Urban Travel Forecasting:
A 60 Year Retrospective

David Boyce

Northwestern University

In collaboration with Huw Williams

Royal Institute of Technology

Stockholm

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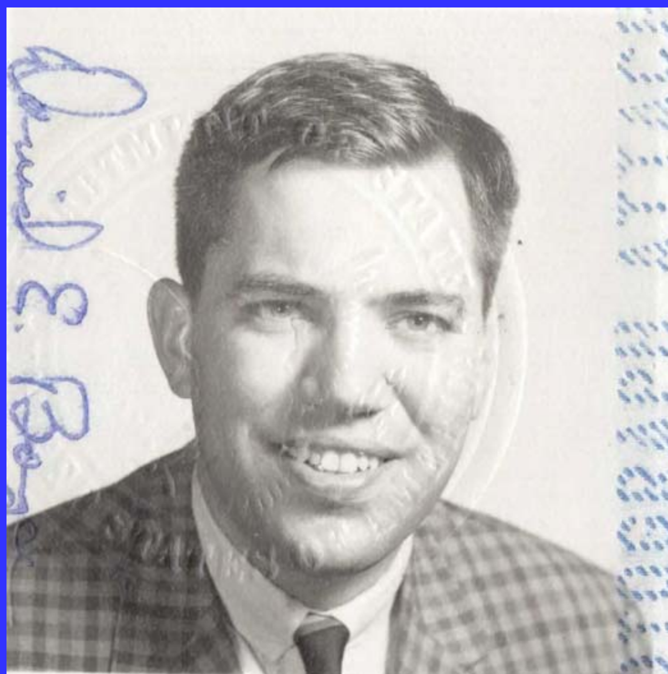
About the authors

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

Actually, we looked more like this.



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.
- Writing a retrospective seemed like an interesting way to top off our careers.
- Now, ten years later, our manuscript is nearly complete, and we have largely accomplished what we intended.

Dimensions of our review

- Research and Practice
- Travel Demand (Behavioral) 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

Overview of this Lecture

- Emergence of the traditional approach – US
- Further developments of the approach – UK
- Forecasting with individual choice models
  - Extensions to the discrete choice approach
  - Activity-based travel models
- Forecasting with network equilibrium models
  - Beckmann’s optimization formulation & extensions
  - Generalization of the optimization formulation
- Tradition and innovation in practice – US & UK
- Computing environment and software
- Achievements and current challenges

Getting started – a look at the origins of terms

Traditional and evolving terminology of travel forecasting			
	Traditional	Evolving	Current
Travel Representation	Trips	Tours	Activity locations
Spatial representation	Zone	Individual	Individual/ Household
Network / cost representation	Link-based	Route-based	Origin-based
Choice representation	Aggregate	Disaggregate	Individual
Solution procedure	Sequential	Integrated/ combined	Agent-based simulation

Context of model formulation and use

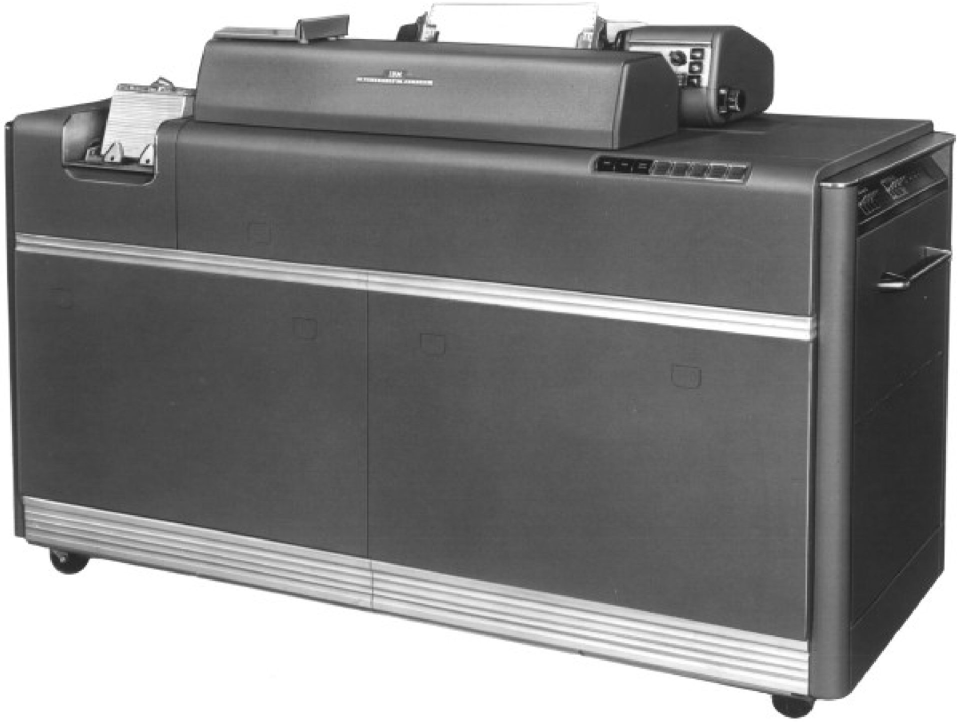
- Forecasts for a future design year, relative to a base year, both for facility planning and for demand management;
- Tests of the impacts of alternative policies;
- Explanation and exploration of observed travel behavior;
- Design of model systems and evaluation frameworks, given computational feasibility;
- Design of transportation networks and land use patterns.

Drivers of change in modeling in the US

- 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
- 1990-2010s:
  - sustainability, climate change, non-motorized modes
- Developing regions now face these drivers of change all at once

The Formative Era – Practice - US

- Surveys and inventories:
  household travel, land use, road and
  public transport systems
- Data processing and reduction →
  early computer models



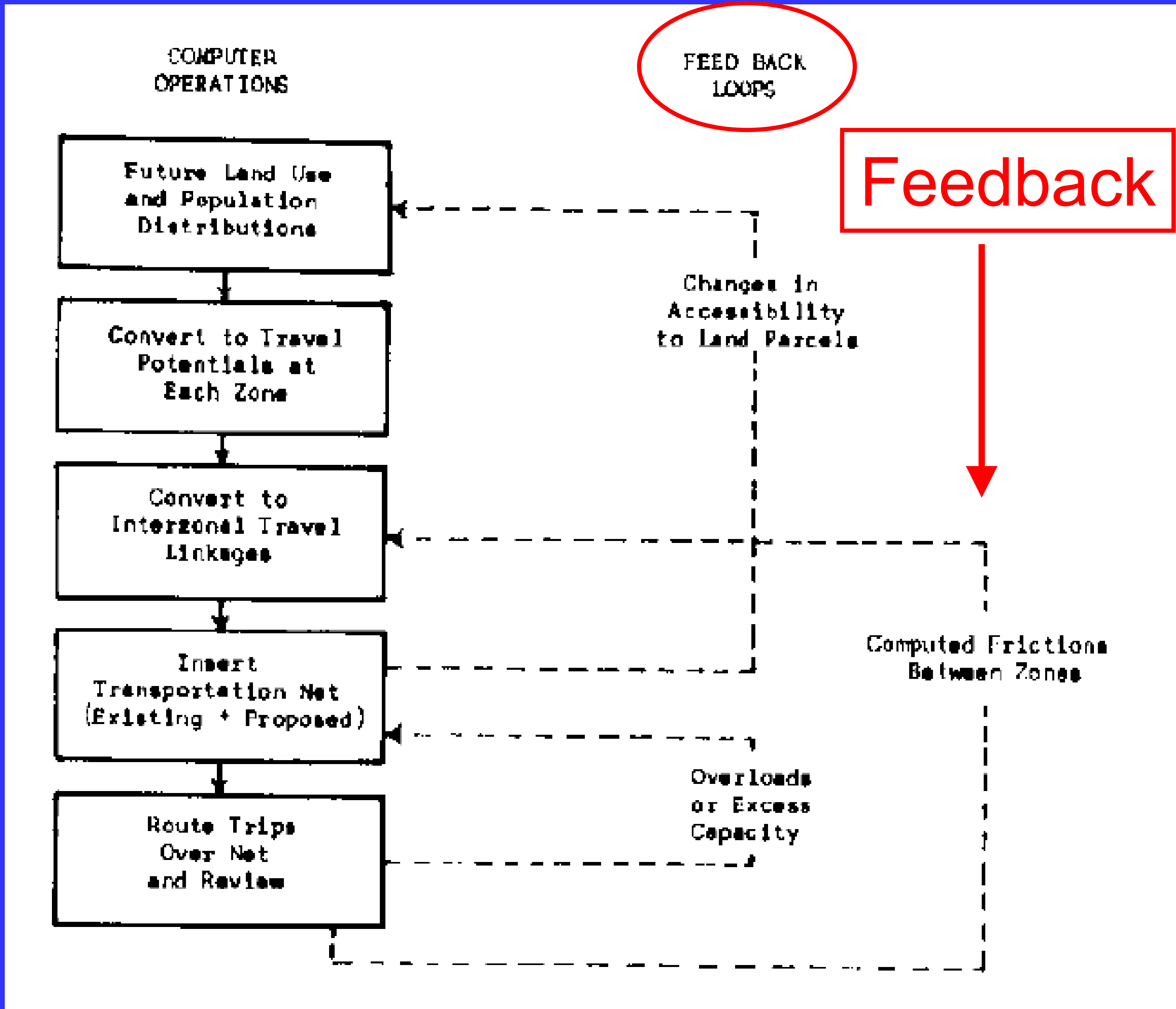
IBM 407
Accounting
Machine

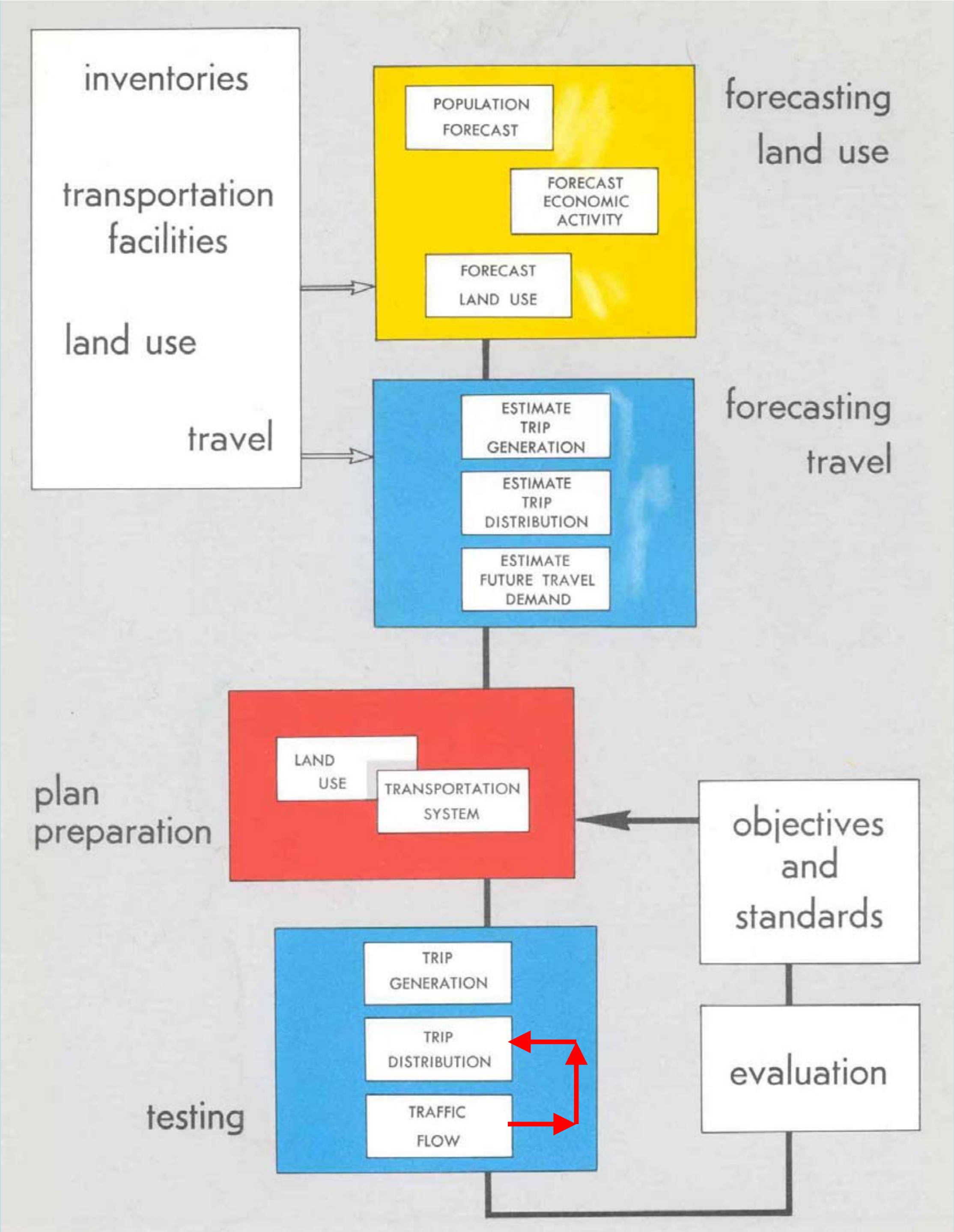
IBM 704
Computer

The Formative Era – Practice - US

- Surveys and inventories:
  household travel, land use, road & transit systems
- Data processing and reduction →
  computer models
- Representing travel through aggregation:
  (zones, 24 hour weekday, trip classes, ..)
- Partition of travel choices: frequency, O-D, route;
  daily travel only, and often roads only
- Role of land use as the determinant of travel
- The first sequential procedure flowchart showed
  how to connect these ‘steps’

First known travel forecasting flowchart - 1957





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

The Formative Era – Practice - US

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

(Chicago Area Transportation Study)

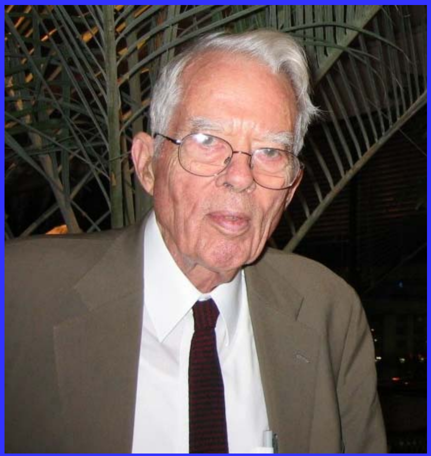
The Formative Era – Practice - US

- 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
- A failed attempt to identify a desired land use pattern by forecasting the response of activity locations to road – transit network alternatives (Penn Jersey Transportation Study)

- Detroit (DMATS) – 1953-56
  - early gravity model experiments (J.D. Carroll, Jr.)
  - early attempt at computerized 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)

- 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.’

Transfer of Early Practice to the UK

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

- generalized costs based on micro-behavioral foundations
- Questions raised 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

Early contributors, 1960-75

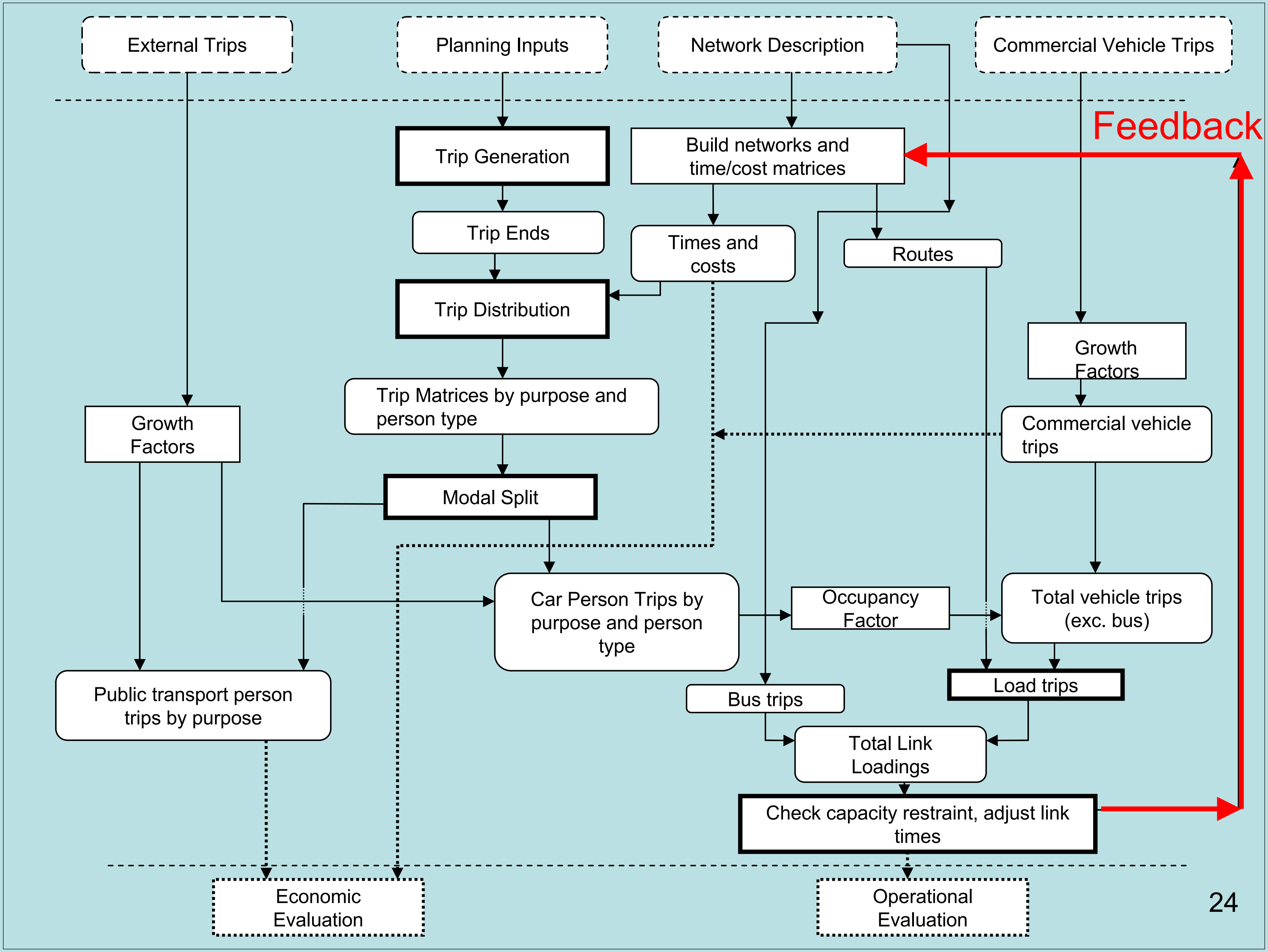
- US-trained British engineers
  - Tony Ridley and John Wootton (UC Berkeley)
  - Brian Martin (MIT)
- UK-trained economists and mathematicians
  - Christopher Foster & Michael Beesley (Oxford)
  - Alan Wilson (Cambridge, and later Oxford)
  - David Quarmby (Cambridge, and later Leeds)
- London Traffic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

- 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)

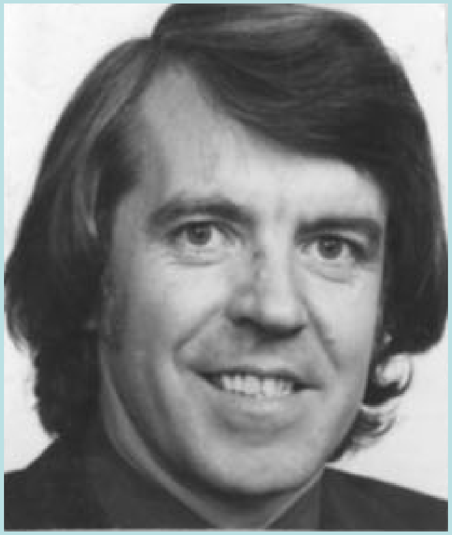
  included all major UK innovations to date
- Road Research Laboratory studies
- Next generation of British researchers:

  Michael Batty, Dirck Van Vliet, Huw Williams, Peter Batey, to name several

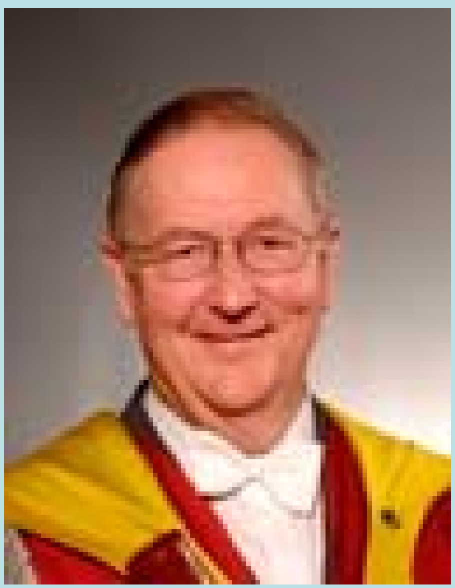
Proposed SELNEC Transport Model Structure (Wilson et al, 1969)



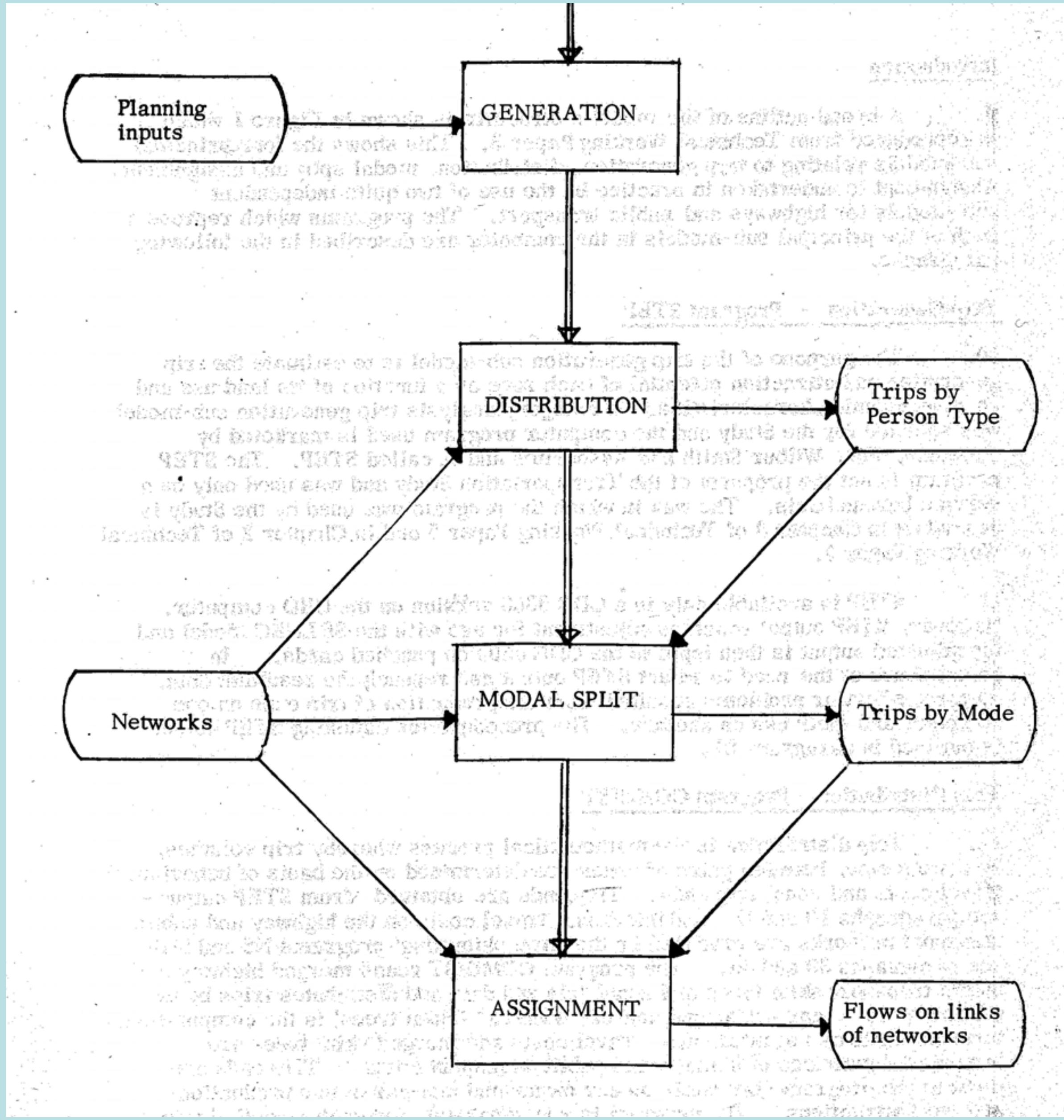
Implemented SELNEC Transport Model Structure



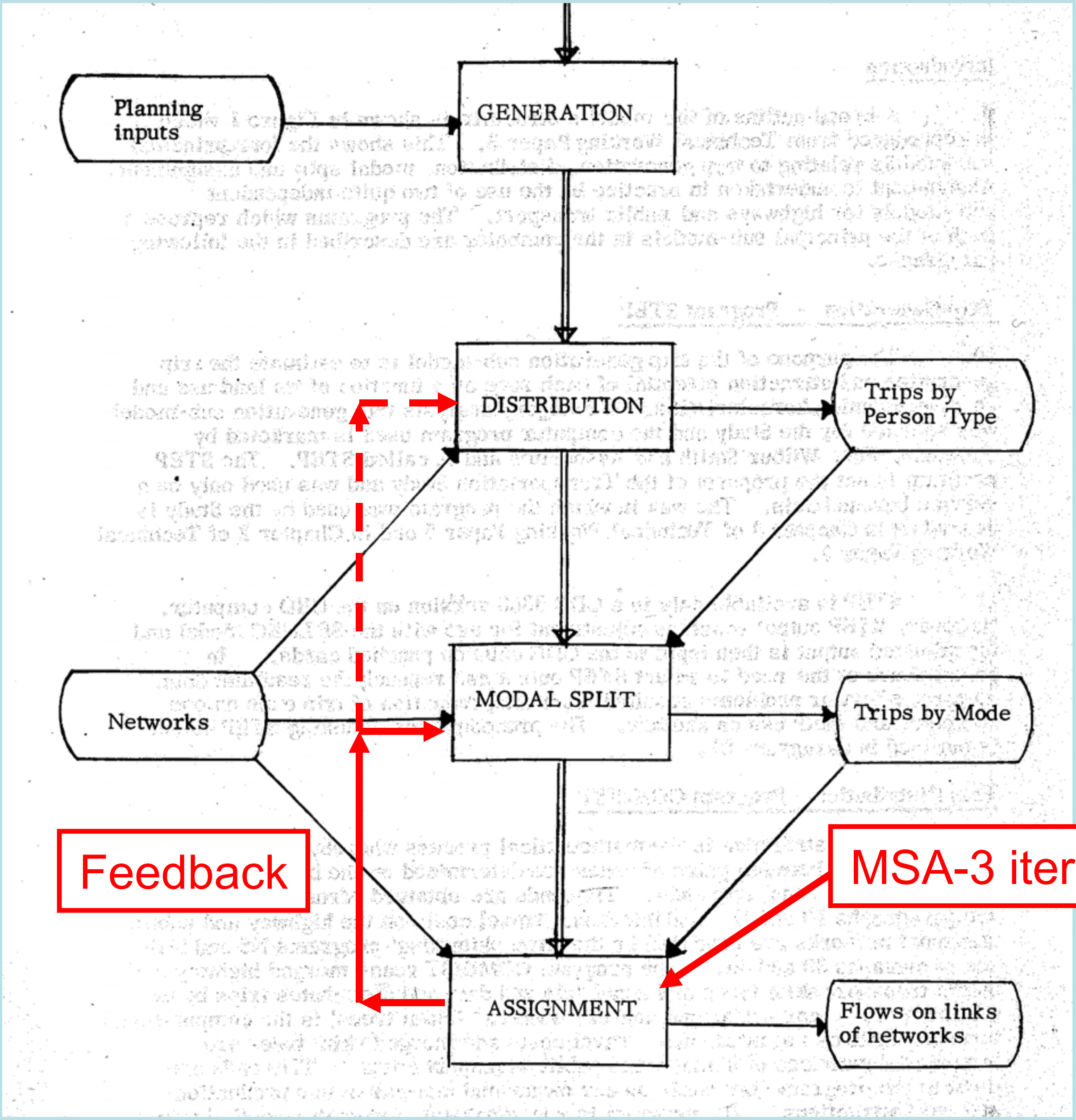
Alan Wilson, 1970



David Quarmby, 2003



SELNEC Model Structure showing Feedback



Individual Choice Models (~1965-75)

- Widening criticism of traditional methods up to 1973
  - lack of behavioral basis for individual travelers
- Improved mathematical specification of systems of models (Manheim)
- Discrete choice models based on random utility maximization (Quandt, McFadden)
- Economic-statistical properties of MNL (McFadden)
- Many applications of MNL to mode choice in US
- Early exploration of nested logit models (Charles River Associates, Ben-Akiva)
- Increased recognition of restrictive properties of multinomial logit (IIA property)

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

Discrete Choice Models (~1975-85)

- Nested logit models (NL) with parameter restrictions (Williams, Daly-Zachary)
- GEV models with NL as a special case (McFadden)
- Traditional models reconstituted as NL models (Williams and Senior)
- First application of comprehensive micro approach (Bay Area by Ben-Akiva; Holland by Daly et al)
- Early tour-based models introduced in Holland
- Stated Preference methods introduced and slowly gain acceptance (Louviere, Hensher and others).

Activity-based analysis framework

- Widening criticism of both traditional aggregate and disaggregate models:
  - poor behavioral representations of trip-based approach
  - need to represent household interactions and structure of journeys
- Activity-based choices of households:
  - importance of time, space, household constraints (Hagerstrand, What about people?, Jones et al, Oxford)
  - Tour-based representations of travel through the day
- Alternative modeling strategies
  - econometric approaches (Ben-Akiva and Bowman)
  - rule-based approaches (Pas and Kitamura)
- Early fixed travel cost prototypes without congestion effects (Bowman, Bradley & Vovsha)

Network Equilibrium – Optimization-based

- Cowles Commission study: allocation of resources
  ~ 1951-55: T. Koopmans, and others
- Formulation of models of network equilibrium and efficiency based on the Kuhn-Tucker theorem
  ~ 1952-55: Martin Beckmann, & McGuire-Winsten
  - Variable origin-destination demand
  - Link flows with average and marginal cost pricing
- Network equilibrium with fixed demand
  ~ 1954-70: Jorgensen, Charnes, Prager, Braess
- Convergent algorithms for fixed demand
  ~ 1968-76: Dafermos, Florian-Nguyen, LeBlanc
  ~ 1992-06: Larsson-Patriksson, Bar-Gera, Dial, Nie

John Wardrop in 1977
(1920-1989)

Martin Beckmann in 1977
(1924 -   )

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

- Stochastic network equilibrium with fixed demand
  ~1977-87: Daganzo, Fisk, Sheffi-Powell, Mirchandani
- Network equilibrium-trip distribution-mode split
  ~1969-79: Murchland, Evans, Erlander
  ~1980-99: Boyce-LeBlanc, Boyce-Lundqvist, Abrahamsson-Lundqvist
- Location models with endogenous travel costs
  ~1980-99: Boyce, Boyce-LeBlanc, Boyce-Mattsson
- Implementation-validation of combined travel choice and network equilibrium models
  ~1980-00: Florian et al, Boyce-LeBlanc-Bar-Gera
- Precise assignment solutions & unique route flows
  ~2000-10: Bar-Gera, Dial, Gentile, Nie

Generalized Network Equilibrium

- Asymmetries in modes and intersection flows:
  ~1977-79: Florian, LeBlanc-Abdulaal
- Nonlinear complementarity and variational inequalities problems
  ~1979-84: Aashtiani, Smith, Dafermos, Fisk-Nguyen
- Solution methods and side constraints:
  ~1980-00: Dafermos-Nagurney, Florian-Spiess, Larsson-Patriksson
- Prototype applications
  ~1990s: Meneguzzer and Berka
- Congested public transport assignment
  ~1990s: Florian-Spiess, De Cea-Fernandez, Santiago
- Network design with equilibrium constraints

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 Studies in the Economics of Transportation at San Francisco INFORMS in 2005

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 by Los Alamos National Laboratory
- Goods movement models (Southworth)
- Prototype use of activity-based models, and later integration with land use and dynamic traffic assignment simulation methods (Pendyala- Waddell-Chiu, 2008-12)

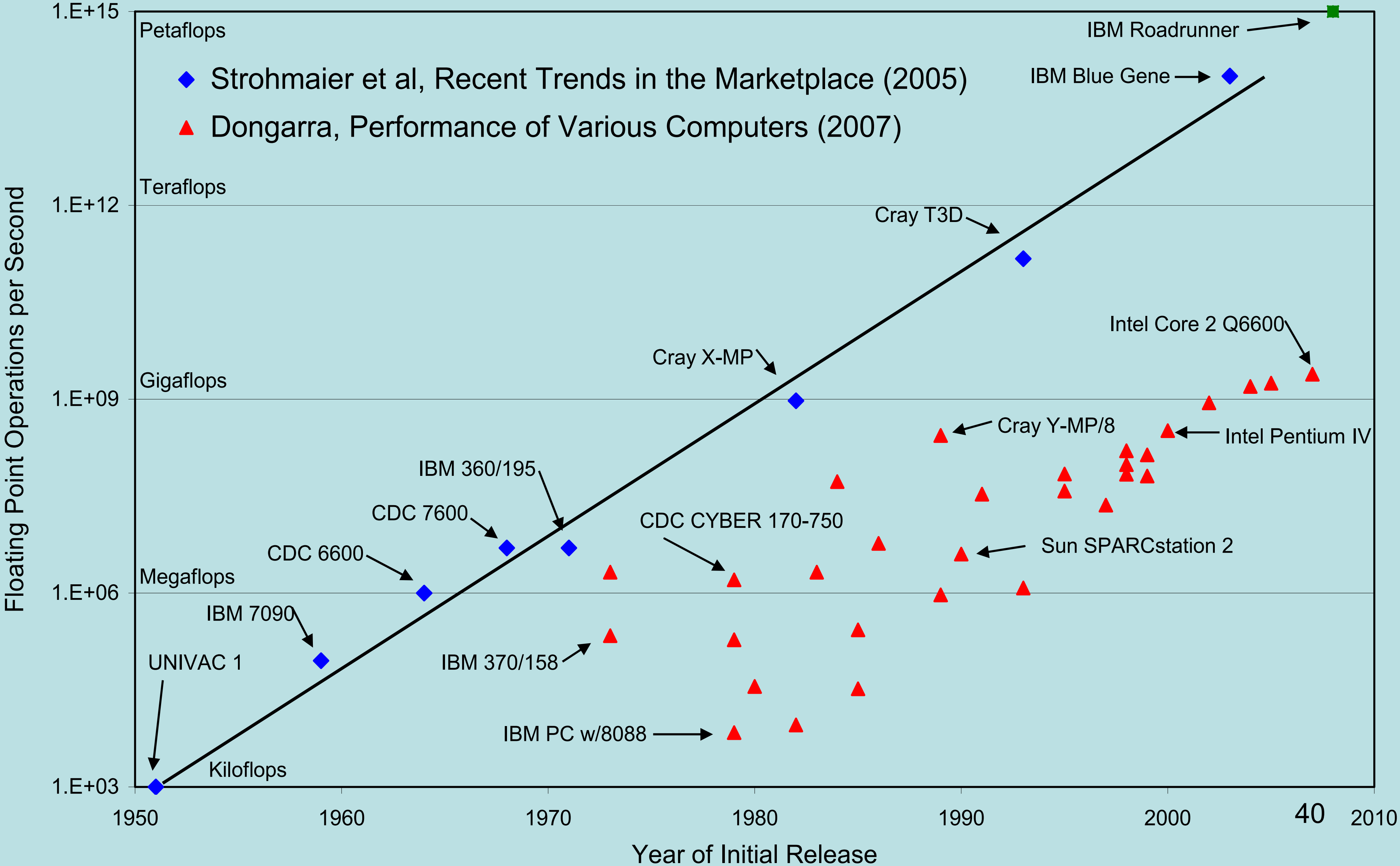
Tradition and Innovation in UK Practice

- Relative decline in travel modeling since 1980s
- Increased technical guidance of Government for traditional methods and discrete choice theory
- Emphasis on elasticities and journey timing
- A few tour-based and activity-based models (PRISM in West Midlands)
- Incremental nested logit model widely applied
- Traffic management and microsimulation: (SATURN, PARAMICS, VISSIM)
- Integrated land use – transport models: (MEPLAN, TRANUS, DELTA-START)
- Goods transport models (growth factor and spatial input-output; logistics)

Computing Environment and Software

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

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



Apple Lisa, an improved version of Apple II, 1983

IBM PC, model 5150,1982

Computing Environment and Software

- Origins of travel forecasting software
  - Urban transportation studies: CATS, PJTS, etc.
  - Bureau of Public Roads – distribution & assignment
  - US Dept. of Housing – transit planning package
  - Alan M. Voorhees and Associates – TRIPS, a combination of BPR and HUD packages
  - Control Data Corporation – TRAN/PLAN
  - London Traffic Survey and London Transportation Study, 1962-68 – TAP, TRANSITNET
  - Martin & Voorhees Associates, moved TRIPS to UK

- US Department of Transportation
  - Urban Transportation Planning System, initially TRIPS, distributed and extended by Urban Mass Transportation Administration
  - PLANPAC, battery 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
  - TRACKS, New Zealand

Transition to mini- and microcomputers

- Knowledgeable software developers began developing software from the 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

Travel forecasting software systems today

- *CUBE* (Citilabs, US) – evolved from TRANPLAN, TRIPS, MinUTP and TP+, combining features of those legacy systems
- *EMME* (INRO, Canada)– developed from research of Michael Florian, 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

Specialized forecasting software systems

- *EVA* (Technical University Dresden, DDR)
- *ESTRAUS* (MCT, Chile)
- *OmniTRANS* (OmniTRANS Int., Netherlands)
- *QRS II* (AJH Associates, US)
- *SATURN* (WS Atkins, UK)
- *STRADA* (Japan Int. Cooperation Agency)
- *TRACKS* (Gabites Porter Consultants, NZ)
- *TRANUS* (Modelistica, Venezuela)
- *UFOSNET* (RST International, US)
- *VENUS* (IVV, Aachen, Germany)

Achievements and current challenges

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

- 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 versus glass box)
  - 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

- 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 lacked sensitivity; is this still the situation today?
  - overly simplified assumptions of basic models
    - representation of travel delay at intersections
    - cross-elasticities of demand by mode and destination

- 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?
  - 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?