Urban Travel Forecasting: A 60 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.
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**

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

Feedback
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)

- **External Trips**
- **Planning Inputs**
  - **Trip Generation**
  - **Trip Ends**
  - **Trip Distribution**
    - **Trip Matrices by purpose and person type**
  - **Modal Split**
    - **Car Person Trips by purpose and person type**
  - **Growth Factors**
    - **Public transport person trips by purpose**
  - **Economic Evaluation**
- **Network Description**
  - **Build networks and time/cost matrices**
  - **Times and costs**
  - **Routes**
  - **Growth Factors**
    - **Commercial vehicle trips**
      - **Total vehicle trips (exc. bus)**
      - **Load trips**
      - **Total Link Loadings**
      - **Check capacity restraint, adjust link times**
    - **Occupancy Factor**
      - **Bus trips**
      - **Operational Evaluation**
      - **Feedback**
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
• Location models with endogenous travel costs
• 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
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
  – 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?