DATA FUSION FOR TRAVEL DEMAND MANAGEMENT: STATE OF THE PRACTICE & PROSPECTS

Transportation Systems

- ***Christopher Zegras***, Dept. of Urban Studies & Planning (DUSP), MIT, USA
- ***Francisco Pereira***, Cognitive and Media Systems Group (CMS), Centro de Informática e Sistemas da Universidade de Coimbra (CISUC), Portugal
- **Andrew Amey**, DUSP, MIT, USA
- **Marco Veloso**, CMS, CISUC, Portugal
- **Liang Liu**, SENSEable City Laboratory, DUSP, MIT, USA
- **Carlos Bento**, CMS, CISUC, Portugal
- **Assaf Biderman**, SENSEable City Laboratory, DUSP, MIT, USA

U.PORTO

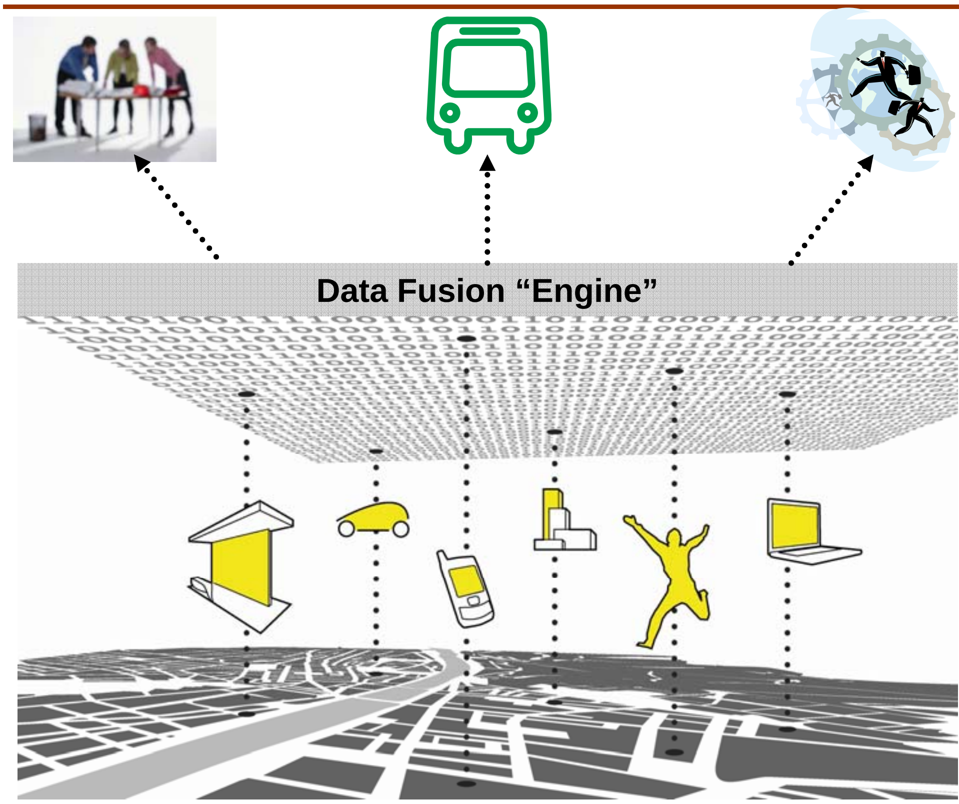
Outline

- Basics of Data Fusion
- Opportunities for Data Fusion in TDM
- Data Fusion Computational Architectures: State of Knowledge
- Data Fusion: State of the Industry
- Data Fusion: State of Practice in USA Metro Areas
- Data Fusion: Prospects

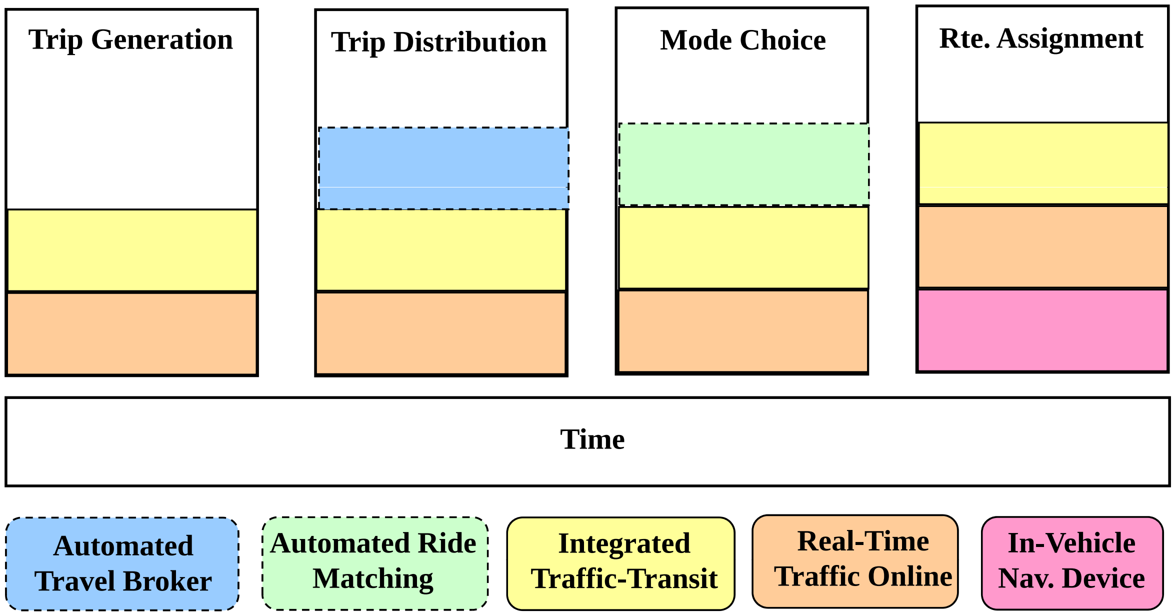
Data Fusion (DF) Definition

- Seamless detection & combination of data, from multiple sources to
  - Extract new knowledge from the data
  - Generate improved information
  - Transmit to relevant users
- We consider ***data fusion*** occurs when:
  - Simultaneous feed of > one data source;
  - Data sources have distinct inherent properties (specific technology, data type, etc.);
  - Integrated data sources create at least one sort of unified information

Ubiquitous Urban Information: The Potential



Data Fusion & TDM Potentials



DF for TDM: Computational Architectures

Several relevant levels

- "Signal Level"
  - e.g. aggregating GPS positioning with accelerometer information
  - Plenty of existing research in multi-sensor integration (using Kalman filters, Bayesian estimators, etc.)
- "Information Level"
  - e.g. combining GIS with GPS data for inferences
  - Less research

DF for TDM requires a broad system

- Cope with several levels and kinds of information
- Integrate and add value

DF for TDM Architectural Issues

- Several relevant models exist
  - Waterfall, JDL, Luo and Kay
- Physical, economic, institutional constraints
  - Multiple sources of information or centralized institution requires *parallel* sensor distribution.
  - *Serial* distribution possible with consortium of closely related providers (sequential info provision through virtual pipeline)
- Involvement/mutual confidence of institutions
  - Higher detail allows for better accuracy/value added
  - Higher detail also introduces important privacy concerns

DF for TDM Architectural Issues

- TDM apps have inherent complexity + some need for centralized control
  - Centralized architecture introduces reliability concerns
  - Distributed architectures more complex, but more flexible – important issue for rapidly growing metropolitan areas.
- Feedback introduces complexity
  - e.g., continuous sensor tuning

DF for TDM: State of the Industry

- Data “Manufacturers”
  - e.g., Sensors, maps
- Data Aggregators and “Distributors”
- Data “Retailers”
  - e.g., Garmin, TomTom, NextBus

Data “Manufacturers” (& “Distributors”)

Industry Players	Deployment Locations	Data Provider - GPS-based	Data Provider - Cellular-based	Data Provider - Traditional Sensors	Data Aggregators / Distributors
INRIX	US, UK	☑		☑	☑
iTIS Holdings	UK, EU, US, Israel	☑	☑	☑	☑
Traffic-Master	UK	☑		☑	☑
Skymeter	CAN	☑			
CellInt	US, Israel		☑		
IntelliOne	US		☑		
AirSage	US		☑		
DeCell	EU, Israel		☑		
Traffic-Cast	US, China		☑	☑	☑
Trisent	Scotland		☑		
SpeedInfo	US			☑	
Sensys Networks	US			☑	
Globis-Data	CAN	☑		☑	

Data “Distributors” (& “Manufacturers”)

Industry Players	Deployment Locations	Data Provider - GPS-based	Data Provider - Cellular-based	Data Provider - Traditional Sensors	Data Aggregators / Distributors	Digital Mapping	End User Devices
Traffic-Gauge	US	☑		☑	☑	☑	☑
Clear Channel	US				☑		
Westwood One	US			☑	☑		
AA UK	UK	☑			☑		
TrafficLand	US			☑	☑		
Navteq/ Traffic.com	US, UK, Worldwide		☑	☑	☑	☑	☑

Data “Retailers” (& “Distributors” & “Manufacturers”)

Industry Players	Deployment Locations	Data Provider - GPS-based	Data Provider - Cellular-based	Data Provider - Traditional Sensors	Data Aggregators / Distributors	Digital Mapping	End User Devices	Public Transport
TomTom Navigation	EU, UK, US		☑		☑		☑	
Garmin	US, EU, UK						☑	
DASH Navigation	US		☑		☑		☑	
GM OnStar	US	☑					☑	
NextBus	US	☑						☑
HopStop	US							☑
Google Transit	US, CAN, EU							☑

Industry Applications: A few observations

- Low level of inputs in general – do we need more
  - e.g. do we need text processing?

- Systems don't seem too complex
  - e.g.: Off-the-shelf signal level fusion + simple GIS map matching methods + Traffic estimator parameterization

Data Fusion for TDM:
State of Practice in USA Metro Areas

DF Spectrum of "Sophistication"

Time		**Modality**		
		Single mode	*Multi-modal, separate systems*	*Multi-modal, integrated system*
Time	*Static*	Table-based system, no sensors	Table-based systems, no sensors	Table-based system, many tables, no sensors, synchronization and communication between subsystems needed
	Real time	Real Time Traffic Conditions (RTT), sensor fusion needed	RTT, sensor fusion needed	RTT, sensors, tables fusion and synchronization needed; complex communication
	Predic-tive	RTT, sensors and historical data fusion needed	RTT, sensors and historical data fusion needed	RTT, sensors, tables and historical data fusion and synchronization needed; complex communication

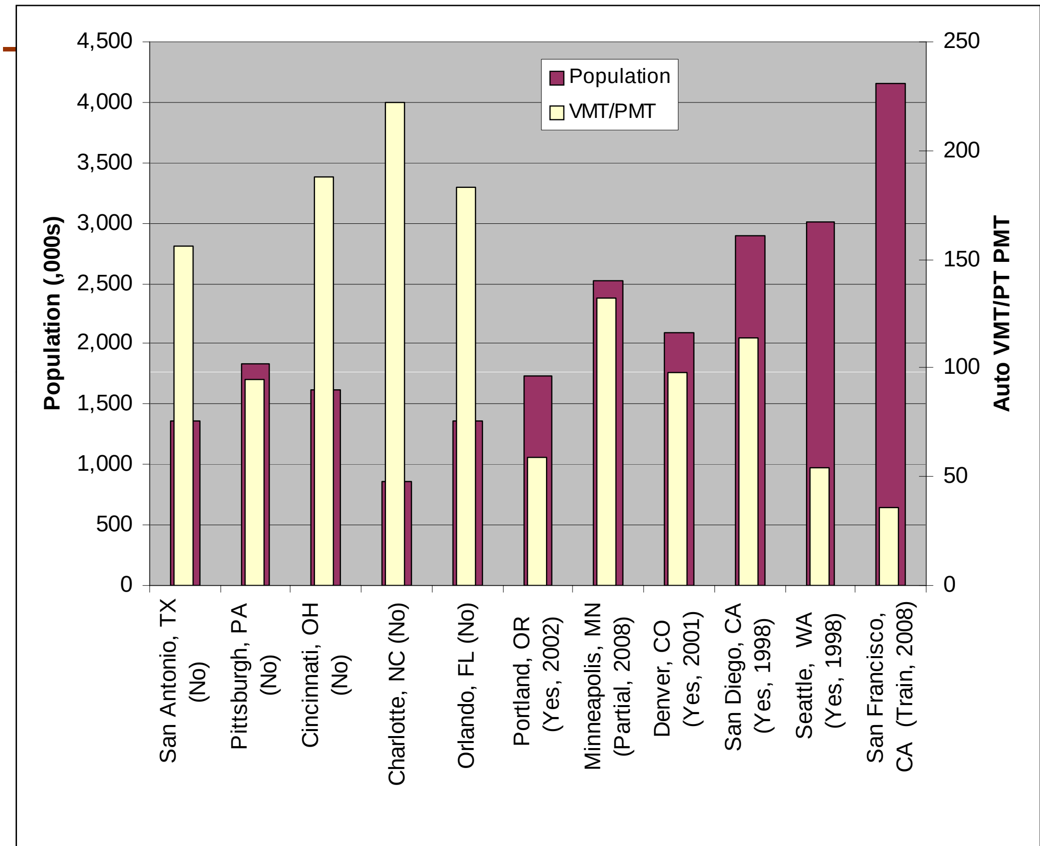
DF Adoption in US Metro Areas: Hypothesized Effects

- Population
- Congestion levels and automobile dependence
- "High Tech" industry presence
- Federal support for ITS
- Metropolitan transport authority (MPO) fiscal independence and political structure

DF Adoption in US Metro Areas: Methodological Approach

- Case Studies
- Varying levels of DF "adoption"
- Some variation in "independent variables"

Metro Area Basic Characteristics



US Metro Areas: *Apparent* Associations

- Relative auto dependence
  - Advanced ITS applications and lower auto dependency
- Federal grant support
  - Four of six advanced DF adopters received relatively large number of Federal grants
- “High tech” industry
  - Six advanced adopters in top 15 “high tech” economies
  - Non-adopters do not break the top 20
- MPO jurisdiction or form of representation
  - No clear pattern
- MPO finance
  - Four of six adopters’ MPOs have local taxation authority
  - Five of six fund transportation with $\geq$ 20% local revenue

Data Fusion for TDM: Outlook

“Best” computer architecture for DF-based TDM

- Context-specific
  - Institutions, relationships, data detail necessary and possible, etc.
- Flexible
  - High degree of accuracy
  - Respect for privacy *and* ease of abstraction (e.g., to higher level traffic patterns)
- Scale-able
  - Broad geography & jurisdictions/agencies
  - Diverse range of sensor types
  - Various potential applications and delivery media
- Feedback
  - For efficiency of applications (e.g., TDM) and the DF system itself (e.g. modifying sensors)
- Degree of Centralization?
  - Balance control with robustness and flexibility

Institutional Architectures:
Private Sector Issues

- Many private sector actors **span** related areas
- Most advanced apps appear for the **car**
  - Real time traffic, route choice via in-vehicle devices
  - Advanced services subscription-based
- Few private sector actors for **public transport**
- **Market forces** not enough to provide greatest societal value
- **Institutional** challenges non-trivial
  - May exceed technical challenges
  - Contractual (including existing)
  - Data “ownership”
  - Privacy

Institutional Architectures: Public-Private Issues

- Advanced DF will require public-private partnerships
  - e.g., Berlin approach.
- Public sector must create incentives to maximize public good
- Standards will be required
  - Interoperability protocols
  - Relevant efforts already underway (e.g. DATEX in EU, TIH in the UK, NTCIP in the US).
- Car-to-Infrastructure (C2I), Car-to-Car (C2C) and other communications among different infrastructure subsystems increase opportunities and challenges

Final Thoughts

- How will users actually respond to information generated & made available?
  - Will users make “better” decisions, consistent with TDM goals?
- Will DF-produced information and processes further blur lines between users, service providers, & planners?
  - Movement from “transport1.0” to “transport2.0”? (e.g., “open source”)

Acknowledgments

Government of Portugal: the Portuguese Foundation for International Cooperation in Science, Technology and Higher Education