Hydrogen Systems Analysis:

Validation of "idealized city" models for H_2 delivery in urban areas, with real-city data

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Presented at the

2006 DOE Hydrogen, Fuel Cells and Infrastructure Technologies Program Review

Alexandria, VA

May 17, 2006

Project ID # ANP3

Overview

Timeline

Phase I: 7/05-11/05
Phase II:4/06-

Phase I complete,
Phase II beginning

Barriers Addressed:

- Lack of Understanding of transition of Hydrocarbon Based Economy to H2 Based Economy.
- Lack of consistent data, assumptions and guidelines

Technical Targets:

- By 2007, identify and evaluate transition scenarios consistent with developing infrastructure and H2 resources.

Budget

- Total project funding: $100K (DOE share =100%)
- FY05: $100 K
- FY06: $100 K

Partners/Collaboration

- H2A Delivery Team (NREL, ANL, DOE)
- UC Davis H_2 Pathways Program (21 sponsors incl. Air Products and Chemicals, Inc.,BP, Caltrans, Chevron, Conoco Phillips, ExxonMobil, GM, Honda, Hyundai, Indian Oil, Nissan, Natural Resources Canada, Pacific Gas and Electric, Petrobras, Sempra Energy, Shell, Subaru, Total, Toyota, USEPA, USDOT, USDOE)
- California Hydrogen Highways Network

Objectives

- Assist the DOE in identifying promising paths for developing hydrogen infrastructure.

- Integrate existing UC Davis H_2 infrastructure models with other H_2 models funded by NREL, to address questions related to H_2 infrastructure development.

- Work with H2A core group to develop models of hydrogen delivery systems.

Technical Approach

- **TASK 1: Work with hydrogen analysts at NREL, to identify research areas for collaboration and integration.**

- **TASK 2: Validation of "idealized city" models for H2 delivery in urban areas, with real city data**

- **TASK 3: Coordinate with H2A delivery team and DOE H2 transition analysis efforts**

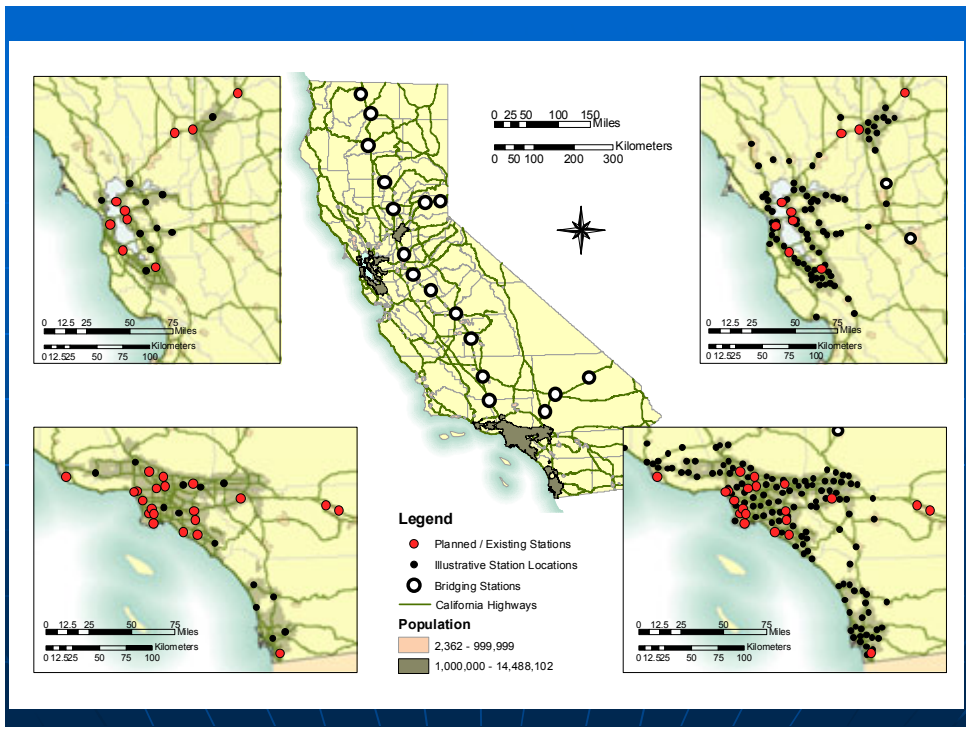
Technical Accomplishments (1)

Task 1: Identified Areas for Collaboration

- **Met with NREL researchers in June 2005 to review UC Davis' modeling tools, and how they relate to other NREL infrastructure modeling studies.**

Background: Hydrogen Pathways Program at UC Davis

Transportation and the H2 Economy: Pathways and Strategies



- Multi-year interdisciplinary research program (began 2003)
- Strategies and Pathways for transportation sector Hydrogen
- automakers, energy firms, government, environmental community
- 21 sponsors

UC Davis Modeling Tools

- H2 Demand Analysis (GIS)
- H2 Station siting and sizing (GIS-based analysis)
- Engineering/economic models
  - Components
    - Analysis of near-term H2 refueling equipment costs
    - Energy station technical/economic analysis
    - Statistical analysis of pipeline costs
  - System models
    - Idealized model for H2 delivery in cities
    - H2A Delivery System Model
    - Steady-state H2 supply system design and cost model
- Regional infrastructure analysis models (GIS)
- H2 Infrastructure Transition Model (dynamic programming)

H2A deliv

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H2A deliv

Identified UCD modeling tools for collaboration FY'06

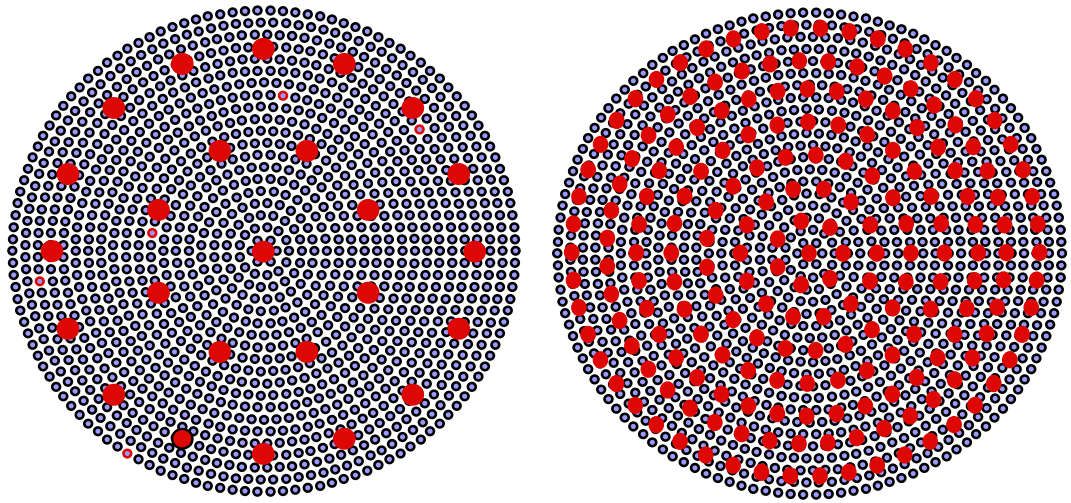
Identified two topics for FY'06 work

1. Validation of "idealized city" models developed at UC Davis for H_2 delivery in urban areas, with data from real cities *(also suggested by 2005 HFCIT Merit review of this project)*

2. Develop equations for design and costs of urban H_2 delivery systems, suitable for inclusion in NREL's regional H_2 system models.

Technical Accomplishments (2)

Task 2: Validation of UCD "idealized city" models for H_2 delivery in urban areas, with data from real cities

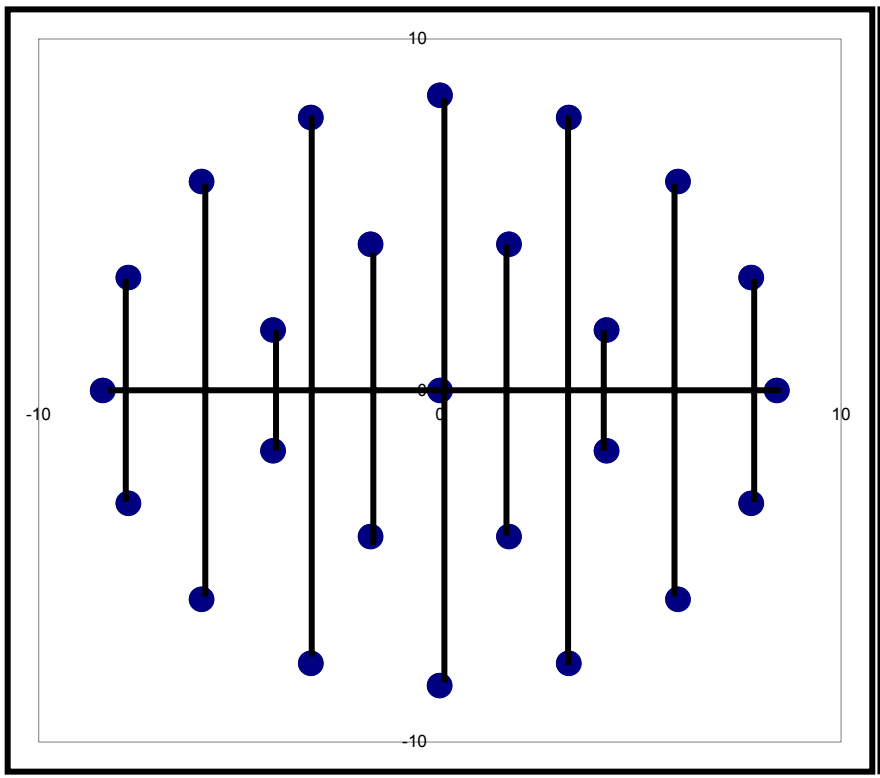


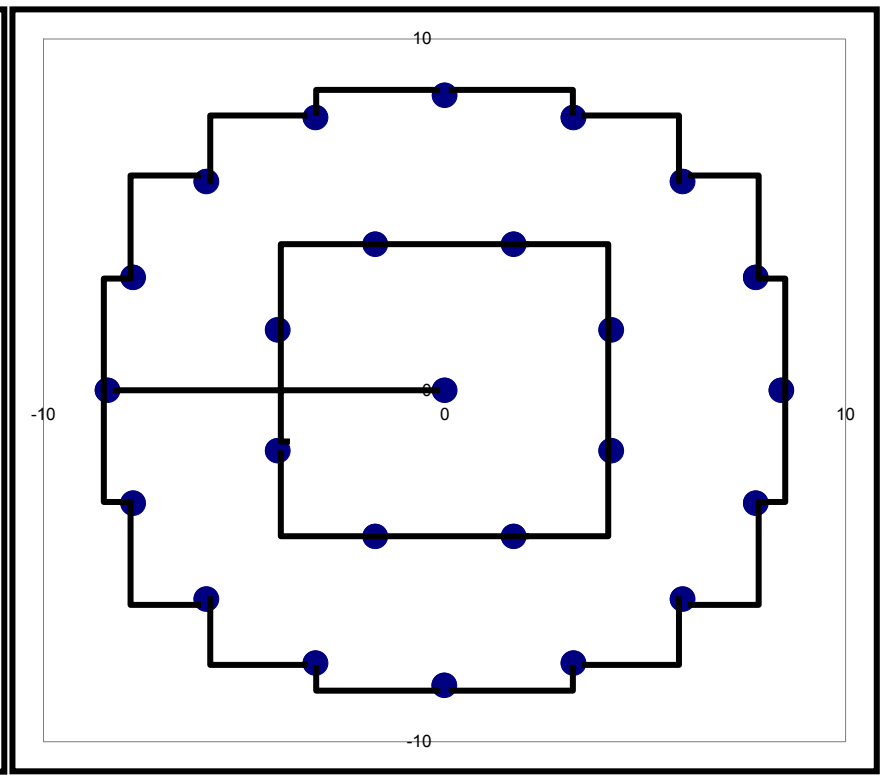
Idealized city model with 25 and 125 hydrogen stations distributed in rings throughout the city.

Assumes circular city. Stations distributed evenly.

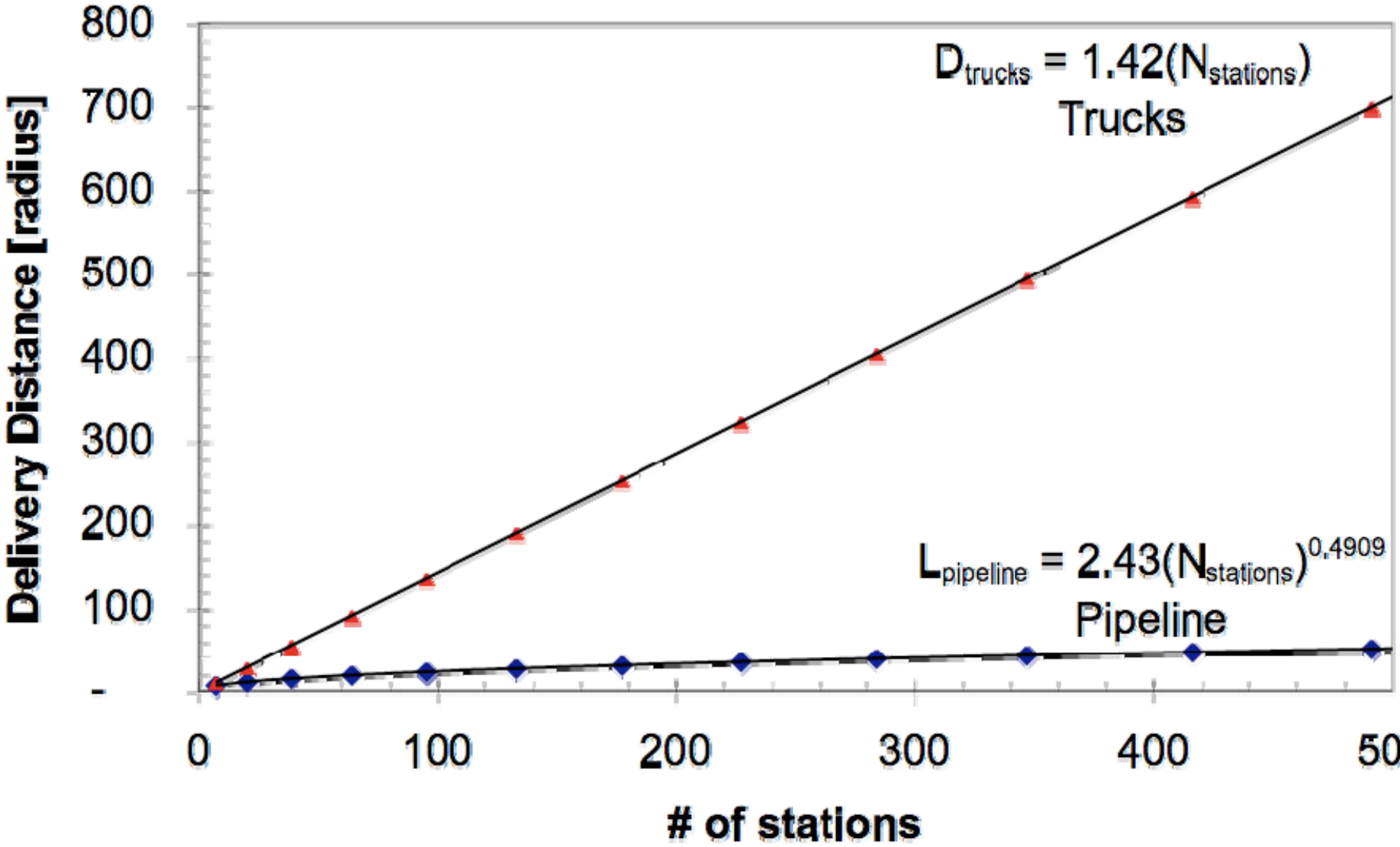
Idealized City Model (ICM)
Distribution System Layout for Idealized City => lengths, costs

Truck delivery **Pipeline**



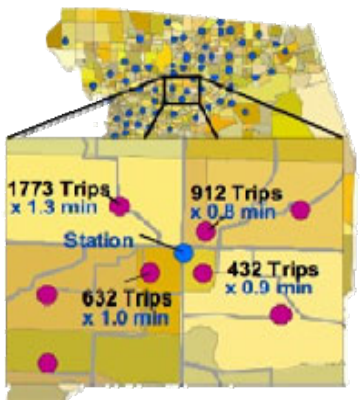


ICM Delivery Distances



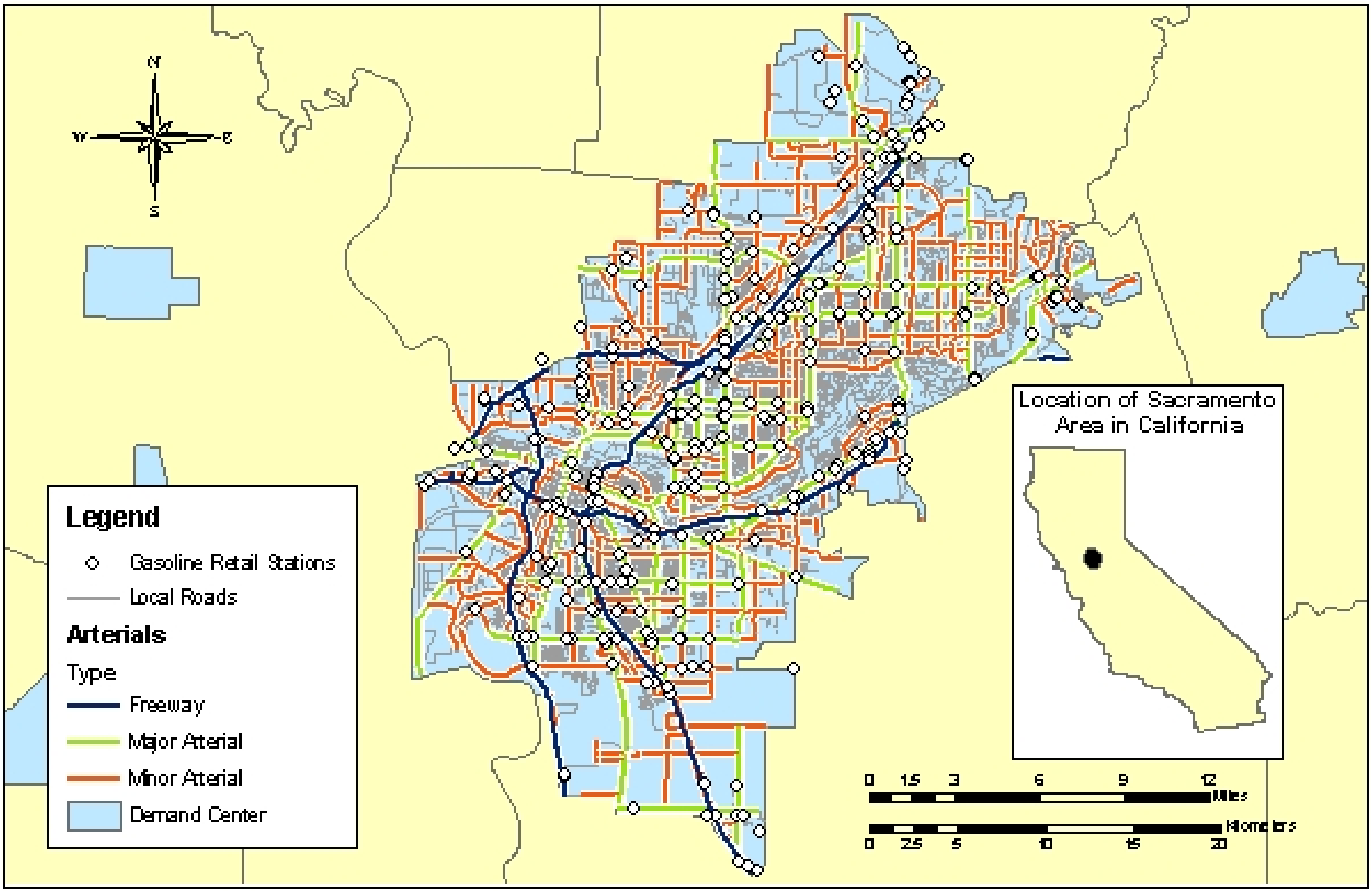
UCD Real-City H_2 Station Siting Model

- **HySS1 - Nicholas et al.**
  - **Uses GIS data from real cities**
  - **Identify existing gasoline stations**
  - **Model calculates drive time to stations**
  - **Select stations that give lowest overall travel time to maximize consumer convenience**

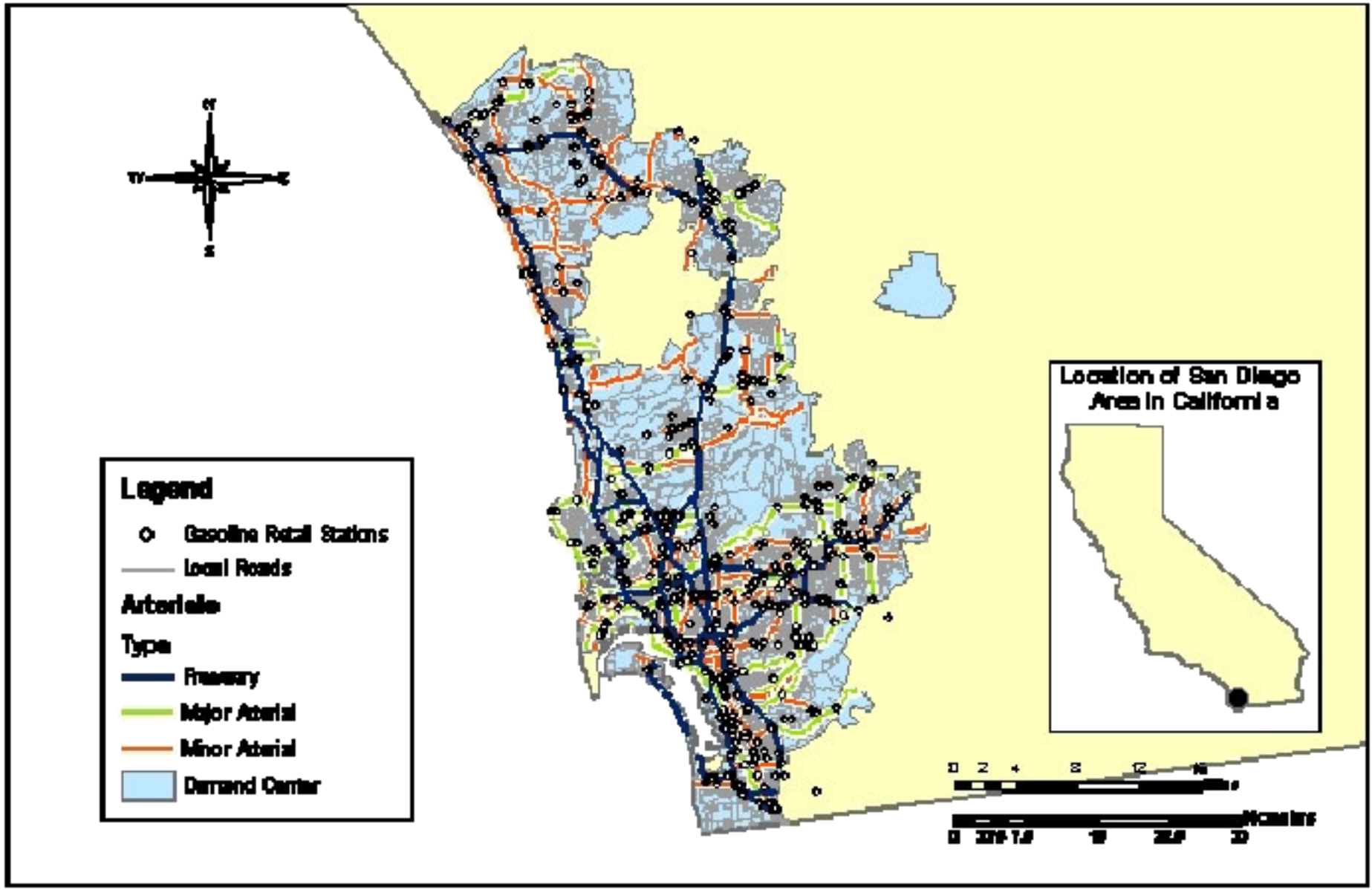


$$AvgTime = \sum_i (Trips * Minutes) \Big/ \sum_i Trips$$

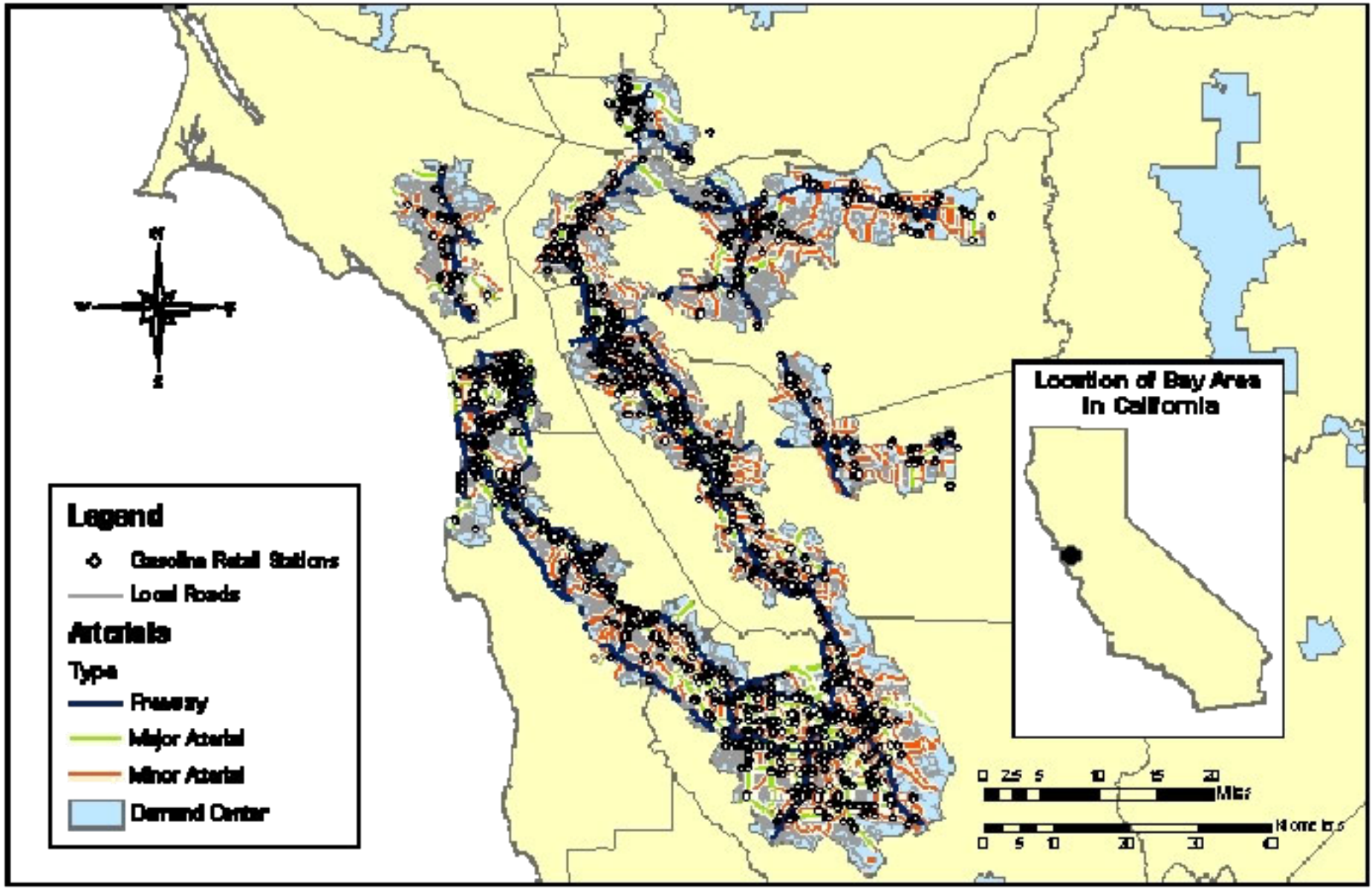
H_2 Station Layout: Sacramento, CA



San Diego, CA


Legend
Gasoline Retail Stations
Local Roads
Arterials
Type
Freeway
Major Arterial
Minor Arterial
Demand Center
Location of San Diego Area in California

Bay Area, CA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Gasoline Retail Stations
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Location of Bay Area in California
0 2.5 5 10 15 20
Miles
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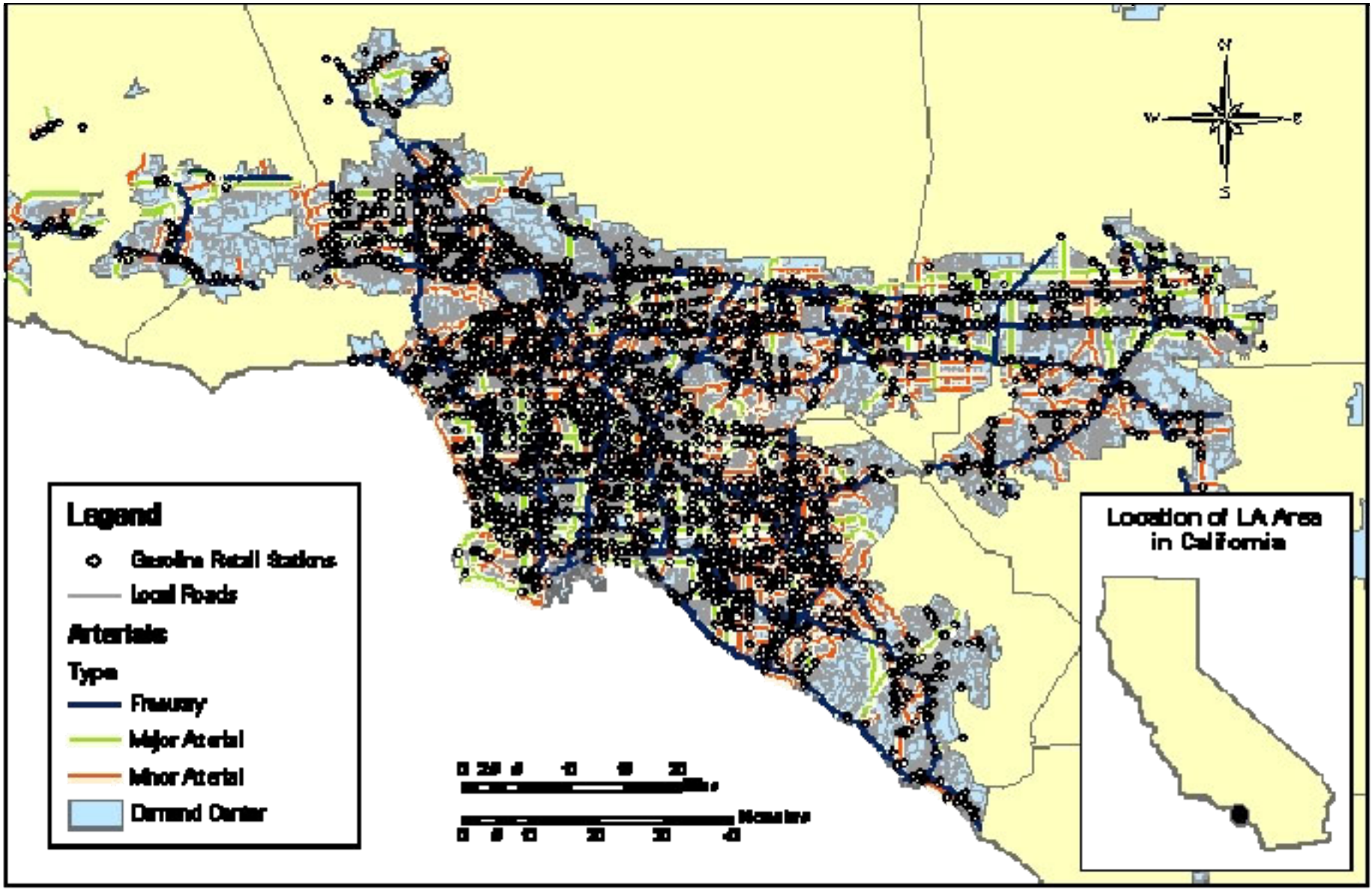
Los Angeles, CA



The layout of stations in a real city is much more complex than the simplified Idealized City Model

How well do idealized city models predict delivery system costs in real cities?

ICM Model Validation

- Compare Real City GIS Station Siting Model (HySS1)

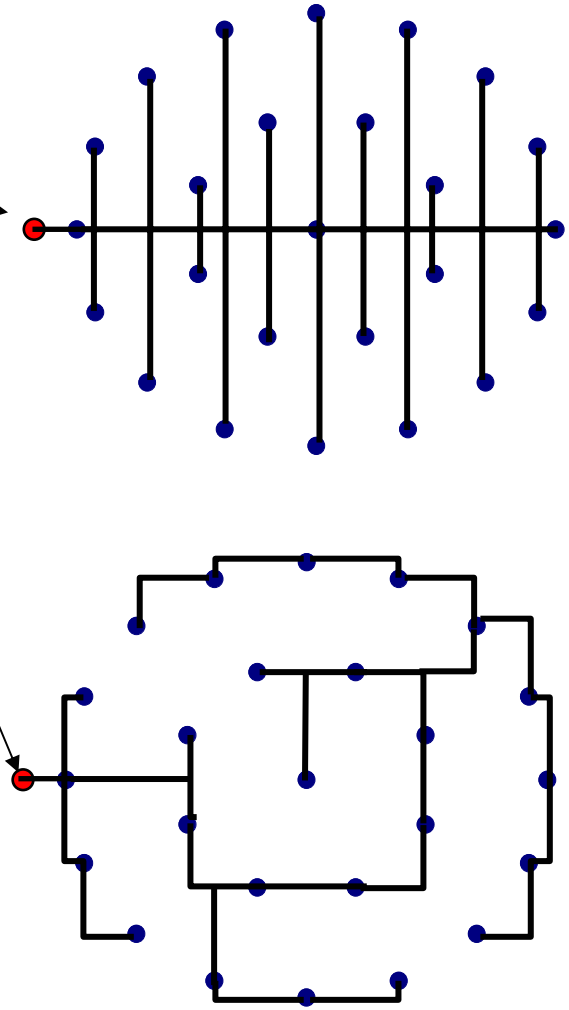
vs. Idealized City Model (ICM)

- Assume the same:
  - Hydrogen Flow
  - Number of Refueling Stations
- Delivery costs depend on *Distances*
- Distance is main metric for comparison of these two models

Calculating H_2 Distribution Distance

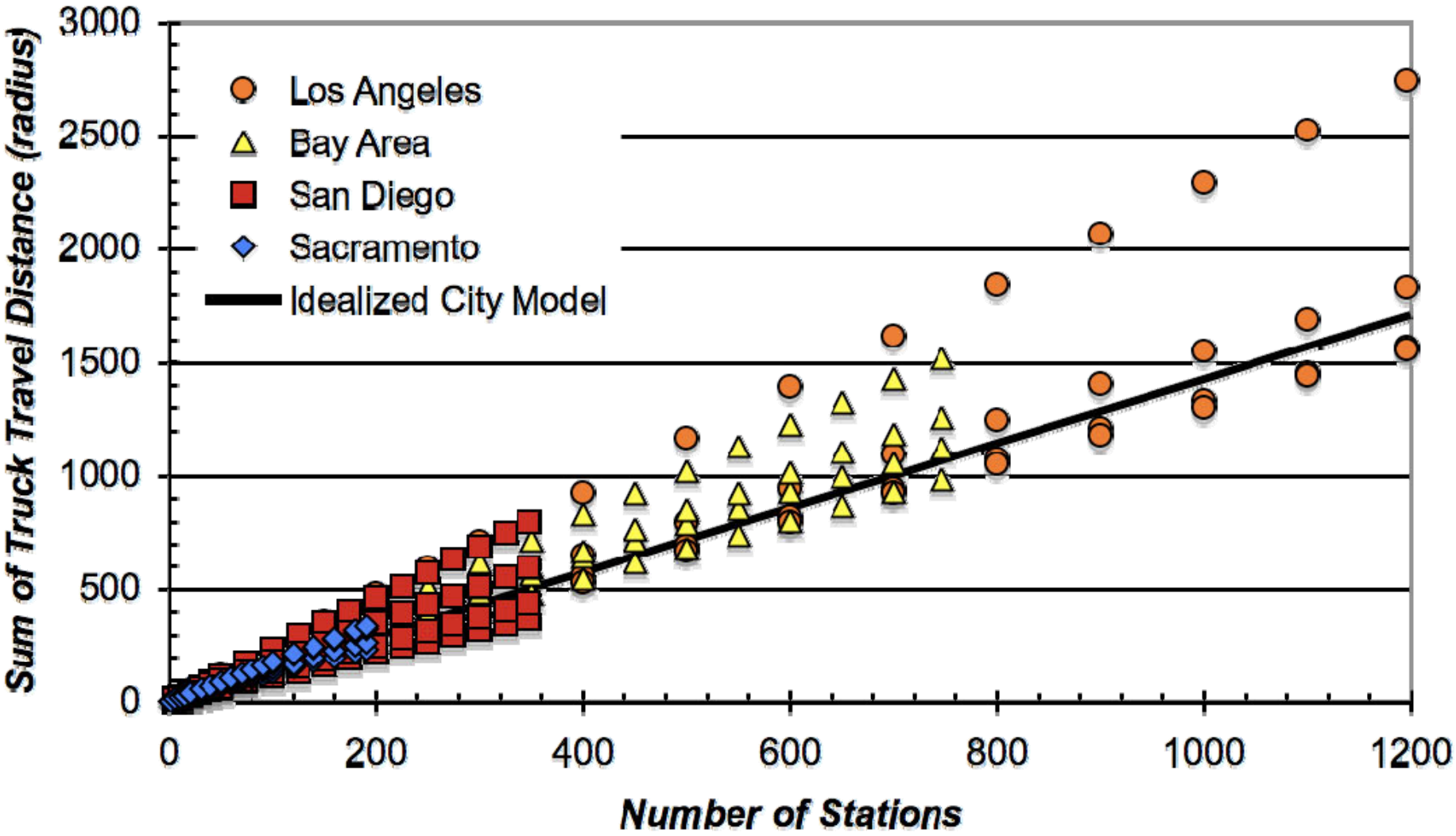
Assumptions

- **Depot is at city gate (edge of city)**
- **Trucks**
  - **Only one station per H_2 load**
  - **Use arterial road network for real-city case studies**
  - **Use rectilinear road network for idealized city case studies**
- **Pipelines**
  - **Stations are connected in a minimal spanning tree (MST) network**
  - **Use arterial roads as rights-of-way for real-city case studies**
  - **Use grid-constrained, rectilinear network for idealized cities**

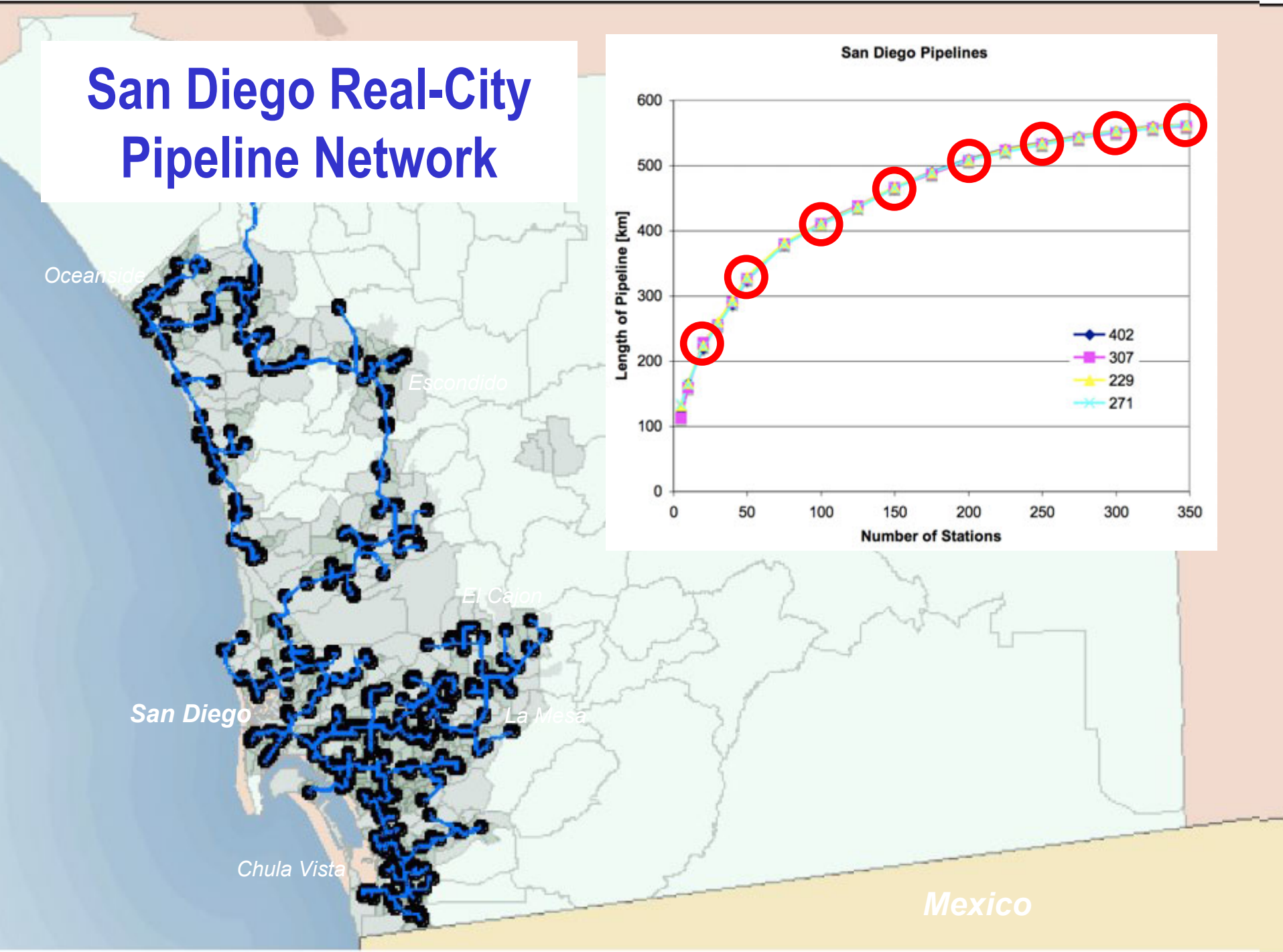


Truck Distances: Real-City vs. Ideal

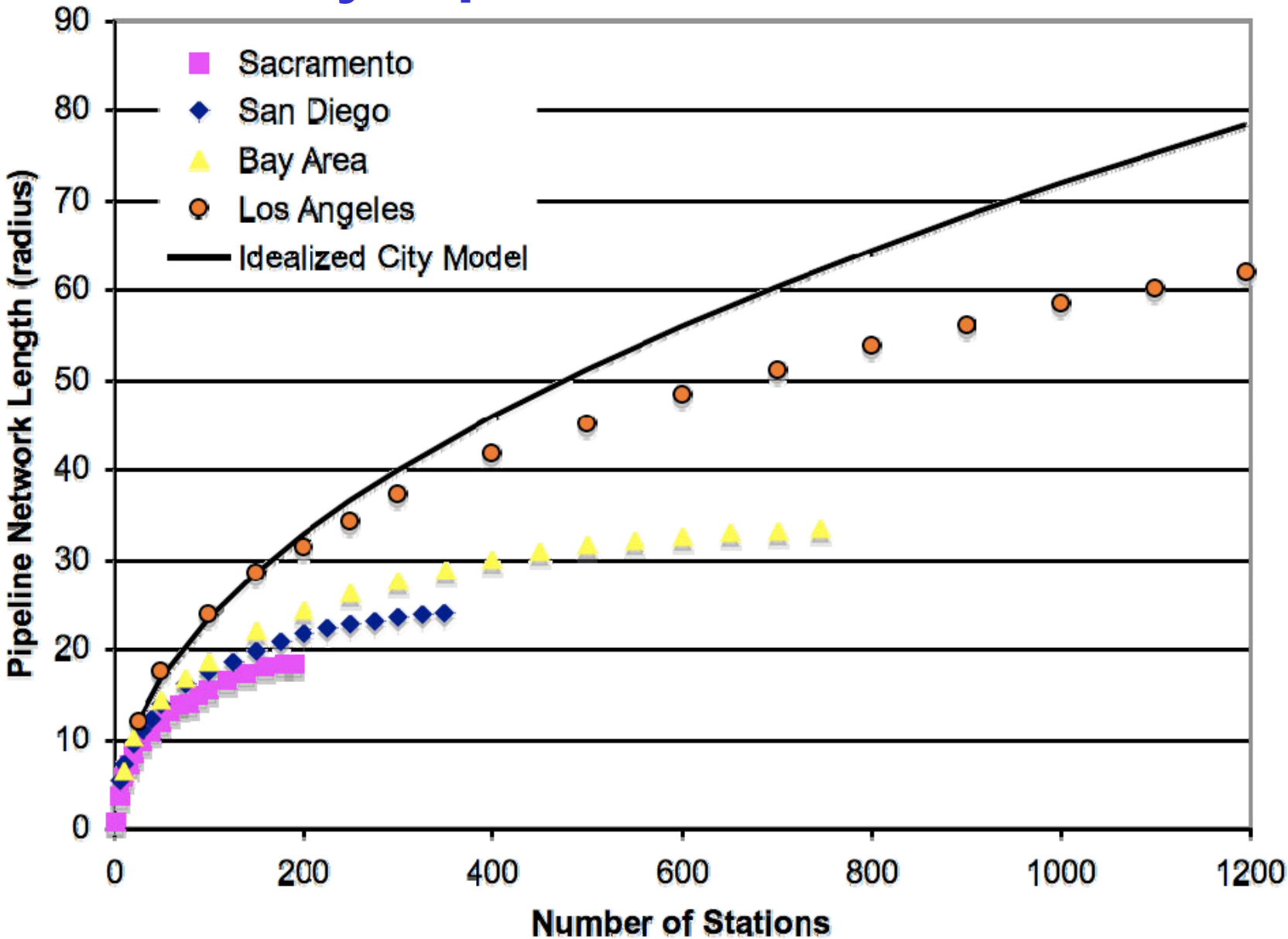
with 4 different depot locations



San Diego Real-City Pipeline Network

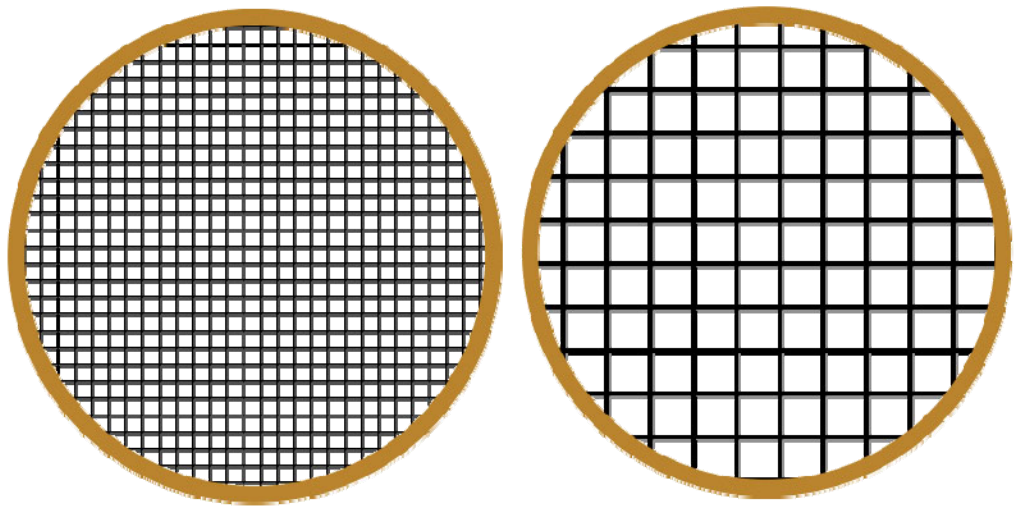


Real City Pipeline Networks vs ICM



Grid-Constrained ICM

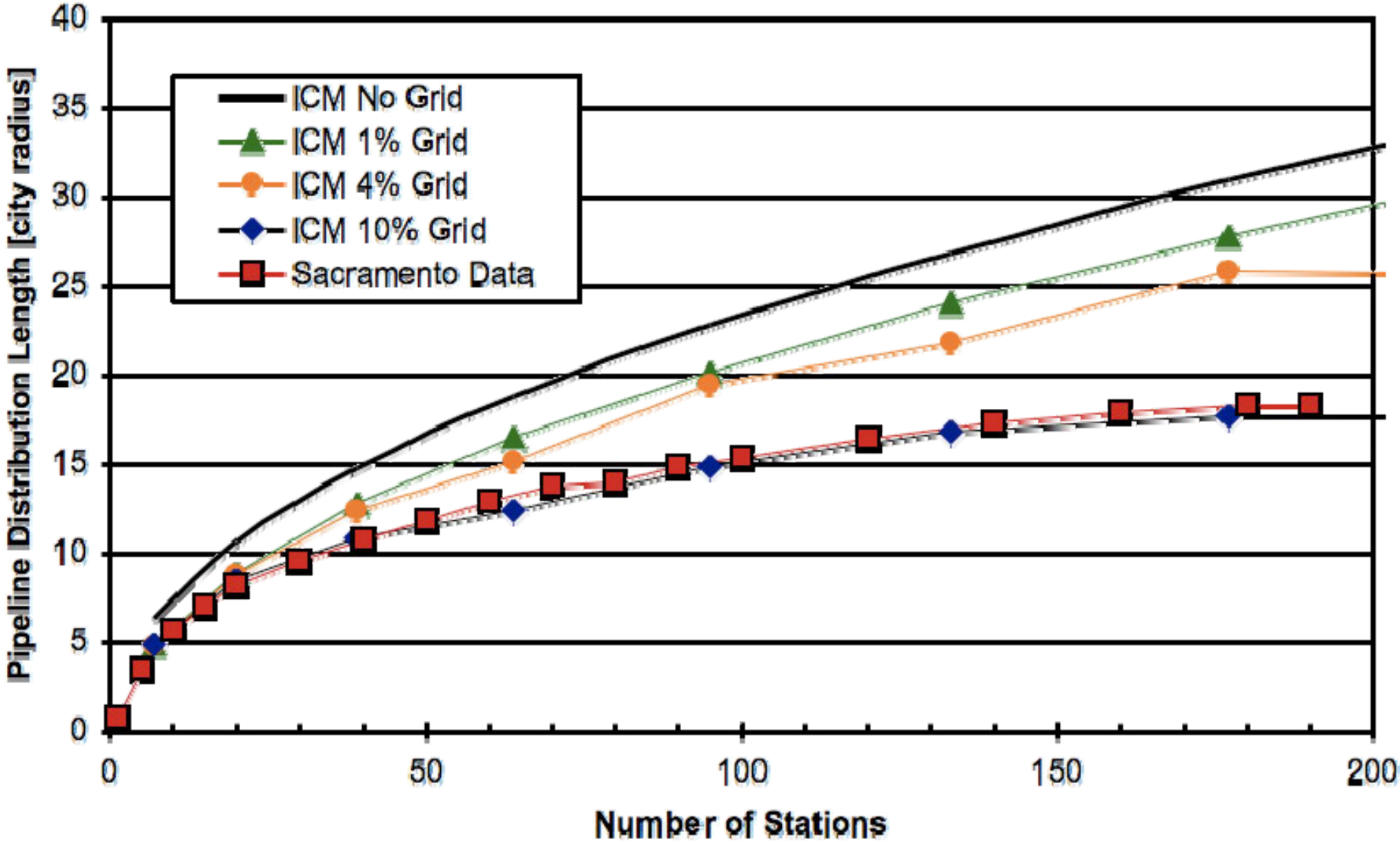
- **Problem**: If stations are evenly spaced, idealized city model *over-estimates* pipeline lengths
- **Solution**: Constrain stations to lie along a "grid" of evenly-spaced major roads in the city
- A city can be characterized in terms of:
  - The size (radius or area)
  - Spacing of major road network (length or density)
- If we normalize for city radius:



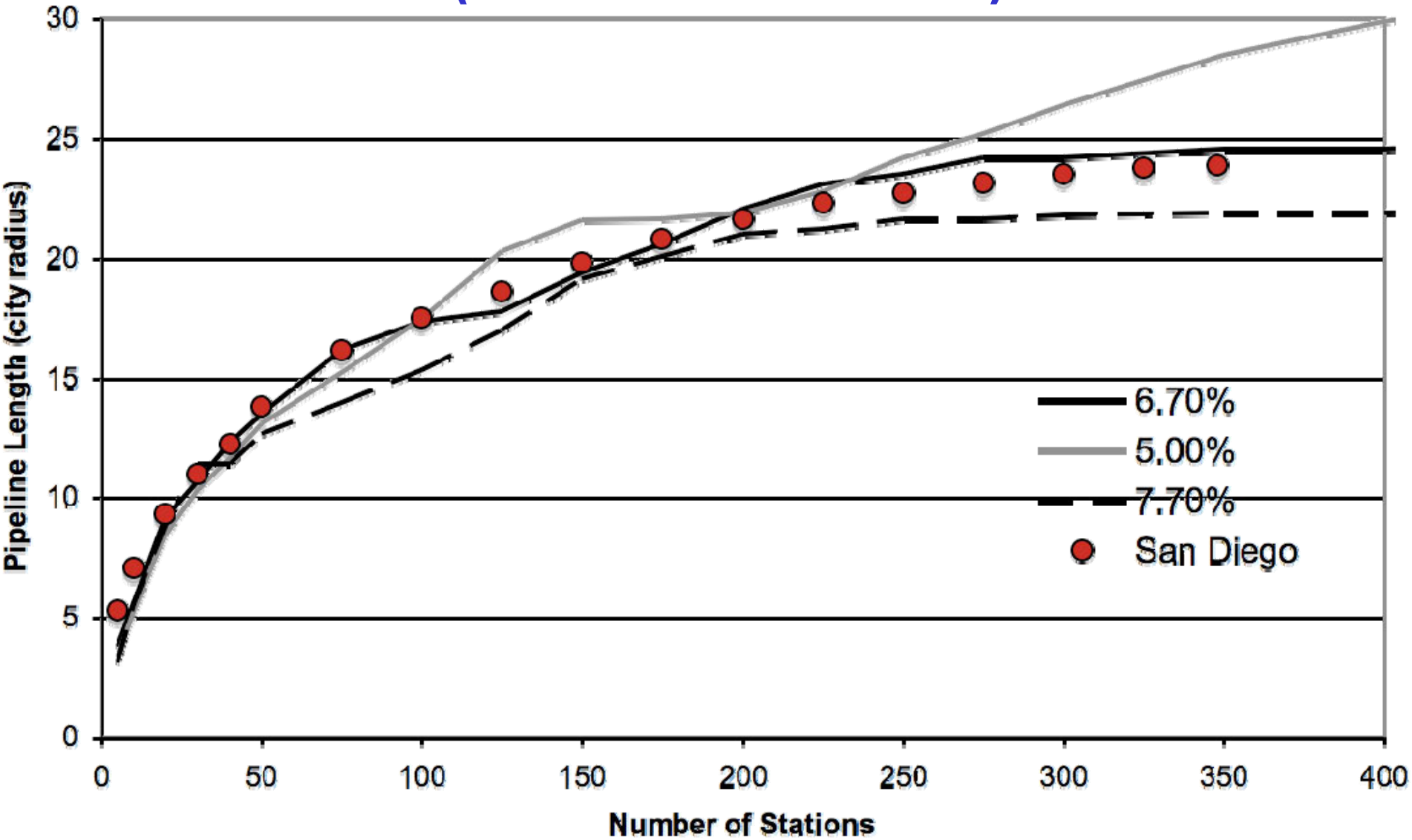
Input Data for Grid-Constrained ICM

Parameter	Sacramento	San Diego	Bay Area	Los Angeles
Area (km^2)	888	1746	2936	4360
City Radius (km)	16.8	23.6	30.6	37.3
Arterial Road Length (km)	564	1189	3030	5391
Arterial Road Length (radius)	33.5	50.4	99.1	144.7
Arterial Road Density (km/km^2)	0.6	0.68	1.03	1.24
Arterial Road Density (R/R^2)	10.7	16.1	31.6	46.1
Grid Spacing	10.0%	6.7%	3.3%	2.2%
Stations	304	632	1246	3355
Station Density ($/km^2$)	0.34	0.36	0.42	0.77

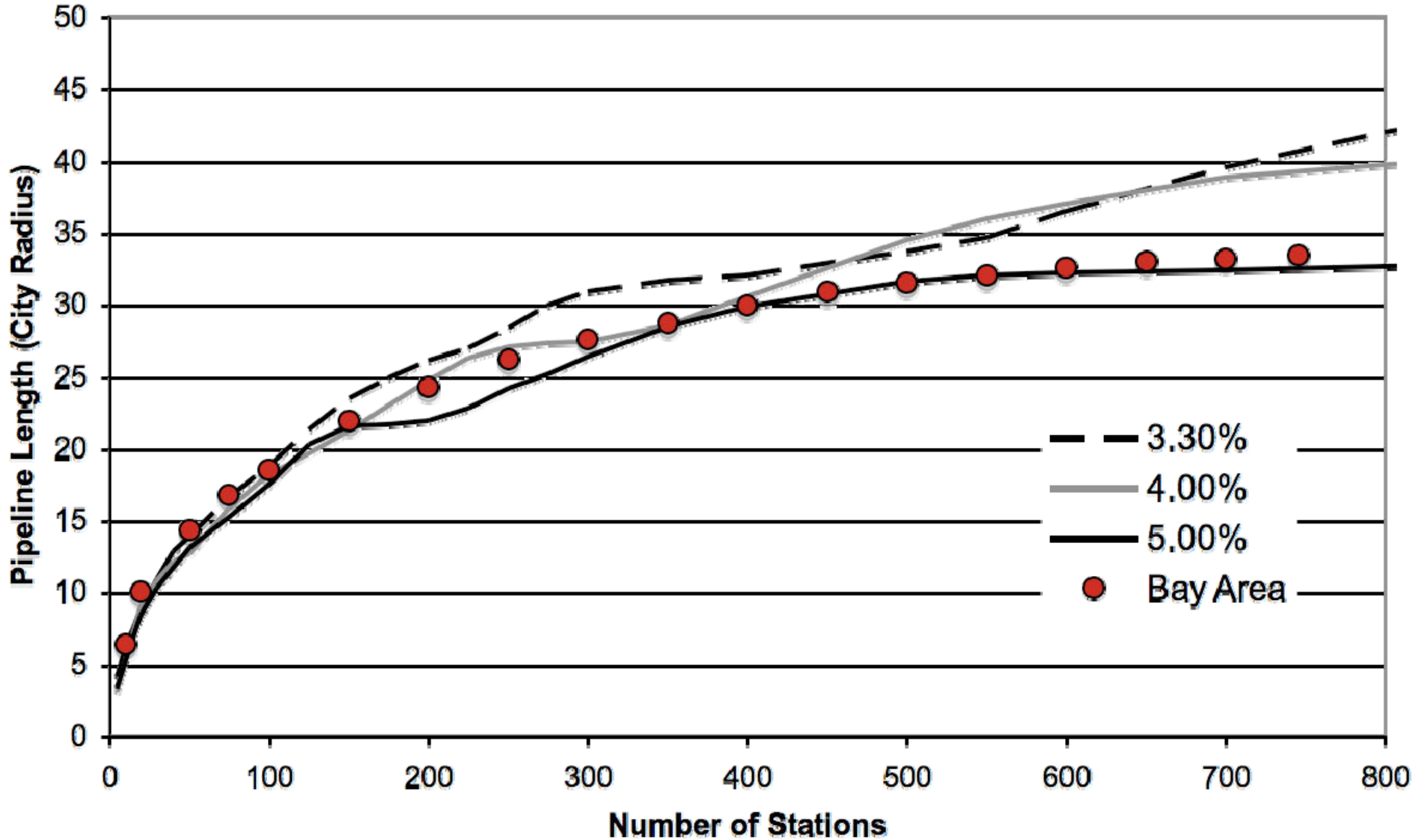
Sacramento Pipeline Network Distances



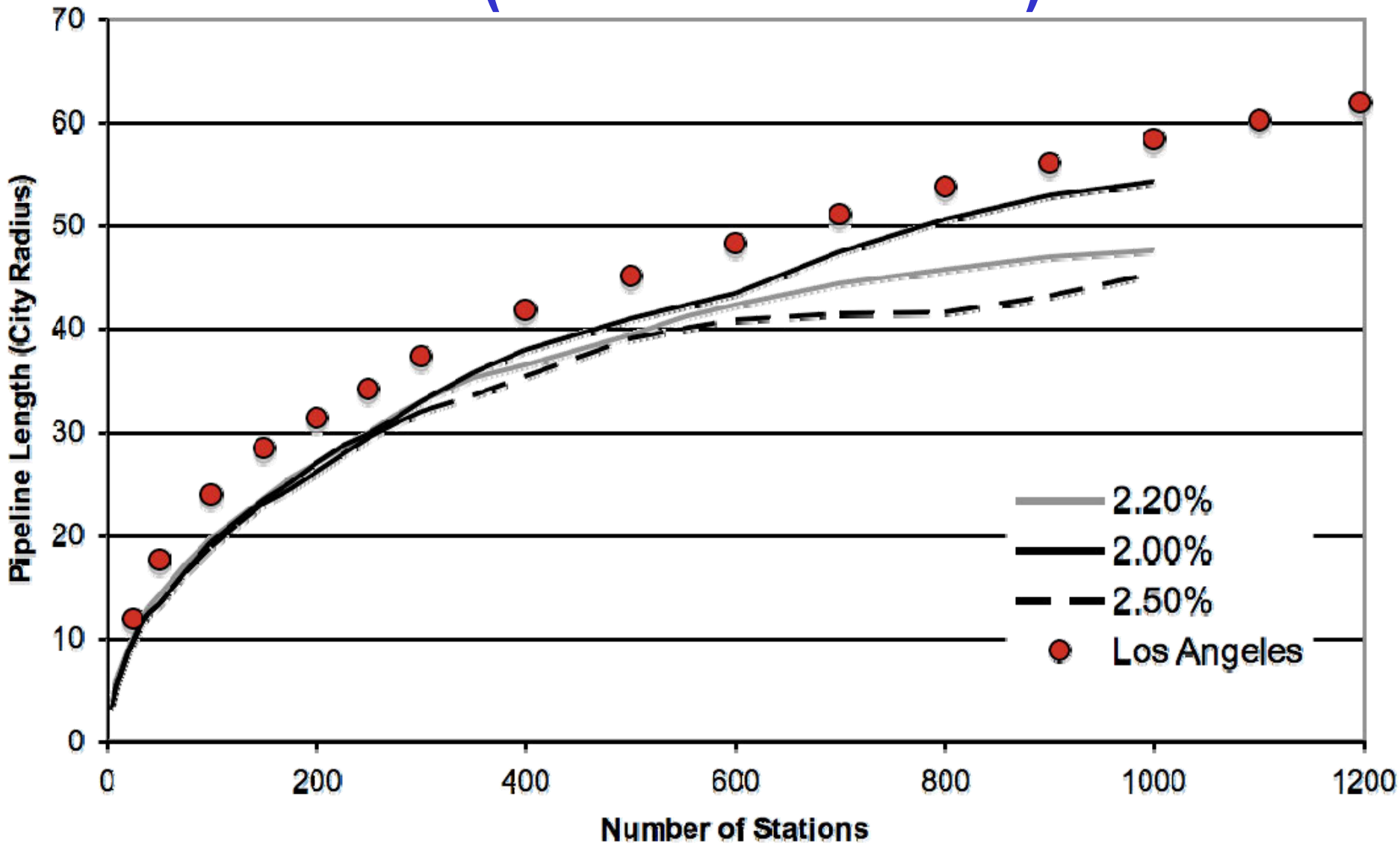
San Diego Pipelines vs ICM (Grid constrained)



Bay Area Pipelines vs ICM (Grid constrained)



Los Angeles Pipelines vs ICM (Grid constrained)



Validation of Idealized City Model

- **Trucks**
  - Good agreement between ICM and real-city models
- **Pipelines**
  - Real-city pipeline length saturates as station number approaches the number of existing gasoline stations
  - ICM agrees with real-city distribution network *if* stations are constrained to lie along an evenly spaced grid of major roads.
- **We have developed ideal city model that predicts real-city delivery lengths quite accurately.**
- **Next steps**
  - Validate with more cities
  - Improve models (correlate grid spacing w/easily obtained data)
  - Look at distribution of station sizes and mixed delivery modes
  - Incorporate into next version of H2A delivery model?

Task 3: Coordinate with H2A delivery team and DOE transition analysis efforts

- Attended DOE H2 analysis workshops in DC (January 2006)
- Presentations to DOE H2 Transition Modeling Team (March 2006)
- Presentations to H2A Delivery Team (April 2006)

Response to Previous Year Reviewers' Comments

Comments

"The ideal networks could be ground-truthed against actual city layouts and then calibrated to key city characteristics."

This year's work addressed this suggestion from last-year's reviewers.

Future Work

Planned for remainder of FY'06

- **We have developed an ideal city model that predicts real-city delivery lengths quite accurately.**
- **Next steps**
  - Validate with more cities
  - Improve models (correlate grid spacing w/easily obtained data)
  - Look at distribution of station sizes and mixed delivery modes

Proposed for FY'07

- **Collaborate on areas where UCD Models might be incorporated into next version of H2A delivery models**
  - **Station siting and sizing; distribution of sta. sizes**
  - **Near-term station costs**
  - **Pipeline lengths and layout**
- **Improve and extend UCD regional transition models to assist in DOE Transition analysis efforts (case studies in CA and NE)**

Additional slides

Publications and Presentations (1)

J. Ogden, “Hydrogen System Modeling at UC Davis,” presentation at the National Renewable Energy Laboratory, Golden, CO, July 7, 2005.

J. Ogden, “The Hydrogen Economy,” invited plenary talk at the 26th Annual Pittsburgh Coal Conference, Pittsburgh, PA, September 15, 2005.

The Transition to Hydrogen. Ogden, Joan. *Access Magazine*. Fall 2005. UCD-ITS-RP-05-22.

J. Ogden, “Pathways Toward an Affordable Hydrogen Infrastructure: Insights from the H2 Pathways Program at UC-Davis,” presented to the Steering Committee of the California Fuel Cell Partnership, Davis, CA, October 18, 2005.

J. Ogden, “The Outlook for Hydrogen as an Energy Carrier,” invited lecture at Humboldt State University, Arcata, CA, October 21, 2005.

J. Ogden, “Strategies for Developing H2 Infrastructure: Insights from the H2 Pathways Program at UC-Davis,” presented at the 5th Annual Meeting of the Canadian Transportation Fuel Cell Alliance, Victoria, BC, October 25, 2005.

J. Ogden, “Hydrogen Infrastructure Prospects,” presented at the Federal Highway Administration Advanced Research Forum on Advancing Future Transportation with Breakthrough Innovations, October 26, 2005, Berkeley, California

Publications and Presentations (2)

Lin, Z., J. Ogden, Y. Fan and D. Sperling, "Optimal Dynamic Strategy of Building a Hydrogen Infrastructure in Beijing," Proceedings of the Fourth Asia Pacific Conference on Transportation and the Environment, November 2005.

J. Ogden and C Yang, “Implementing a Hydrogen Energy Infrastructure: Storage Options and System Design “, Proceedings of the Materials Research Society Fall Meeting, Boston, MA, November 28, 2005.

The Hydrogen Infrastructure Transition (HIT) Model and Its Application in Optimizing a 50-year Hydrogen Infrastructure for Urban Beijing. Lin, Zhenhong; Ogden, Joan; Fan, Yueyue; Sperling, Dan. Proceedings of the Transportation Research Board Annual Meeting, Washington D.C. February 2006. UCD-ITS-RR-06-05.

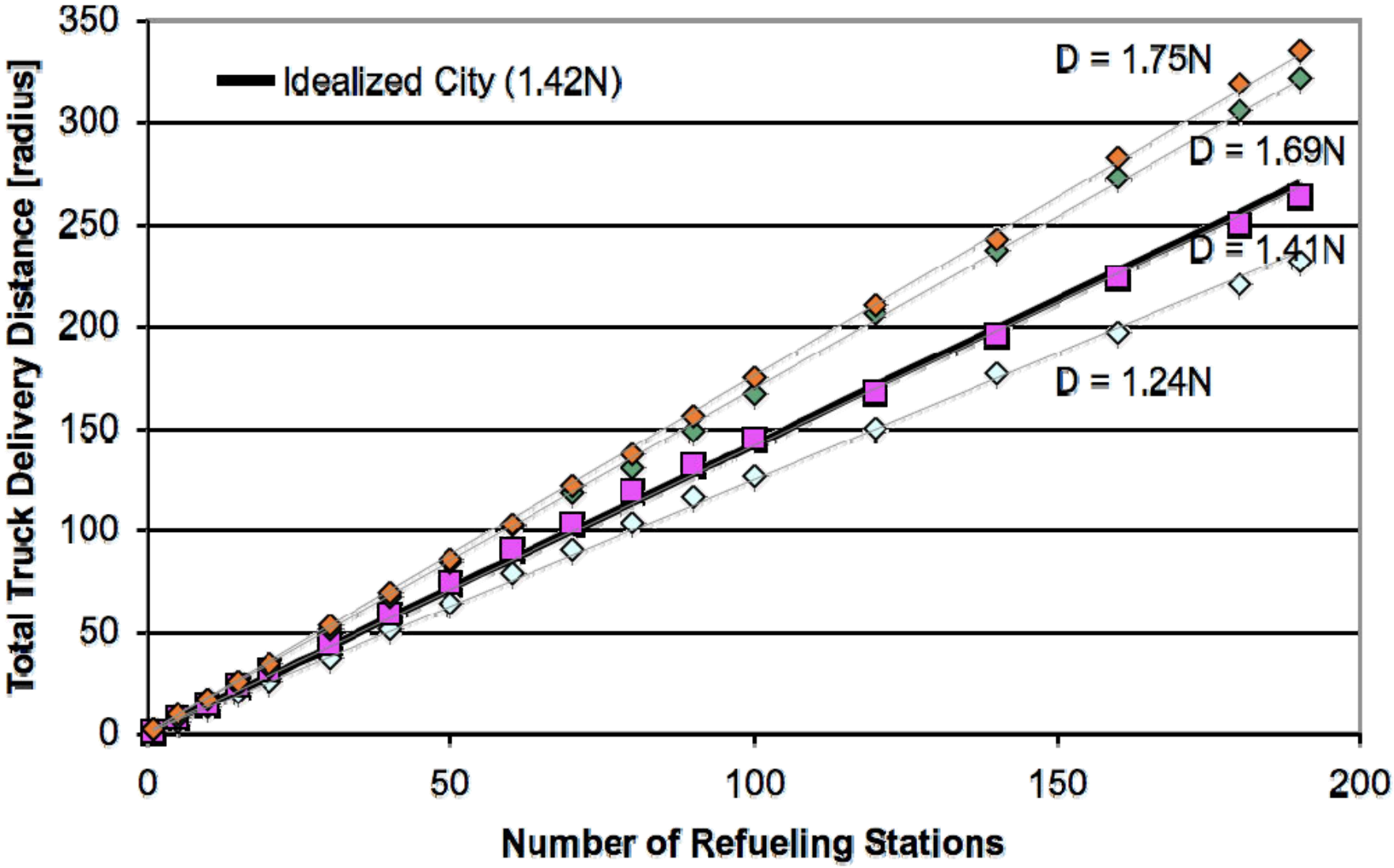
C. Yang, M. Nicholas and J.M. Ogden, Comparison of Idealized and Real-World City Station Siting Models for Hydrogen Distribution, presented at the National Hydrogen Association meeting, Long Beach, CA , March 11-16, 2006.

David Z. Lin, J. Ogden, Y. Fan, D. Sperling, Hydrogen Infrastructure Transitions (HIT) Model, “ presented at the National Hydrogen Association meeting, Long Beach, CA , March 11-16, 2006.

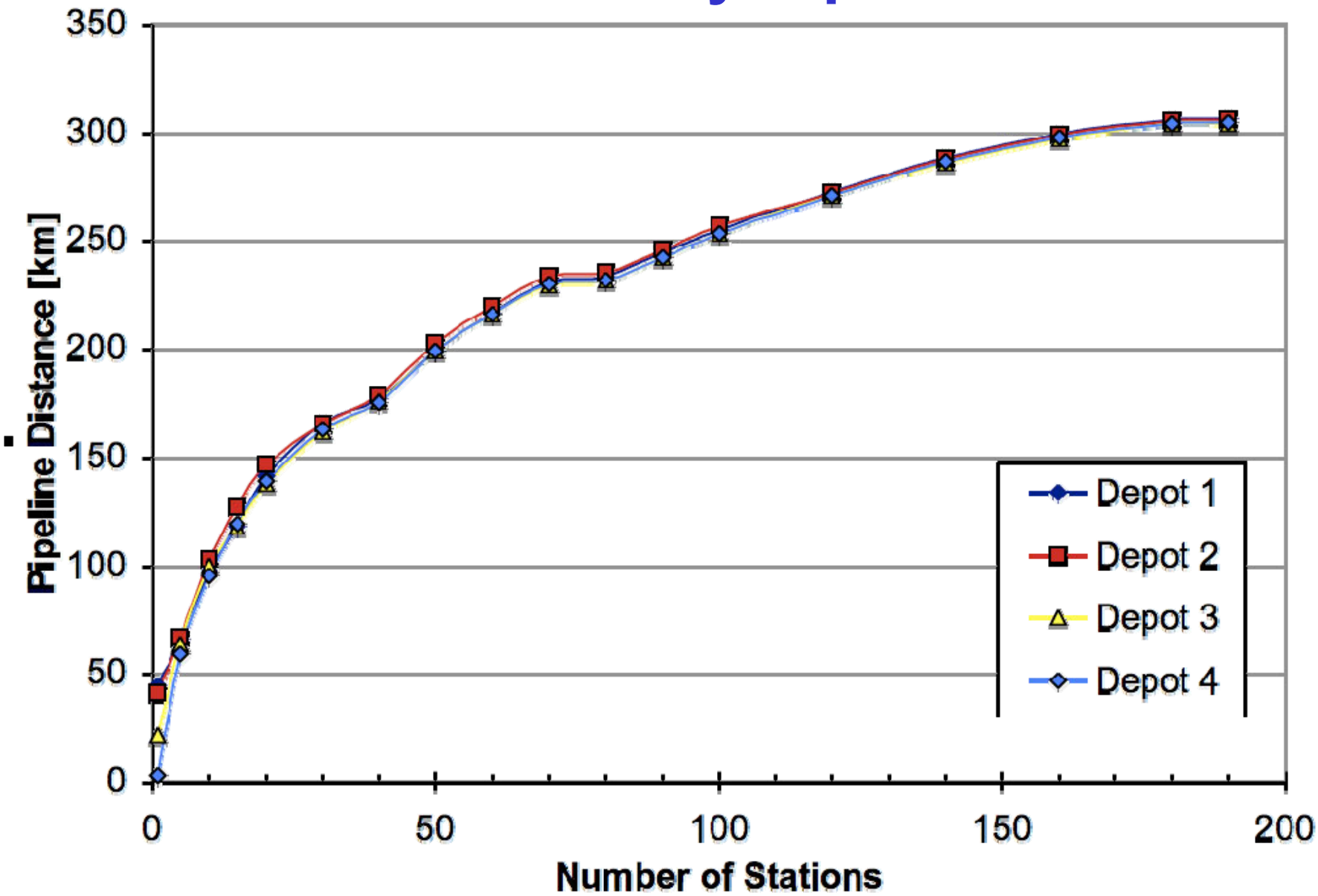
N. Johnson, C. Yang and J. Ogden, “Build-out Scenarios for Implementing a Regional Hydrogen Infrastructure,” presented at the National Hydrogen Association meeting, Long Beach, CA , March 11-16, 2006.

Sacramento Truck Travel Distances

- Real city (w/ 4 different depot locations) vs. ICM



Sacramento Real-City Pipeline Network



Meeting with DOE H2 Transition Modeling Team (March 2006)

- Reviewed recent UC Davis results and discussed their relevance for DOE Transition Analysis
  - UCD Station siting and sizing models. How many stations do we need for coverage? Is 10% the right number?
  - Case studies in Southern California
  - Regional transition models (UCD GIS models)
  - UCD HIT (Hydrogen Infrastructure Transition) Dynamic Programming Model for regional transitions
- Identified areas where UCD Models could complement & assist ongoing DOE Transition Analysis work

Meeting with H2A Delivery Team (April 2006)

- Reviewed recent UC Davis results and discussed their relevance for H2A delivery models
  - UCD Station siting and sizing models. How many stations do we need for coverage? Is 10% the right number?
  - Idealized city delivery models: comparison with designs using real city data
  - Data on near-term refueling station costs
  - System-level storage sizing
- Identified areas where UCD Models might be incorporated into next version of H2A delivery models