Spatio-Temporal Relationship between Land Use and Transportation

Soon Chung and Fang Zhao
Lehman Center for Transportation Research
Department of Civil & Env. Engineering
Florida International University
Miami, FL 33199

Background

- Transportation system shapes cities
- Dependency of automobiles => increased travel demand => more roadways built => urban sprawl
- Urban sprawl results from irresponsible, poorly planned development:
  - Loss of green space
  - Greater demand on infrastructure (Crowded schools, inadequate drainage system, etc.)
  - Rising taxes
  - Increased traffic congestion
- Smart-growth solutions
  - to guide growth into existing areas with mixed use and public transportation options
  - to conserve farmland and open space
- Integrating transportation and land use planning important to achieve smart-growth solutions

Problem Statement

- Changes in the transportation system are usually fed into a land use model assuming an immediate response in land use to transportation improvements.
- Studies of land use and transportation interactions have been limited (e.g., focusing on changes in property values or travel behaviors measured in vehicle-miles traveled).
- More detailed studies are needed to answer a wider range of questions (e.g., patterns of land development, time lags, and growth rate of development)

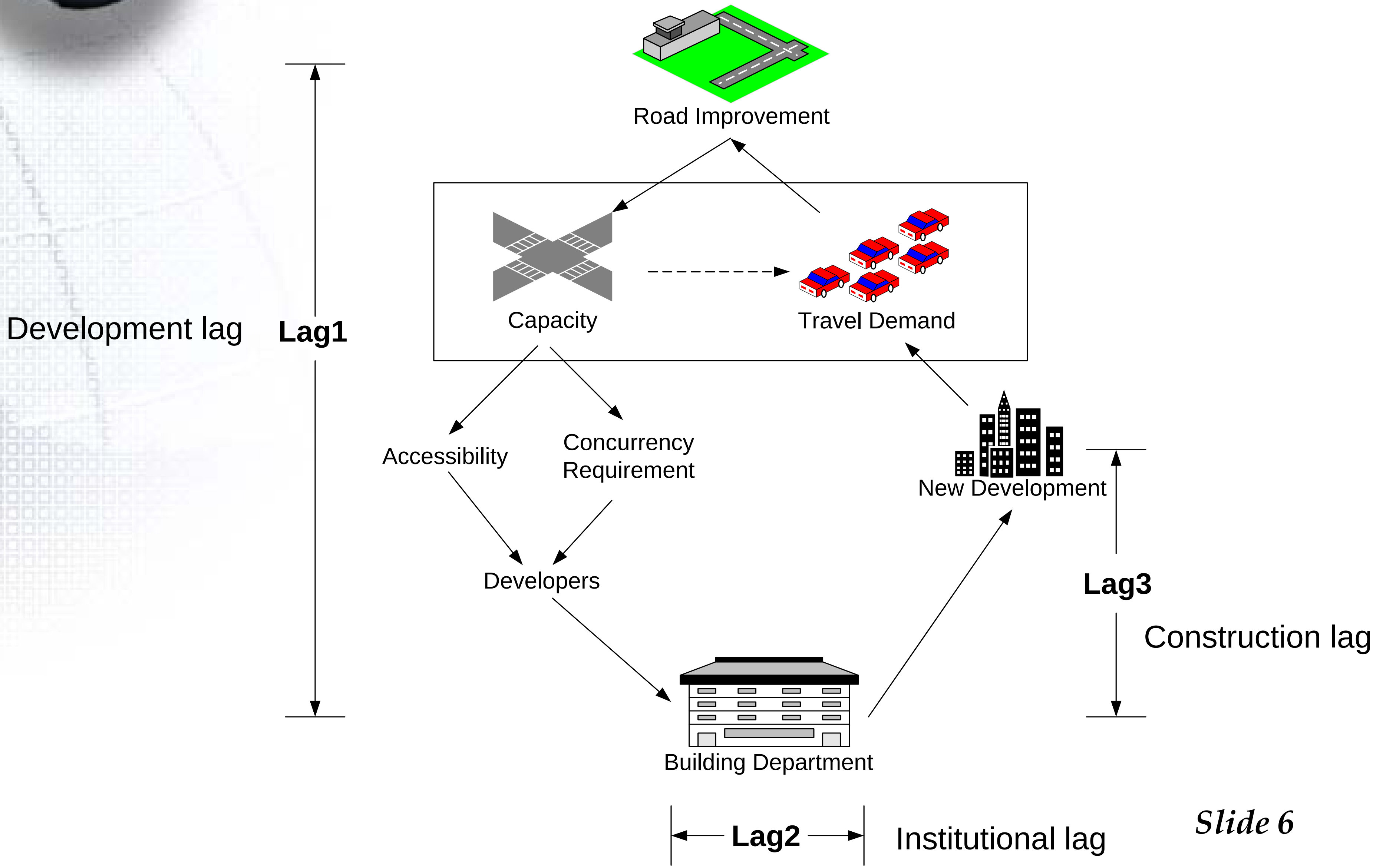
Previous Studies

- Effects of transportation improvements (mainly added capacity) on travel demand at metropolitan scale – Noland (1999), Noland and Cowart (2000), Strathman et al. (2000), Fulton et al. (2000)
- Effects of transportation projects on land development (types and property value change) – Cosby and Buffington (1978a, 1978b, and 1979), Herndon (1980), Buffington et al. (1992), Swenson et al. (1998), Vadali and Sohn (2001)
- Integrated land and transportation models
  - Kim's Chicago model (Southworth 1995)
  - MASTER model (Mackett 1990a, 1990b) (assuming no lag)
  - Dortmund model (Wegener 1986) (assuming 6-year lag between transportation changes and new construction)
- Path model (Cervero 2003) :
  - 2 to 3 years for the addition of lane miles to induce development activity;
  - 3 years for development activity to increase vehicle miles traveled (VMT); and
  - the entire lag structure took 7 to 8 years
  - data for 24 California freeway projects across 15 years

Goals and Objectives

- Gain a better understanding of the mechanisms of land use and transportation interactions;
- Identify data availability and requirement to support research of the same kind;
- Develop a methodology for investigation of the interactions between land use and transportation improvements over time at corridor or sub-area levels;
- Investigate possible causal relationships between land use change and transportation investment; and
- Determine lag effects between them

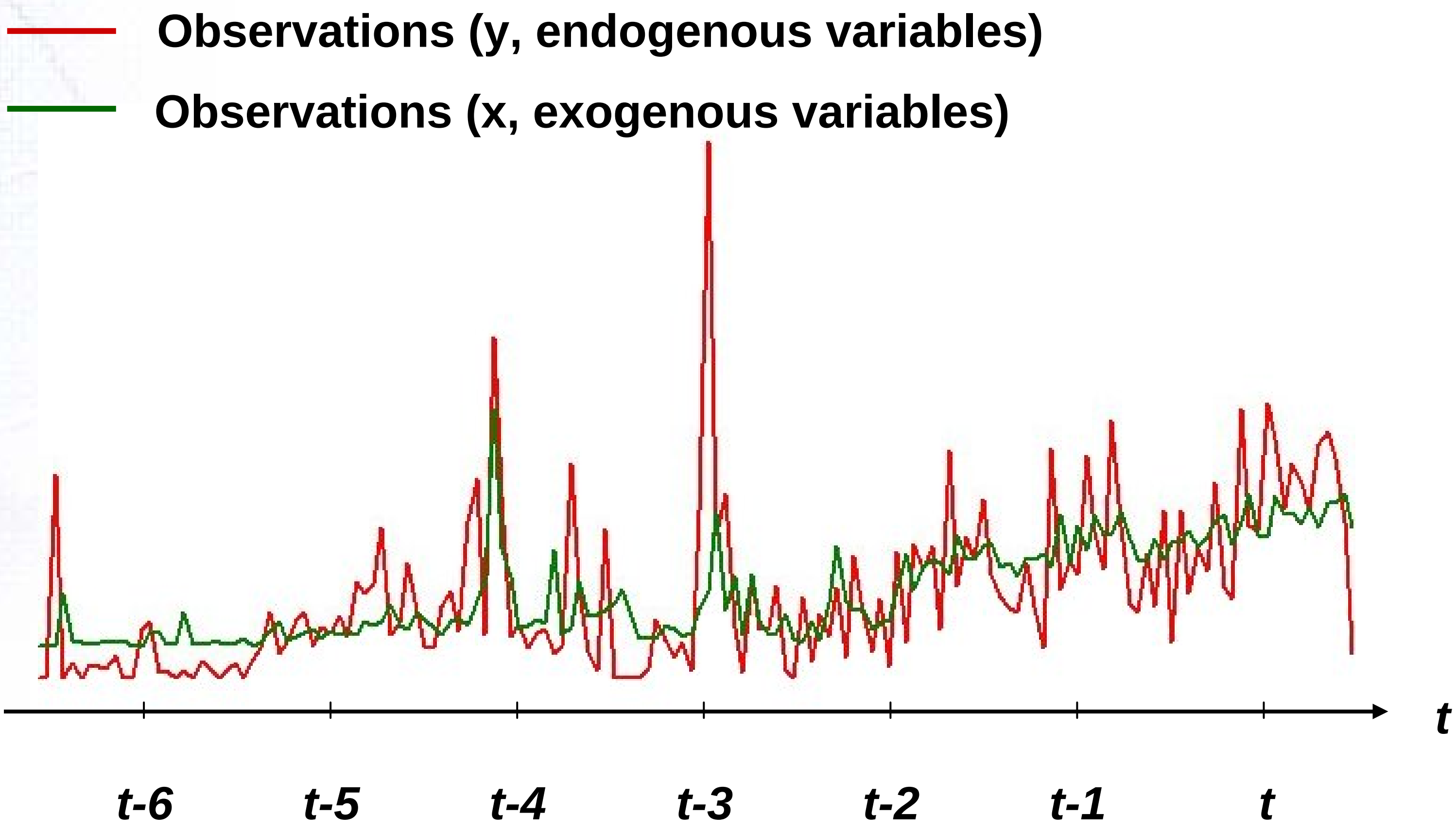
Interactions between Transportation and Land Use



Lag Definitions

- Lag1: time span after the expansion of roadways is completed and before developers apply for building permits for new developments.
- Lag2: an institutional lags for the building department to review applications and issue permits.
- Lag3: the construction period for new developments.

Time Series Analysis



Terms related to Time Series Analysis

- A time series: an ordered sequence of values of a variable observed at equispaced time intervals
  - the following two time series may be observations of two events, X_t and Y_t, at t = 1, 2, …, n: $x_1, x_2, \ldots, x_n$, $y_1, y_2, \ldots, y_n$
- Time series analysis: develop models to describe the dynamic consequences of time series and forecast the future of the system based on historical trends
  - Basic assumption: the time series is stationary
- Lag: a fixed time displacement
  - If there are observations, $y_1, y_2, \ldots, y_n$, over time, the lag between y_2 and y_7 is 5 (= 7 – 2).

Time Series Analysis vs. Regression Analysis

- Regression Analysis
  - Dependent Variables: $y_1, y_2, \ldots$
  - Independent Variables: $x_1, x_2, \ldots$

- Time Series Analysis
  - Dependent Variables: $y_{1,t}, y_{2,t}, \ldots$
  - Independent Variables: $y_{1,t-1}, y_{1,t-2}, \ldots, y_{2,t-1}, y_{2,t-2}, \ldots, x_{1,t-1}, x_{1,t-2}, \ldots, x_{2,t-1}, x_{2,t-2}, \ldots$

VAR with an eXogenous variable

VARX(*p*,*s*)

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix}_t = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \vdots \\ \delta_N \end{bmatrix} + \sum_{i=1}^{p} \begin{bmatrix} \Phi_{11} & \Phi_{12} & \cdots & \Phi_{1N} \\ \Phi_{21} & \Phi_{22} & \cdots & \Phi_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ \Phi_{N1} & \Phi_{N2} & \cdots & \Phi_{NN} \end{bmatrix}_i \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix}_{t-i} + \cdots + \sum_{j=0}^{s} \begin{bmatrix} \Theta_1 \\ \Theta_2 \\ \vdots \\ \Theta_N \end{bmatrix}_j [x]_{t-j} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_N \end{bmatrix}_t$$

where δ is a constant

Φ is a matrix containing autoregressive estimated parameters

Θ is a matrix containing model parameters for exogenous variable

ε_t is a purely random process with mean zero

Multipliers Analysis

- To investigate the marginal impact of changes in the exogenous variables

$$D = (\Theta_0 + \Theta_1 L + \ldots + \Theta_s L^s) / (I_N - \Phi_1 L - \ldots - \Phi_p L^p)$$

  - For example, transportation planner or policy maker like to know the effects of a change in toll price.

Restricted System

- Coefficients not significantly different from zero may be interpreted in two ways:
  - no causal relationship
  - not enough information in the data to provide sufficiently precise estimates with confidence intervals that do not contain zero
- Large estimation uncertainty for the VARX coefficients leads to poor forecasts and imprecise of estimates of the impulse responses and forecast error variance components
- Solution – impose zero coefficients on variables with small parameter estimates

Databases

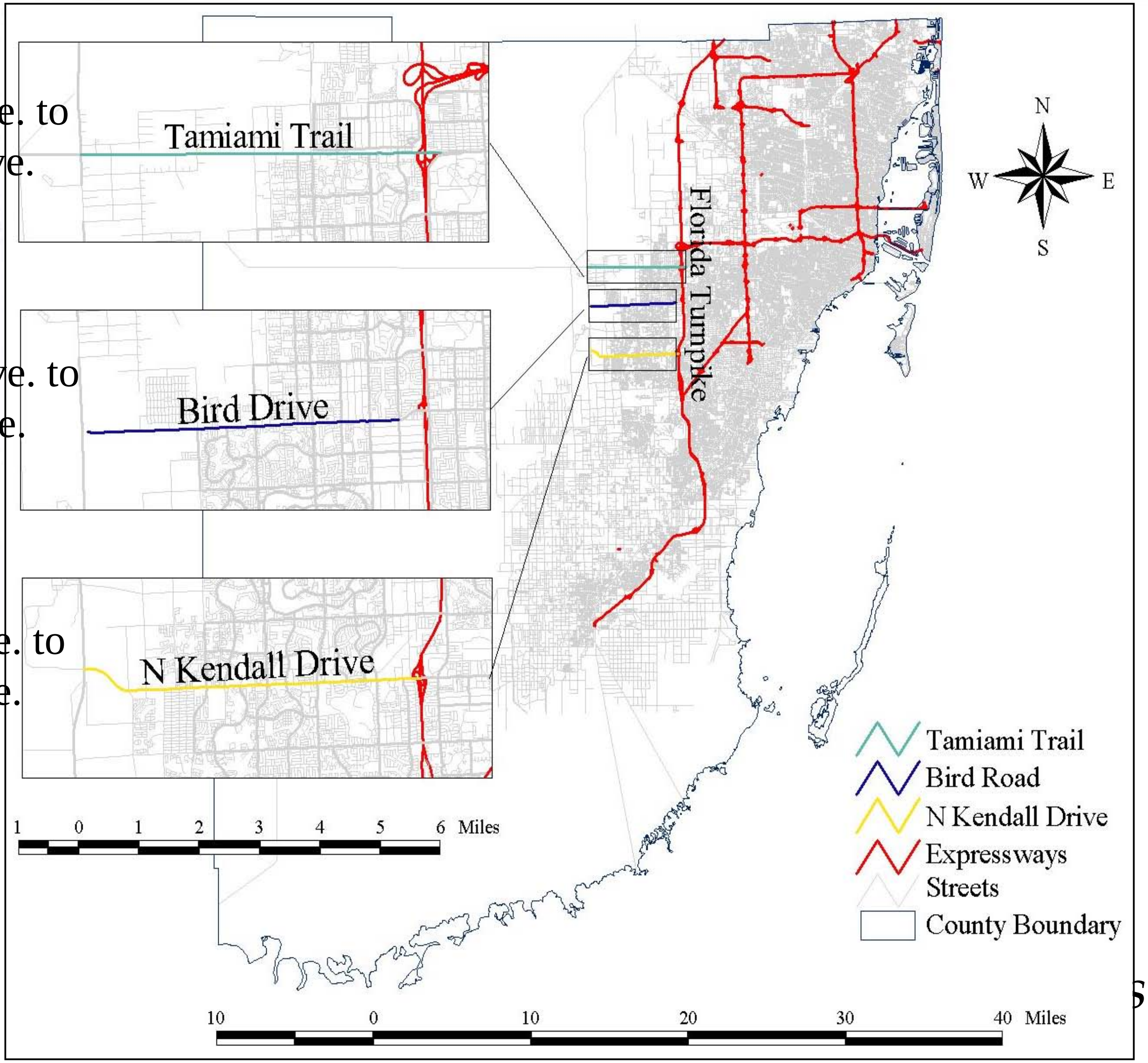
- Transportation improvements (1978 – 2001)
  - From TIP reports
  - Created temporal database
- AADT on state roads (1985 – 2001)
- Property parcel GIS data (2001)
- Property tax data (1992 – 2001)
  - Structure square-footage, year built, use
- Building permit data (1987 – 2001)
  - Construction type, use, dates of application and CO

Locations of Study Areas

SW 112th Ave. to
SW 152nd Ave.

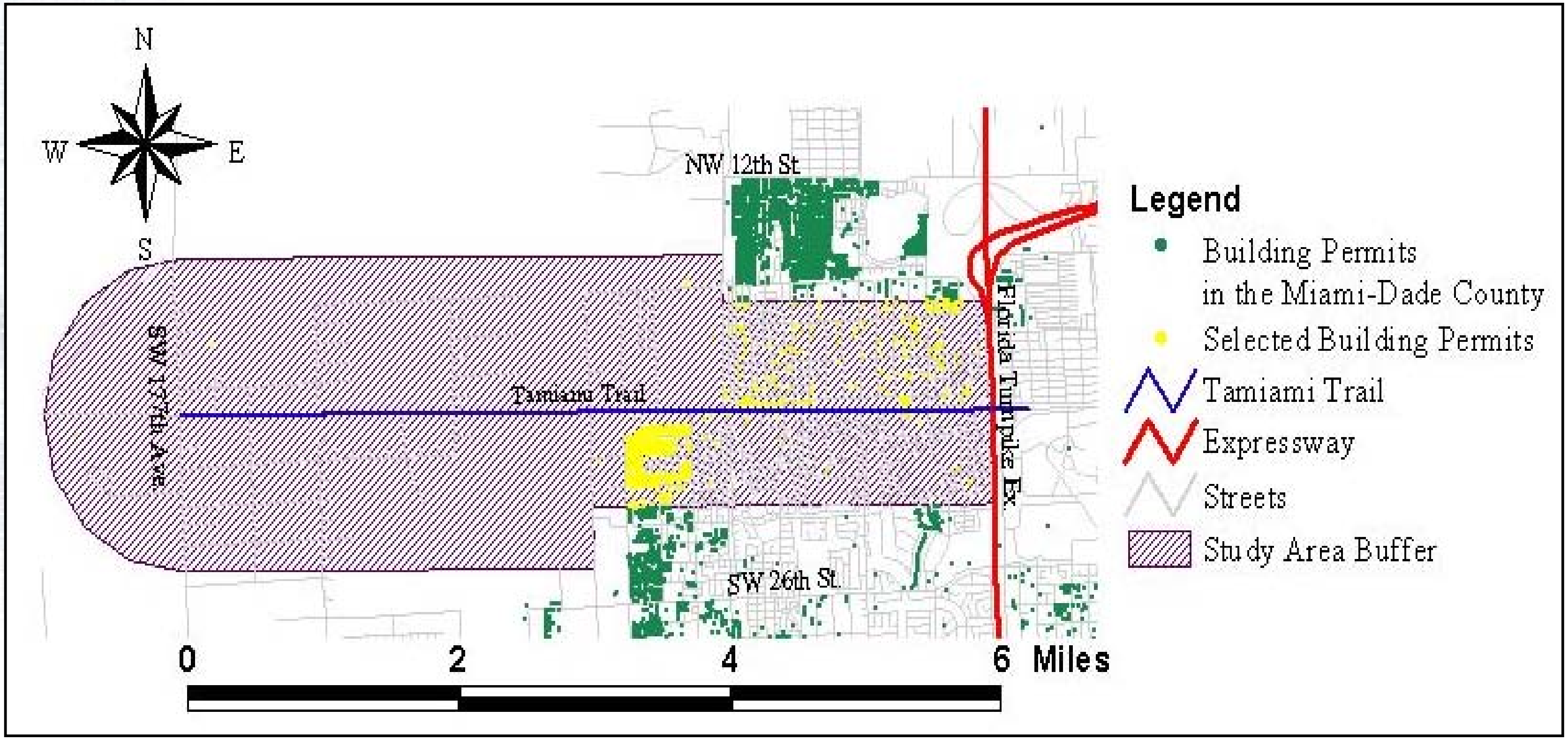
SW 122nd Ave. to
SW 177th Ave.

SW 117th Ave. to
SW 177th Ave.



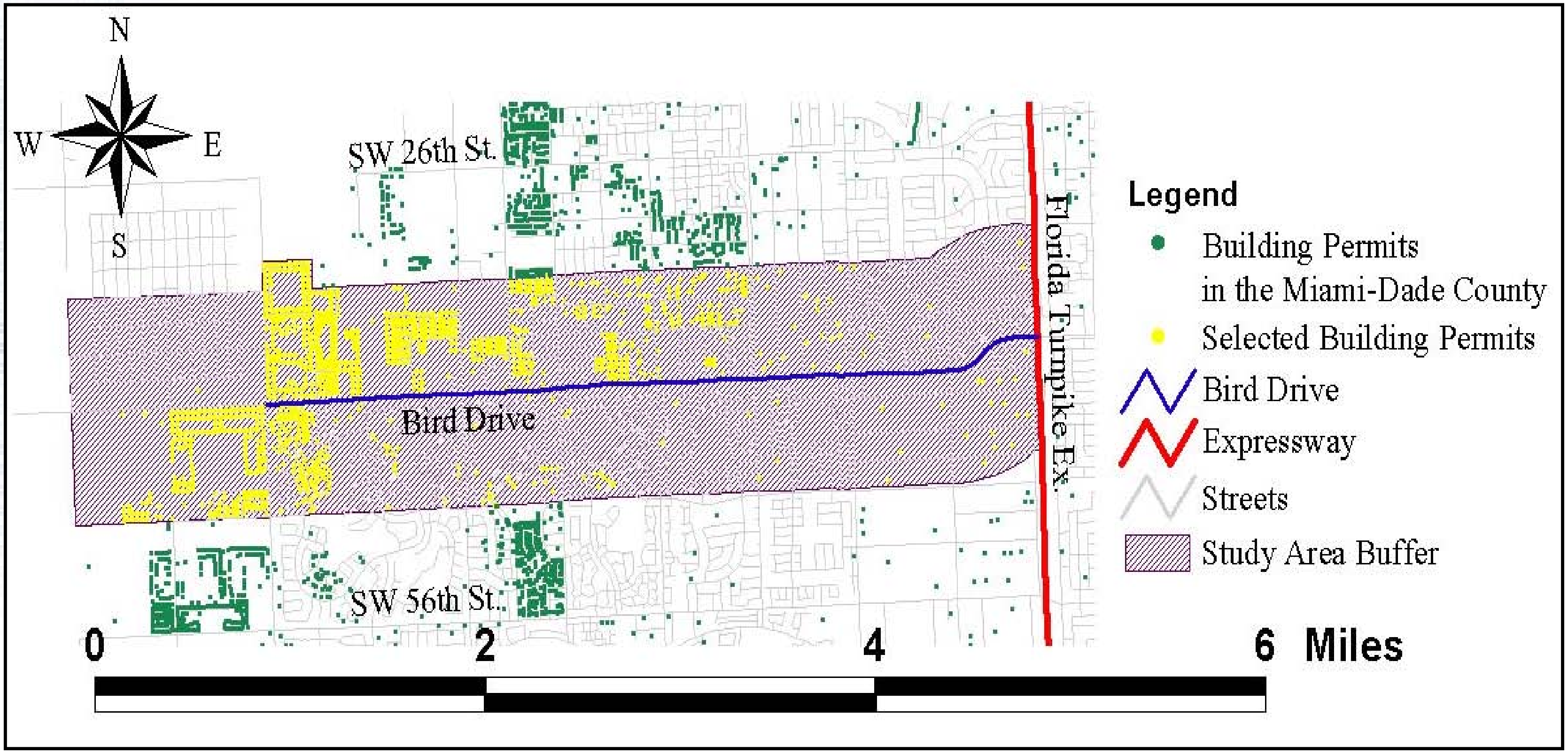
Distribution of Selected Building Permits

Tamiami Trail



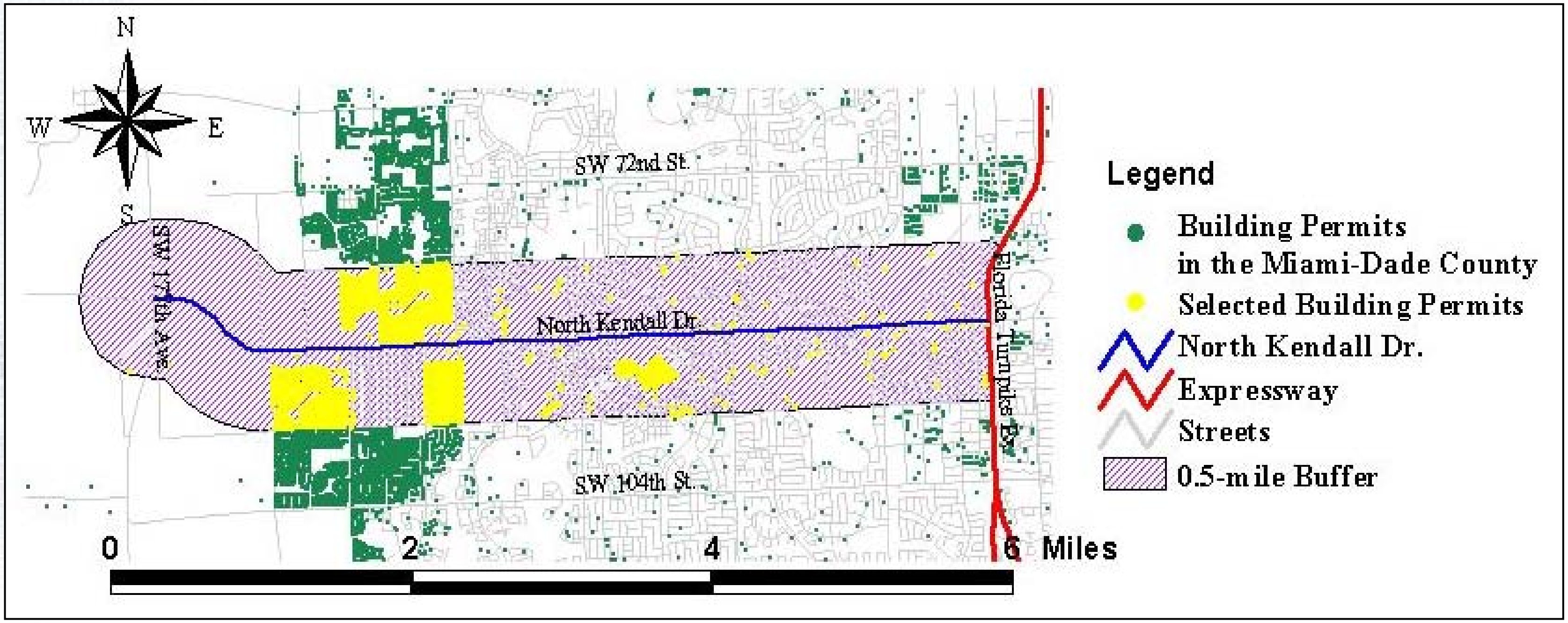
Distribution of Selected Building Permits

Bird Drive



Distribution of Selected Building Permits

North Kendall Drive



Variable Definitions

Total Developments (*dtotal*):

$$dtotal_t = \sum_{i=1}^{N} (BLDG\_TOTAL)_{i,t}$$

Commercial Developments (*dcom*):

$$dcom_t = \sum_{i=1}^{N} (BLDG\_COM)_{i,t}$$

Residential Developments (*dres*):

$$dres_t = \sum_{i=1}^{N} (BLDG\_RES)_{i,t}$$

where

N:	number of building permits within a study area in month *t*,
BLDG_TOTAL:	building square footage for all types of use measured in 1000 sq-ft
BLDG_COM:	building square footage for commercial use measured in 1000 sq-ft
BLDG_RES:	building square footage for residential use measured in 1000 sq-ft

Variable Definitions (2)

Lanemile:

- An Index to represent Transportation Improvements

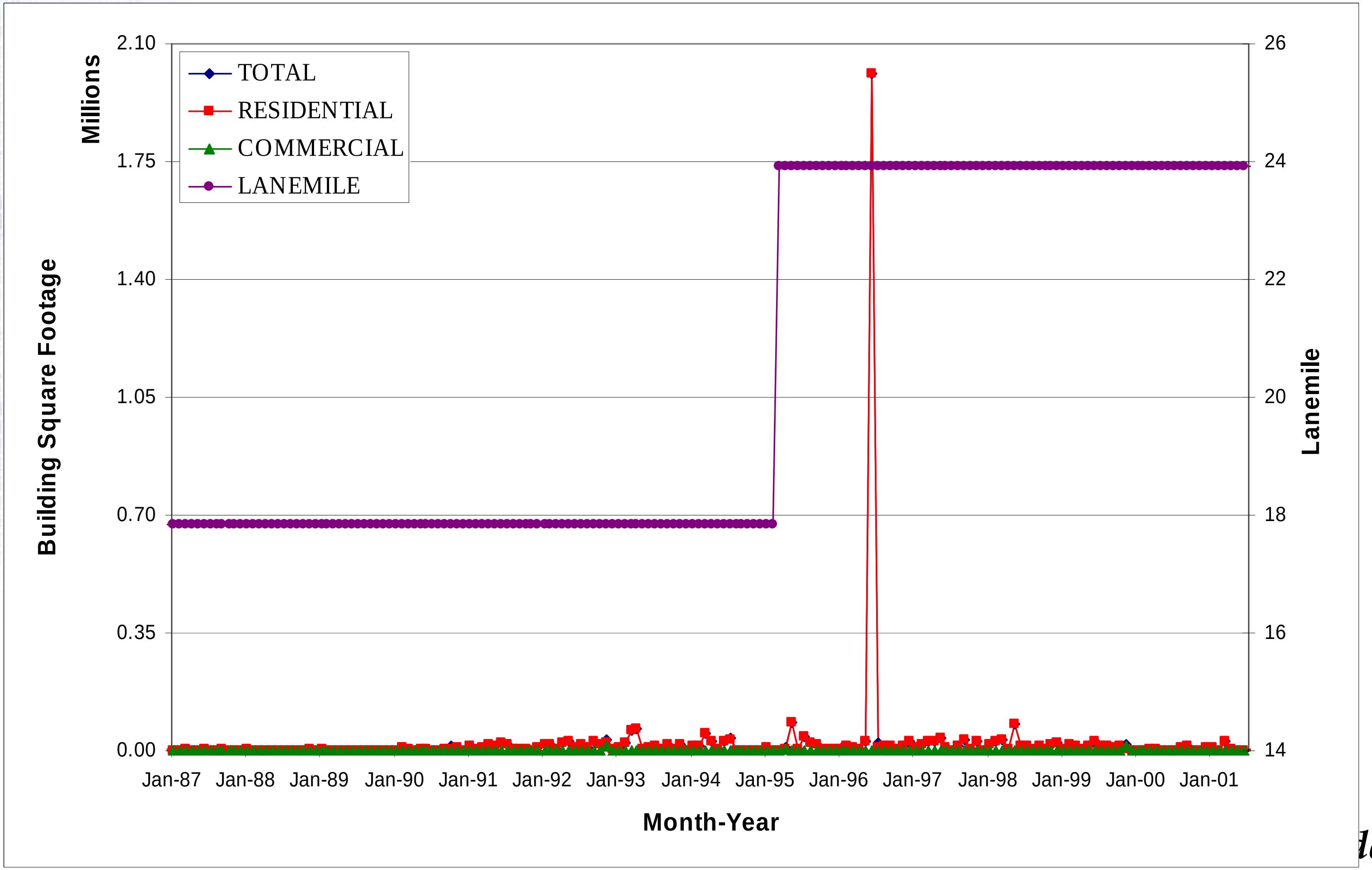
  Lanemile = number of lane × length of section
- Sample Calculation (North Kendall Drive)
  - FL TURNPK ~ SW 132nd Ave (1.15 miles): 4 lanes to 8 lanes
  - SW 132nd Ave ~ SW 152nd Ave (2.06 miles): 4 lanes to 6 lanes
  - SW 152nd Ave ~ SW 177th Ave (2.46 miles): 4 lanes to 4 lanes
  - lanemile before construction = 4 × 5.67 = 22.68
  - lanemile after construction = 8 × 1.15 + 6 × 2.06 + 4 × 2.46 = 31.4
- $dlamemile_t = lanemile_t - lanemile_{t\text{-}1}$

Summary of TIP for Study Corridors

Corridor	Segment From	Segment To	Length (mile)	Opening Month	Lanes Added	Increase of Lanemiles
Tamial Trail	SW 112th Ave	SW 127th Ave	1.52	04/1995	4	6.08
	SW 127th Ave	SW 137th Ave	1.00	–	0	–
	SW 137th Ave	SW 177th Ave	4.01	–	0	–
	Total		6.53			
Bird Drive	SW 117th Ave	SW 122nd Ave	0.56	02/1994	2	1.12
	SW 122nd Ave	SW 127th Ave	0.50	–	0	–
	SW 127th Ave	SW 142nd Ave	1.50	08/1991	2	3.00
	SW 142nd Ave	SW 147th Ave	0.50	03/1992	2	1.00
	SW 147th Ave	SW 157th Ave	1.00	–	0	–
	Total		4.06			
North Kendall Drive	Florida Turnpike	SW 132nd Ave	1.15	09/1993	4	4.60
	SW 132nd Ave	SW 152nd Ave	2.06	09/1993	2	4.12
	SW 152nd Ave	Krome Ave	2.46	–	0	–
	Total		5.67			

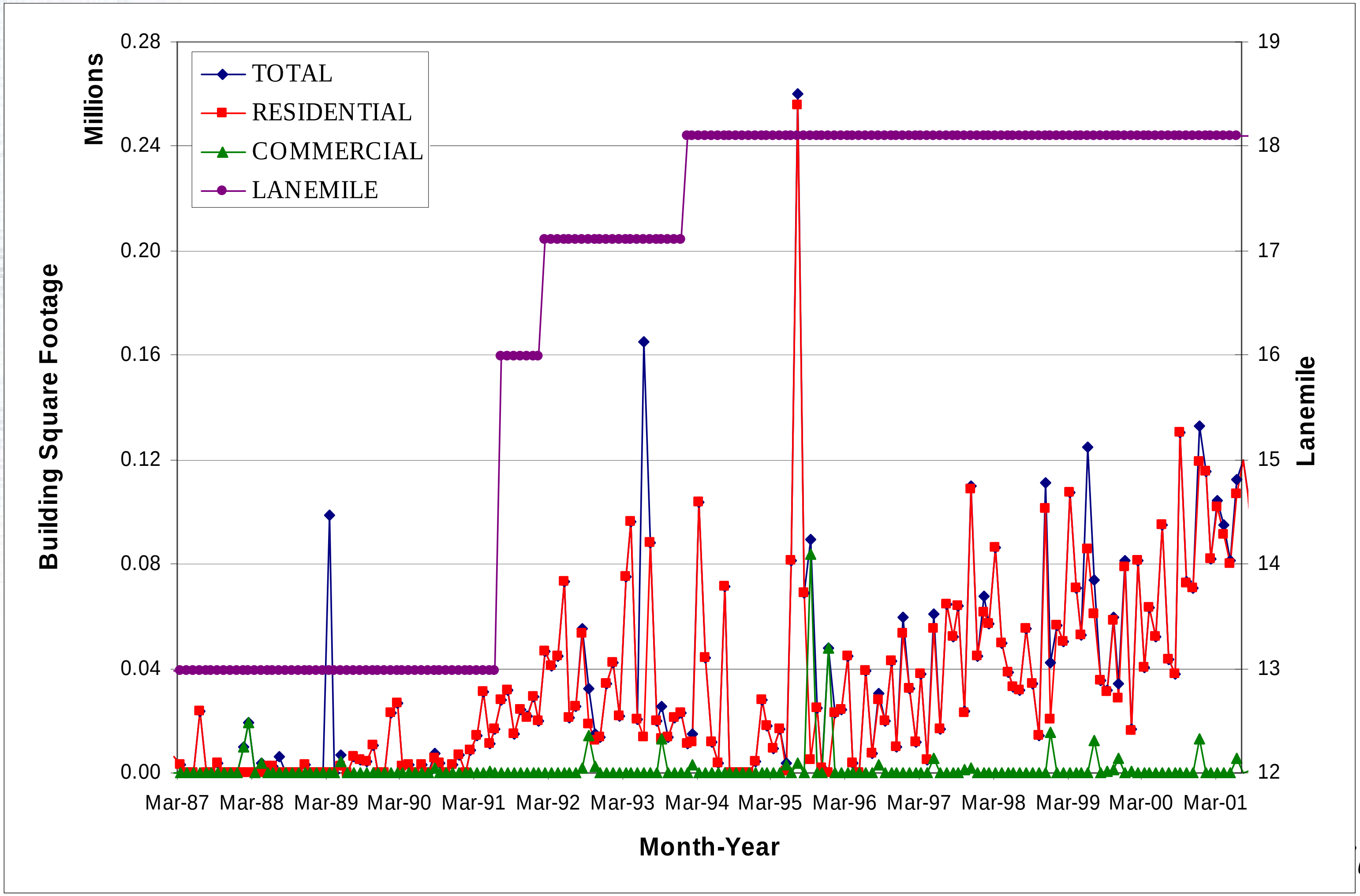
Monthly Building Square Footage for Total, Residential, and Commercial Use

Tamiami Trail



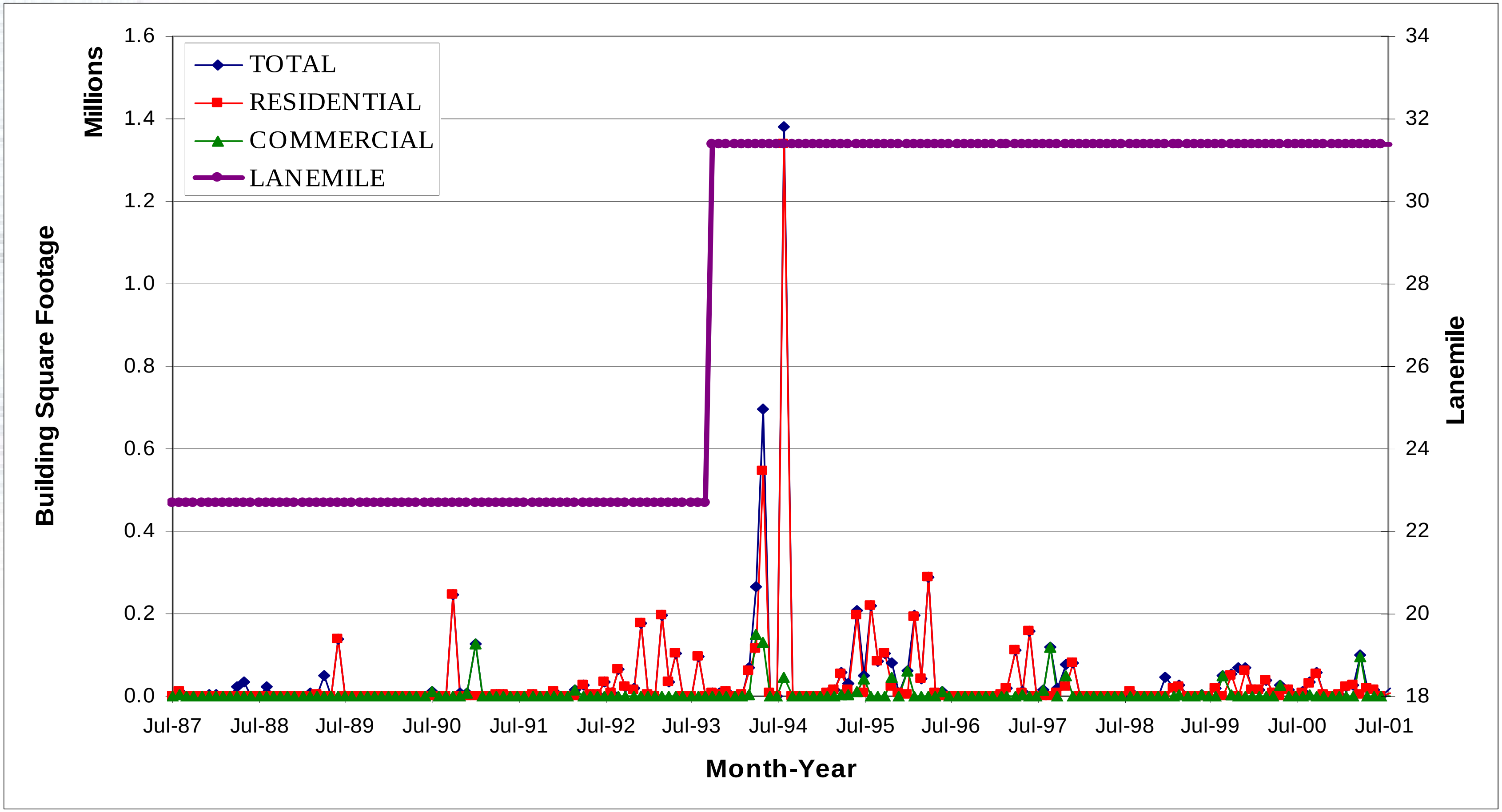
Monthly Building Square Footage for Total, Residential, and Commercial Use

Bird Drive



Monthly Building Square Footage for Total, Residential, and Commercial Use

North Kendall Drive



Model Implementation

- Endogenous Variables
  - Total Building Square Footage of Applied Building Permits for Commercial Use (Y_1)
  - Total Building Square Footage of Applied Building Permits for Residential Use (Y_2)
- Exogenous Variable
  - Lanemile (X)

Restricted Systems

- **Tamiami Trail:**

$dres(t) = 1.379023\times dcom(t\text{-}4) – 1.327276\times dcom(t\text{-}6) + 2.321187\times dcom(t\text{-}16)$
$– 2.324449\times dcom(t\text{-}21) + 0.471442\times dres(t\text{-}1) + 0.011933\times dres(t\text{-}15)$
$+ 0.010363\times dres(t\text{-}17) + 0.034389\times dres(t\text{-}23) – 0.014000\times dres(t\text{-}24)$
$+12.38801\times dlanemile(t\text{-}2) – 6.585278\times dlanemile(t\text{-}3)$
$+ 5.502976\times dlanemile(t\text{-}4) + 327.0074\times dlanemile(t\text{-}15)$
$–154.2895\times dlanemile(t\text{-}16) + 4.638388$

- **Bird Drive:**

$dres(t) = 0.234462\times dres(t\text{-}1) + 22.79471\times dlanemile(t\text{-}18) + 15.76523$
$+ 0.224561\times TrendDummy$

$dcom(t) = 0.388299\times dcom(t\text{-}3) – 0.173641\times dcom(t\text{-}6) + 0.059454\times dres(t\text{-}2)$

- **North Kendall Drive:**

$dres(t) = 0.096\times dres(t\text{-}10) + 0.126\times dres(t\text{-}12) + 0.098\times dres(t\text{-}18)$
$+ 0.099\times dres(t\text{-}20) + 0.648\times dcom(t\text{-}23) + 61.223\times dlanemile(t\text{-}8)$
$+ 151.979\times dlanemile(t\text{-}11)$

$dcom(t) = 0.043\times dres(t\text{-}17) + 16.997\times dlanemile(t\text{-}7)$
$+ 13.804\times dlanemile(t\text{-}8) + 3.695$

Multiplier Analysis

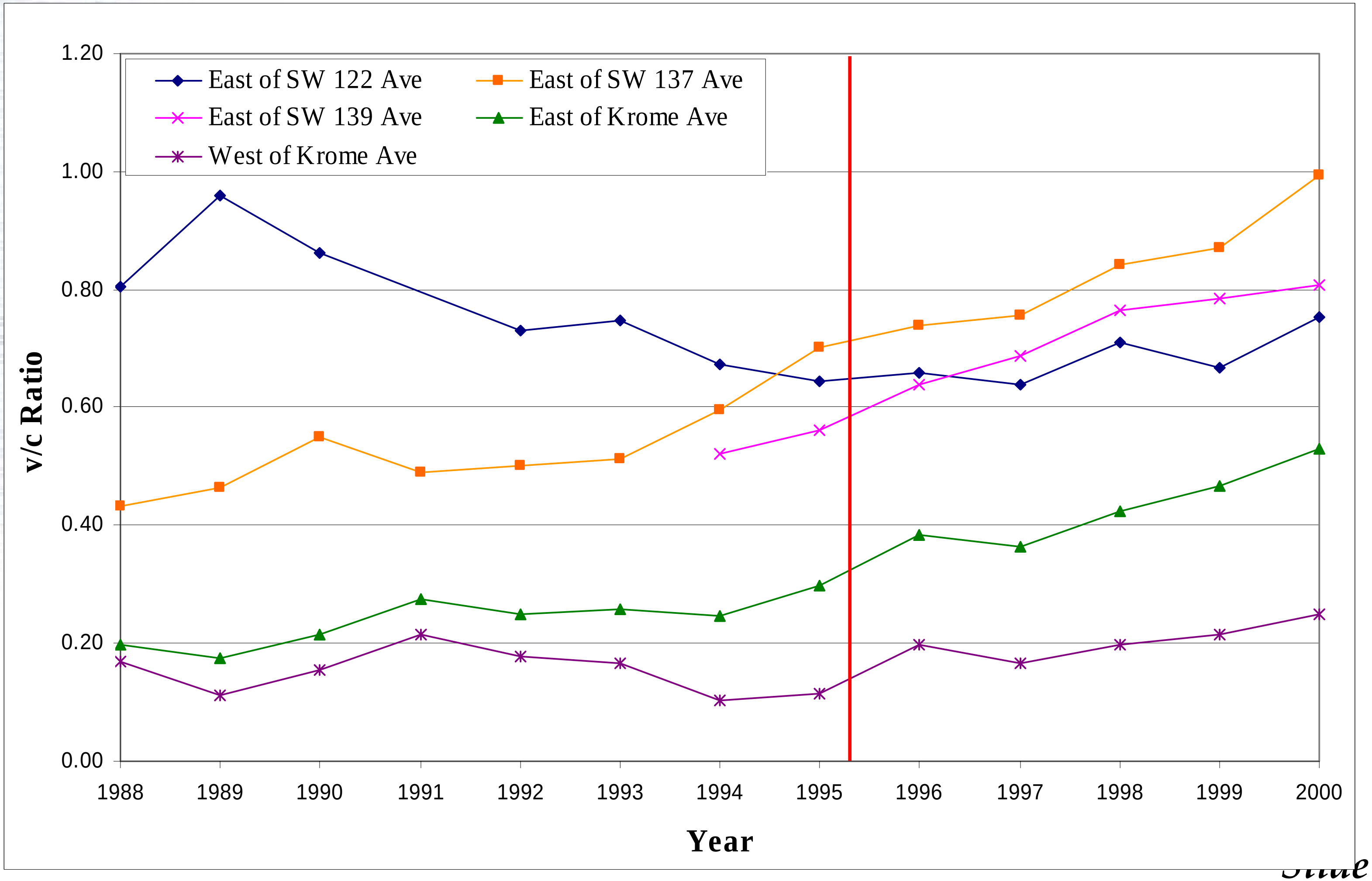
Models	Tamiami Trail	Bird Drive	North Kendall Drive
Commercial Development Model	–	7,632.8	60,654.9
Residential Development Model	345,679.5	38,945.8	349,765.2

Summary of VARX Models

Model Statistics	Model					
	Tamiami Trail		Bird Drive		North Kendall Drive	
	dcom	*dres*	*dcom*	*dres*	*dcom*	*dres*
Estimation Method	LS		LS		LS	
R^2	0.04	0.99	0.47	0.46	0.67	0.94
SER	1.69	12.40	6.47	30.65	19.27	40.96
SSR	404.82	21,672.41	5,322.27	119,294.9	28,954.69	130,867.3
Lags significant (months) for lane-mile	-	2, 3, 4, 15, 16	-	18	7, 8, 14	8, 11, 17, 21
Lags significant for commercial development (months)	-	-	3, 6	-	-	23
Lags significant for residential development (months)	-	1	2	1	3	12, 14, 18, 20
Cumulative impacts from land-mile (sq-feet)	0	345,679.5	7,632.8	38,945.8	60,654.9	349,765.2

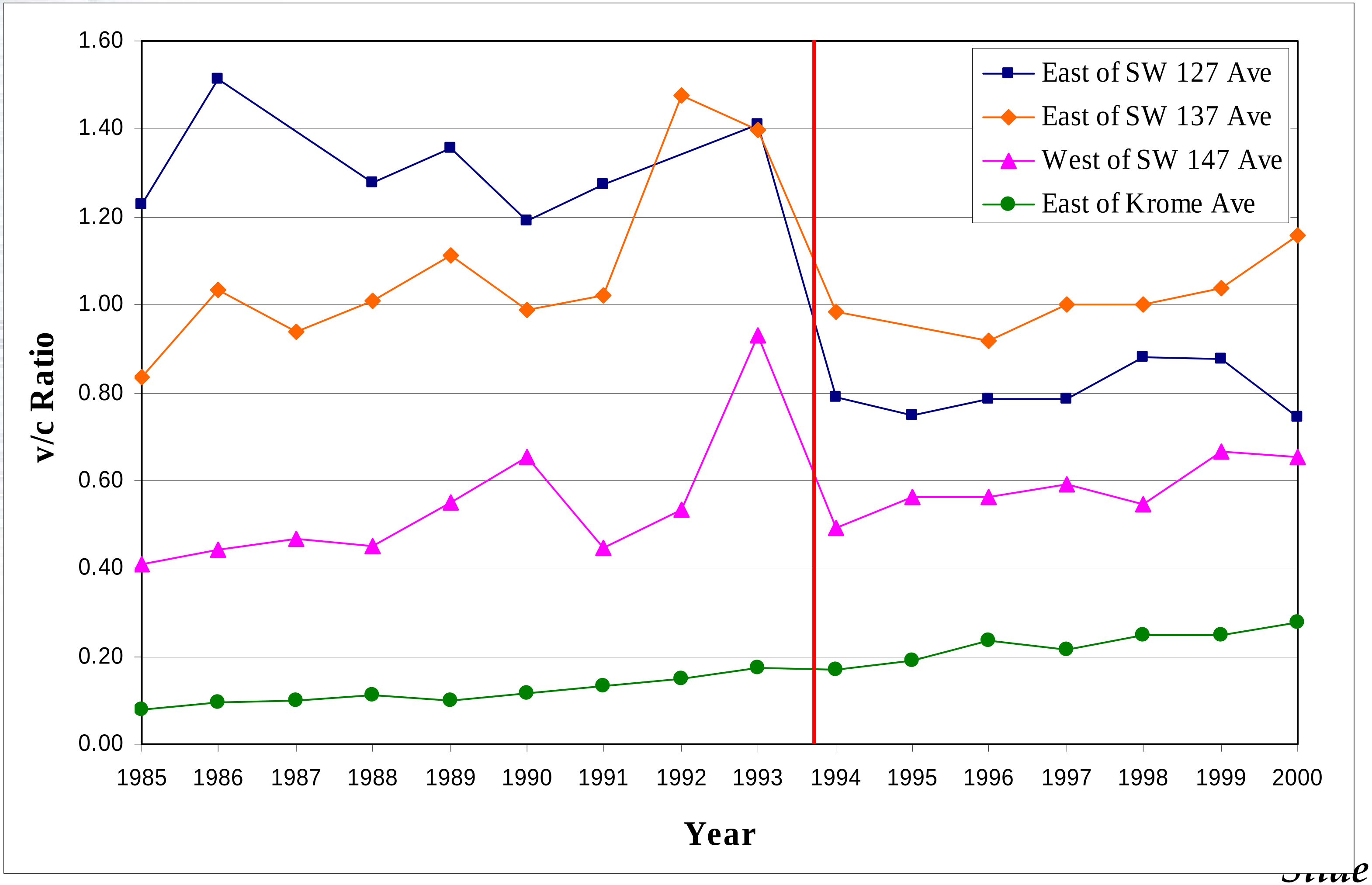
Examination of Traffic Conditions

Tamiami Trail



Examination of Traffic Conditions (2)

North Kendall Drive



Conclusions

- Land use and transportation interaction patterns can be highly variable in different geographic areas.
- Residential development, which was the dominant development, was significantly impacted by roadway improvements.
- Land use changes of two principal arterials, Tamiami Trail and North Kendall Drive, responded to roadway improvements faster than that of the Bird Drive corridor.
- Estimated lag effect for Lag1 ranged from a few months to one and one half years. The averages of Lag2 and Lag3 were found to be four months and 10 months with standard deviations of four and nine months, respectively. Consequently, it took two to four years for travel demand to respond to road investments in the growing areas in Miami-Dade County.
- The historical data available to this study were still limited in the sense that there was only one significant improvement in the transportation system in each of the study corridor.
- The lack of traffic data also prevented the effects of congestion on land development to be adequately considered.