

## 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



### Outline

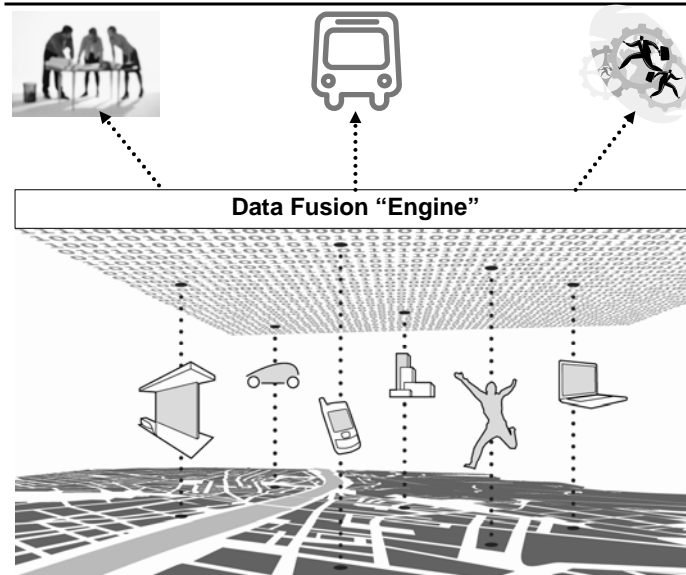
- Basics of Data Fusion
- Opportunities for Data Fusion in TDM
- Data Fusion Computational Architectures: State of Knowledge
- Data Fusion: State of the Industry
- Data Fusion: State of Practice in USA Metro Areas
- Data Fusion: Prospects

## 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

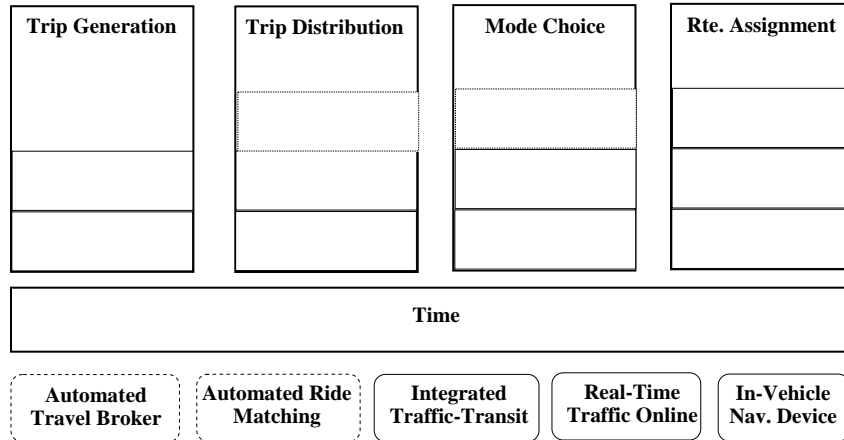
3

## Ubiquitous Urban Information: The Potential



4

## Data Fusion & TDM Potentials



5

## 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

6

## 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

7

## 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

8

## DF for TDM: State of the Industry

---

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

9

## 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	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
iTIS Holdings	UK, EU, US, Israel	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Traffic-Master	UK	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Skymeter	CAN	<input checked="" type="checkbox"/>			
CellInt	US, Israel		<input checked="" type="checkbox"/>		
IntelliOne	US		<input checked="" type="checkbox"/>		
AirSage	US		<input checked="" type="checkbox"/>		
DeCell	EU, Israel		<input checked="" type="checkbox"/>		
Traffic-Cast	US, China		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Trisent	Scotland		<input checked="" type="checkbox"/>		
SpeedInfo	US			<input checked="" type="checkbox"/>	
Sensys Networks	US			<input checked="" type="checkbox"/>	
Globis-Data	CAN	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	

10

## 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	<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Clear Channel	US				<input checked="" type="checkbox"/>		
Westwood One	US			<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
AA UK	UK	<input checked="" type="checkbox"/>			<input checked="" type="checkbox"/>		
TrafficLand	US			<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
Navteq/ Traffic.com	US, UK, Worldwide		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

## 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		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	
Garmin	US, EU, UK						<input checked="" type="checkbox"/>	
DASH Navigation	US		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>		<input checked="" type="checkbox"/>	
GM OnStar	US	<input checked="" type="checkbox"/>					<input checked="" type="checkbox"/>	
NextBus	US	<input checked="" type="checkbox"/>						<input checked="" type="checkbox"/>
HopStop	US							<input checked="" type="checkbox"/>
Google Transit	US, CAN, EU							<input checked="" type="checkbox"/>

## 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

13

---

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

14

DF Spectrum of “Sophistication”		Modality		
		<i>Single mode</i>	<i>Multi-modal, separate systems</i>	<i>Multi-modal, integrated system</i>
Time	<i>Static</i>	Table-based system, no sensors	Table-based systems, no sensors	Table-based system, many tables, no sensors, synchronization and communication between subsystems needed
	<i>Real time</i>	Real Time Traffic Conditions (RTT), sensor fusion needed	RTT, sensor fusion needed	RTT, sensors, tables fusion and synchronization needed; complex communication
	<i>Predictive</i>	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

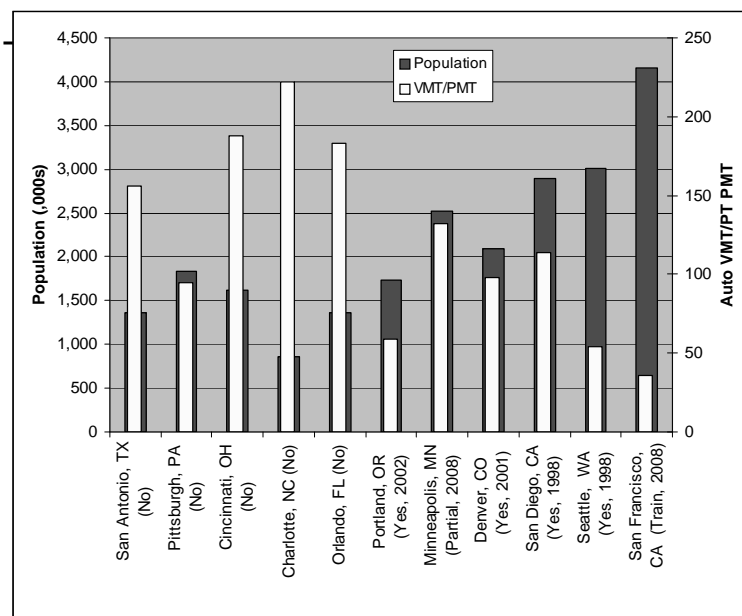
- Population
- Congestion levels and automobile dependence
- “High Tech” industry presence
- Federal support for ITS
- Metropolitan transport authority (MPO) fiscal independence and political structure

## DF Adoption in US Metro Areas: Methodological Approach

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

17

## 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

19

---

## Data Fusion for TDM: Outlook

20

## “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

21

## 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

22

## 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

23

## 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")

24

## Acknowledgments

---

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