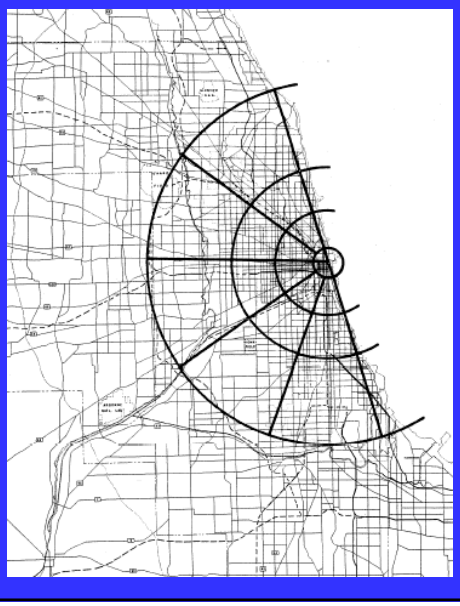
Ring – radial system



Grid – ring system

The Formative Era – Practice - US

- Demand – cost equilibrium solved with a simple feedback procedure
- An early attempt at road network design:
  - expressway spacing formula
  - a strong orientation to road planning, with a secondary concern for transit
- Failed early attempt to identify a desired land use pattern by forecasting the response of activity locations to road – transit network alternatives

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- Detroit (DMATS) – 1953-56
  - early gravity model experiments (J.D. Carroll, Jr.)
  - early attempt at automated traffic assignment
- Chicago (CATS) – 1956-62
  - intervening opportunities model (M. Schneider)
  - shortest routes on large networks (E. F. Moore)
  - linked distribution & assignment (M. Schneider)
  - expressway spacing (R. Creighton, I. Hoch)
- Philadelphia (PJTS) – 1959-67
  - transportation networks imply land use patterns (R. Mitchell and B. Harris)
  - residential location model (J. Herbert and B. Stevens)

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- U.S. Bureau of Public Roads – 1958-66
  - trip distribution by gravity model
  - capacity restrained assignment (G. Brokke et al)
  - zone-based trip generation & modal split
- Alan M. Voorhees and Associates – 1962-69
  - transit forecasting model system (R. Dial)
  - creation of first travel forecasting model system: TRIPS (W. Hansen and T. Deen)

Alan Voorhees, 2000

Britton Harris, 2003

Ben Stevens, 1985

- Land use – transportation programs, 1959-68
  - preparation & evaluation of alternative plans for metropolitan land use and transportation in several regions (Boyce, Day and McDonald, review & synthesis)
  - attempts to apply land use models declared a failure by D. B. Lee, Jr. in his 'Requiem for Large-scale Models.'

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Transfer of US Practice to the UK

- Early traffic research (Wardrop, 1952)
- Consulting consortia initially transferred US modeling practice to London and Glasgow
- British practitioners, and young researchers, began to improve the Transport Model, as it became known, with substantial innovations:
  - variations in trip frequency at household level
  - empirical curves replaced by analytic functions for distribution and mode steps – entropy maximization

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- generalized costs based on micro-behavioral foundations
- issues concerning the order of the steps and how to connect the steps:

  Dest → Mode, Mode → Dest, or Dest – Mode?
- definition of composite cost functions, model interfaces, and specification of nested models
- dispersion of route flows across routes
- line-based Public Transport representation
- trip-based benefit analysis for evaluation

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Early contributors, 1960-75

- US-trained British engineers
  - Tony Ridley and John Wootton (UC Berkeley)
  - Brian Martin (MIT)
- UK-trained economists and mathematicians
  - Christopher Foster & Michael Beesley (Oxford)
  - Alan Wilson (Cambridge, and later Oxford)
  - David Quarmby (Cambridge, and later Leeds)
- London Traffic Survey/Transportation Study, 1962-68
  - Household-based generation (category analysis)
  - User benefit analysis – rule of one-half
  - TRANSITNET

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- Math. Advisory Unit, Ministry of Transport
  - maximum entropy derivation of share models of logit form for trip distribution and modal split
  - generalized cost functions
  - examination of the proper sequence of models
  - increased emphasis on evaluation
- SELNEC Transportation Study (1967-72) included all major UK innovations to date
- Road Research Laboratory studies
- Next generation of British researchers:
  Michael Batty, Dirck Van Vliet, Huw Williams, Peter Batey, to name several

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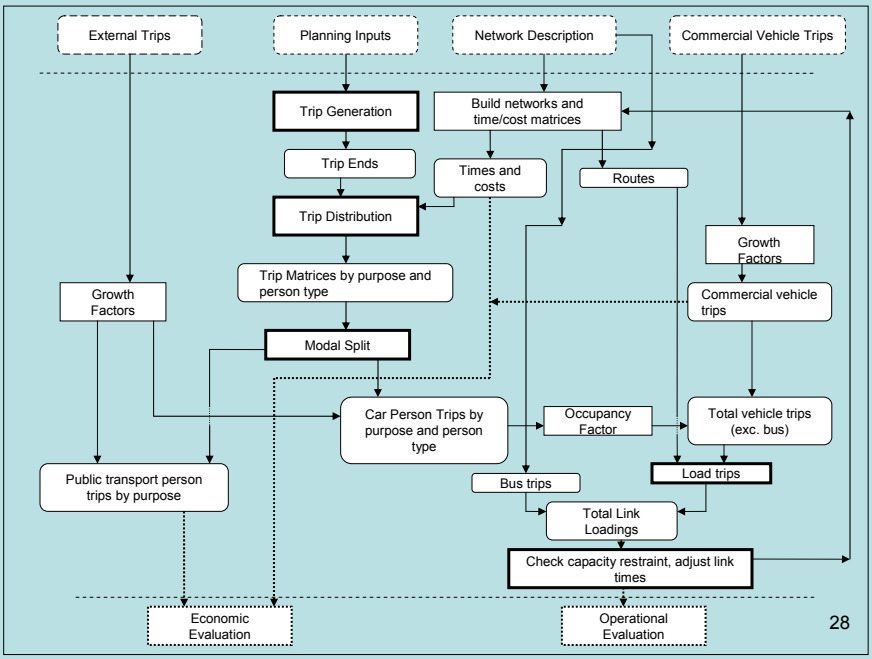
Proposed SELNEC Transport Model Structure (Wilson et al, 1969)



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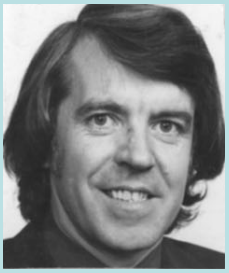
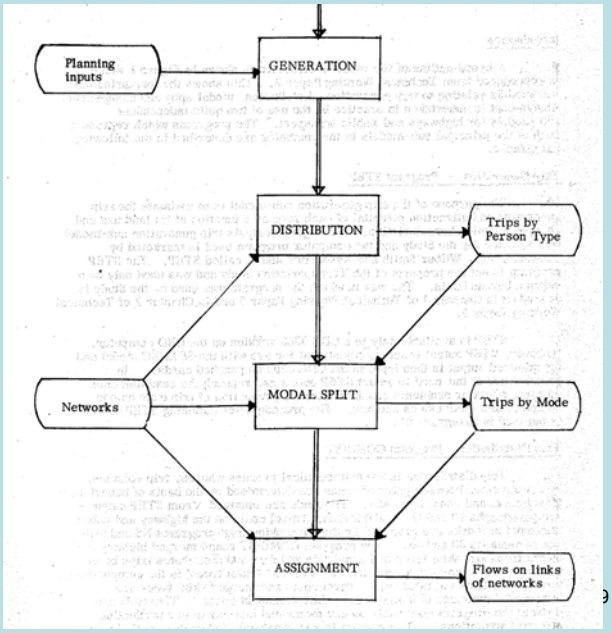
Implemented SELNEC Transport Model Structure

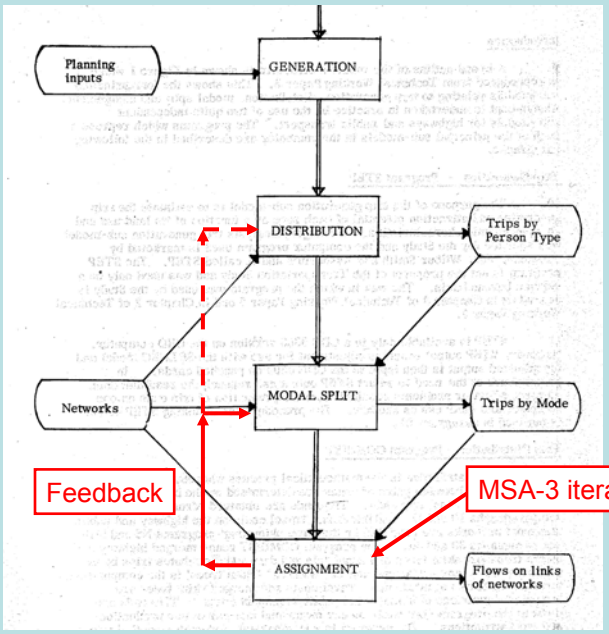


Alan Wilson, 1970

David Quarmby, 2003



SELNEC Transport Model Structure



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Integrated Network Equilibrium Models: A Missed Opportunity in the 1950s

- Cowles Commission study on allocation of scarce resources (T. Koopmans, 1952-55)
- Formulation of network equilibrium and efficiency models with new tool of nonlinear programming and the Kuhn-Tucker theorem (Martin Beckmann, with McGuire & Winsten, 1956)
- Variable demand and network flow models with average and marginal cost pricing
- Models of network user-equilibrium with fixed demand (Jorgensen, Charnes, Prager, Gibert, Dafermos, Braess, 1962-70)

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Martin Beckmann, 1977

Michael Florian spoke with Martin Beckmann, after he received the Robert Herman Lifetime Achievement Award in Transportation Science in 1994.

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- Convergent algorithms for cases of fixed and variable demand (Dafermos, Murchland, Evans, Florian and Nguyen, LeBlanc, 1968-73)
- Correspondence between Beckmann's formulation and the sequential procedure mathematically explored (S. Evans, 1973)
- Nonlinear complementarity and variational inequalities (Smith, Dafermos, 1979-84)
- Implementation of models of activity location (land use) with endogenous travel costs (Boyce & Lundqvist, Erlander)
- Implementation and validation of combined travel choice and user-equilibrium models (Lam & Huang, Boyce & Bar-Gera)

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Suzanne Evans and Anna Nagurney at 2003 recognition of *Studies in the Economics of Transportation* by Beckmann, McGuire and Winsten

Martin Beckmann & Bart McGuire being honored for their *Studies* at San Francisco INFORMS in 2005

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Individual Choice Models (~1965-75)

- Widening criticism of 'traditional methods' in late 1960s to 1973 – lack of behavioral basis at the level of individual travelers
- Discrete choice models based on random utility maximization (Quandt, McFadden)
- Early exploration of nested logit models (McFadden, Ben-Akiva)
- Economic-statistical properties of multinomial logit model (McFadden)
- Increased recognition of restrictive properties of multinomial logit (IIA property)
- Improved mathematical specification of systems of models (Manheim)

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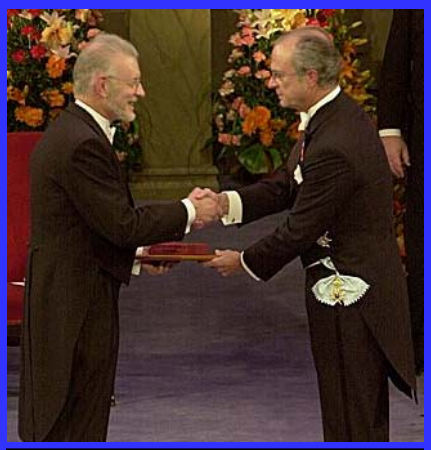

Daniel McFadden receiving the Nobel Prize in Economic Science from the King of Sweden in 2000

Moshe Ben-Akiva and Daniel McFadden in Stockholm in 2000

Individual Choice Models (~1975-85)

- Nested logit with parameter restrictions (Williams, Daly-Zachary)
- General extreme value models, with nested logit as a special case (McFadden)
- Ordering of hierarchical choices, as an improved basis for traditional models (Williams and Senior)
- Individual choice models offered practical alternative to the sequential procedure (Richards and Ben-Akiva, Daly)
- Use of stated preference methods to supplement revealed preference data

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Activity-based model framework

- Widening criticism of traditional procedures and discrete choice theory:
  - lack of behavioral basis
  - inability to represent observed complex tours
- Activity-based choices of households: response to time constraints and alternative plans (Hagerstrand, What about people …? 1970)
- Econometric approach (Ben-Akiva & Bowman)
- Rule-based approach based on satisficing behavior (Pas and Kitamura)
- Early fixed travel cost prototypes without endogenous travel costs/congestion effects) (Bowman & Bradley, Vovsha)

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Tradition and Innovation in US Practice

- Lawsuit challenging the Bay Area model (Garrett & Wachs, *Transp. Planning on Trial*, 1996)
- Federal requirements for solving the sequential procedure with feedback, 1991
- Travel Model Improvement Program (TMIP) initiated by Federal Highway Administration
- TMIP funding reallocated to TRANSIMS, a microsimulation software development effort at Los Alamos National Laboratory
- Prototype use of activity-based models, and later integration with land use and dynamic traffic assignment simulation methods (Pendyala, Waddell and Chiu, Urban Continuum)

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Tradition and Innovation in UK Practice

- Decline of travel modeling since the 1980s
- Increased technical guidance of government, partly a result of *Trunk Roads and the Generation of Traffic* (Standing Advisory Committee for Trunk Road Assessment, 1994)
- Incremental nested logit model applied in various situations
- Traffic management and microsimulation: SATURN, PARAMICS, VISSIM
- Integrated land use – transport models (MEPLAN, TRANUS, DELTA-START)
- Innovations in goods movement models

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Computing Environment and Software

- Mainframes to minis to microcomputers, 1951-2008
- Microcomputer revolution from the 1980s

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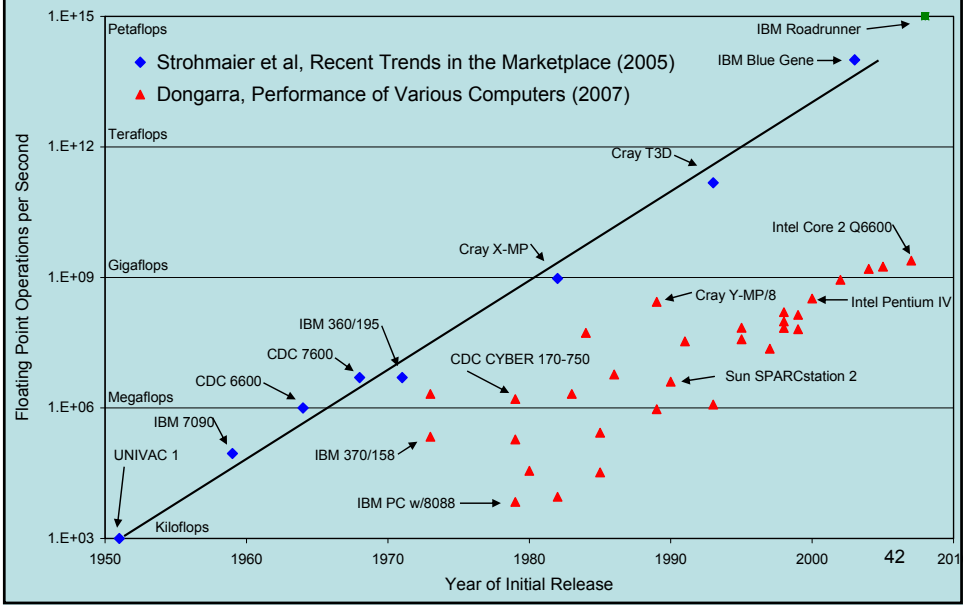
Performance of Super-, Mainframe, Mini- and Micro- Computers, 1951-2008



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Apple Lisa, improved version of Apple II, 1983

IBM PC, model 5150,1982

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Computing Environment and Software

- Mainframes to microcomputers, 1951-2008
- Microcomputer revolution in the 1980s
- Origins of travel forecasting software
  - Urban transportation studies: CATS, PJTS, etc.
  - Bureau of Public Roads – distribution and assignment
  - US Dept. of Housing – transit planning package
  - Transportation Planning Exchange Group
  - Alan M. Voorhees and Associates – TRIPS, a combination of BPR and HUD packages
  - Control Data Corporation – TRANPLAN
  - London Traffic Survey and London Transportation Study, 1962-68 – TAP, TRANSITNET
  - Martin & Voorhees Associates, moved TRIPS to the UK

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- US Department of Transportation
  - Urban Transportation Planning System, initially TRIPS of Voorhees, distributed and extended by the Urban Mass Transportation Administration
  - PLANPAC, a collection of programs developed by the Federal Highway Administration
- Legacy mainframe applications in 1970s
  - UTPS (Robert Dial) UMTA, US DOT
  - PLANPAC, FHWA, US DOT
  - TRANPLAN, James Fennessey, CDC

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- Transition to microcomputers
  - Knowledgeable software developers began developing software for the IBM PC and Apple microcomputers in early 1980s
    - TRANPLAN, James Fennessey, DKS Associates
    - TMODEL, Robert Shull, Professional Solutions
    - MINUTP, Larry Seiders, Comsis
    - MicroTRIPS, PRC Voorhees/MVA Systematica
    - EMME/2, Michael Florian, INRO
    - QRS II, Alan Horowitz, AJH Associates
    - VISUM/VISEM, Tom Schwerdfeger, PTV AG
    - SATURN, Dirck Van Vliet, University of Leeds
    - A few others that did not survive in the marketplace

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- Travel forecasting software systems today
  - *CUBE* (Citilabs, US) – evolved from TRANPLAN, TRIPS, MinUTP and TP+, and combining features of these legacy systems
  - *EMME* (INRO, Canada)– developed from research of Michael Florian, University of Montreal, and continues to be based upon research advances of Florian and his students
  - *TransCAD* (Caliper, US) – developed by Howard Slavin and his associates by seeking to incorporate the best available models
  - *VISUM* (PTV, Germany) – developed from research at University of Karlsruhe, and later adapted to US travel forecasting practice

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- Specialized forecasting software systems
  - *ESTRAUS* (MCT, Chile)
  - *OmniTRANS* (OmniTRANS Int., Netherlands)
  - *QRS II* (AJH Associates, US)
  - *SATURN* (WS Atkins, UK)
  - *STRADA* (Japan International Cooperation Agency, Japan)
  - *TRACKS* (Gabites Porter Consultants, New Zealand)
  - *TRANUS* (Modelistica, Venezuela)
  - *UFOSNET* (RST International, US)

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Achievements and current challenges

- The track record for academic research:
  - research was nearly non-existent in the 1950s, whereas practice was offering innovations
  - continuous improvements in foundations and understanding of models of specific choices
  - less success in advancing the demand-network equilibrium framework
  - lack of empirical validation and understanding of how urban travel phenomena have changed over the past 60 years
  - successful use of the huge advances in computing capability
  - who made the leading innovations?

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- The track record for professional practice:
  - following its early innovations, contributions from practice slowed substantially
  - practitioners are able to apply their software tools, but often without understanding of their properties (black box vs. glass box)
  - relatively few practitioners understand and are able to explain the properties of the models they apply, and sometimes offer misleading or invalid descriptions of model properties
  - is this situation a failure of their education?
  - difficulties of understanding model properties will only become greater in the future

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- Partially unaddressed problems of our field:
  - disaggregation in time and space:
    - geographic scale (zones)
    - timing of travel (static vs. dynamic)
  - design of networks and activity location systems
    - basic normative properties of location and networks remain unstudied and unknown (e.g. land use density and network layout)
    - these questions were studied in the 1960s without success, perhaps because the models were insensitive; is this still the situation?
  - overly simplified assumptions of basic models
    - representation of travel delay at intersections
    - cross-elasticities of demand by mode and destination

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- What are the ways ahead?
  - how should research and demonstration on design problems be undertaken? who decides?
  - at what scale should exploratory research be organized and funded?
  - likewise, at what scale should experimental implementations be undertaken in practice?
  - how should innovative thinking be rewarded?
  - who decides what research is supported?
  - how should progress be evaluated in another 25 years?

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