Freight Flow Modeling and Carbon Emissions in Metropolitan Areas, Freight Significant Corridors, and Enterprise Supply Chains

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Freight Fuel Use and GHG Emissions Modeling is Takes Place in A Variety of Contexts and at A Variety of Different Geographic Levels (and Using Different Data Sets):

These include:

<u>Level 1: At the Single Enterprise Level</u>

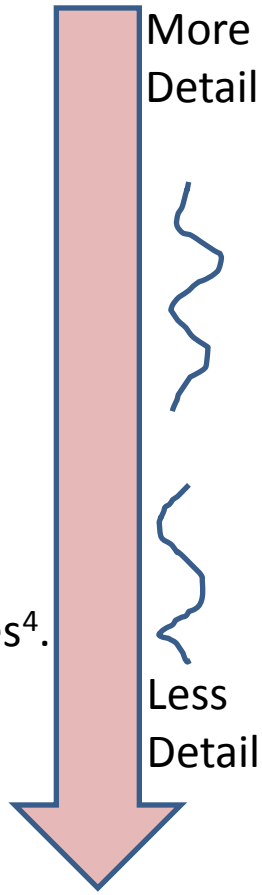
(Single or multiple OEM facility-centered, supply chain analyses)
Specific truck movement volumes from part suppliers to manufacturing sites, and from manufacturing sites to consolidation/distribution centers and final customers. State DOT and local link traffic speed and truck class count data, O-to-D freight delivery volumes ($'s, tons, units). Truck class and average speed based mpg estimates. GHGs/mpg rates.

<u>Level 2: At the Statewide Corridor Level</u>

E.G. HPMS[1] truck count & FAF3[2] link volume data, State DOT truck class-specific traffic counts and speeds, ATRI truck average link speed data[3], EPA's MOVES -based Fuel and GHG/VMT estimates for different vehicle classes & speed ranges[4].

<u>Level 3: At the Metropolitan Area-Wide Level</u>

E.G. HPMS Data (w/VMT expansion factors), VIUS average MPGs by truck class[5], average GHGs/gallon of gasoline or diesel equivalent *. No speed data used.



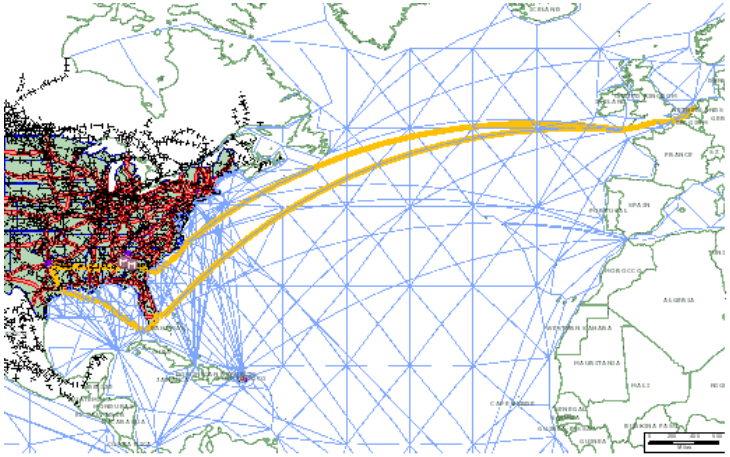
1. http://www.fhwa.dot.gov/policyinformation/hpms.cfm 2. http://faf.ornl.gov/fafweb/
3. http://www.ops.fhwa.dot.gov/freight/freight_analysis/travel_time.htm 4. http://www.epa.gov/otaq/models/moves/index.htm
5. http://www.census.gov/svsd/www/vius/2002.html

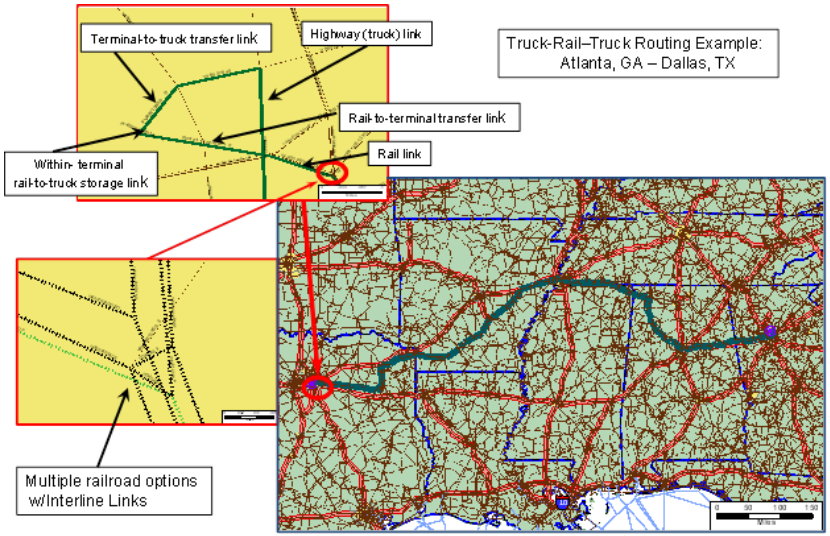
* or per kilowatt hour for Electric Drive Trucks: e.g. 1 gallon of gasoline=33.7 kWh . www.fueleconomy.gov

Level 1 (Disaggregated) Analysis:

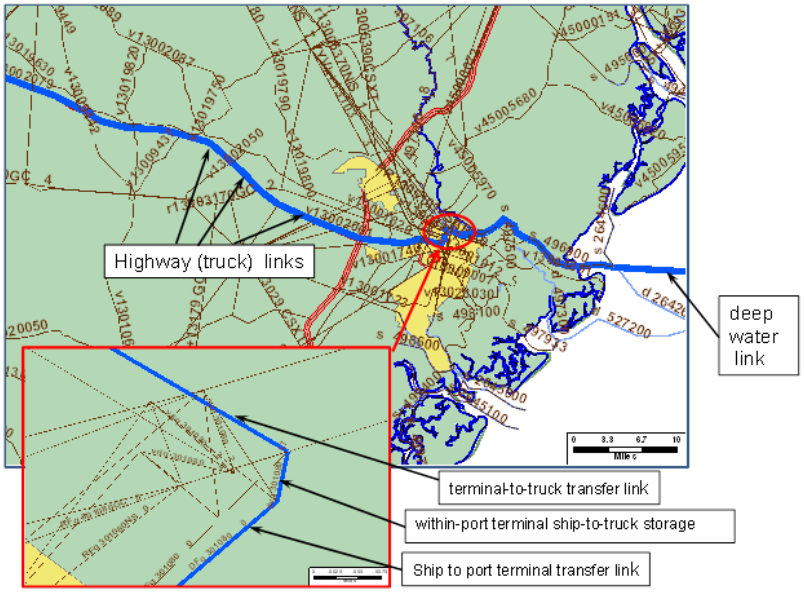
Multimodal (truck-rail-water-air freight)
Individual shipment routings incorporating:

- Line-haul links = most attention to date
- Storage links (energy, emissions, cost implications?)
- Intermodal transfer links (energy, emissions, cost implications?)

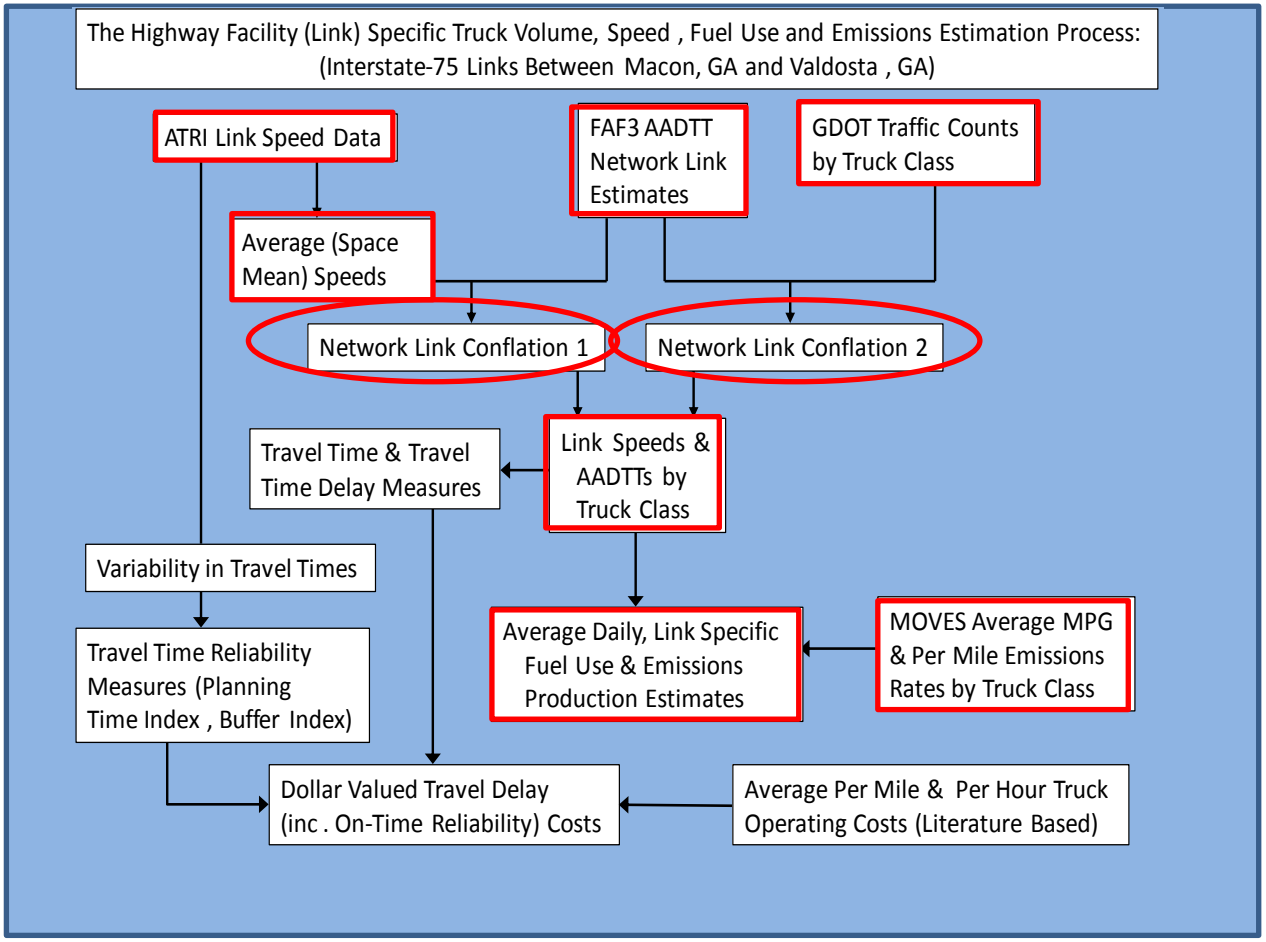


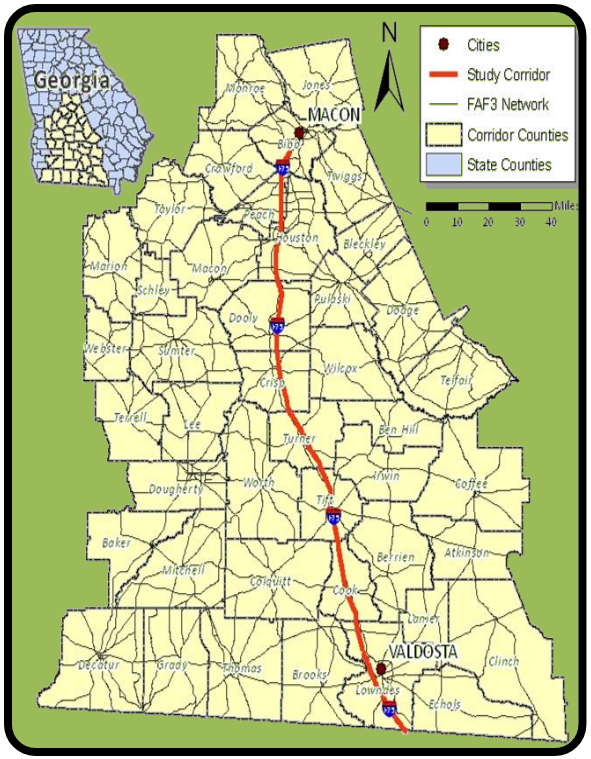


Example of Link-Node Based Deep Sea to Truck Transfer: Port of Savannah, GA



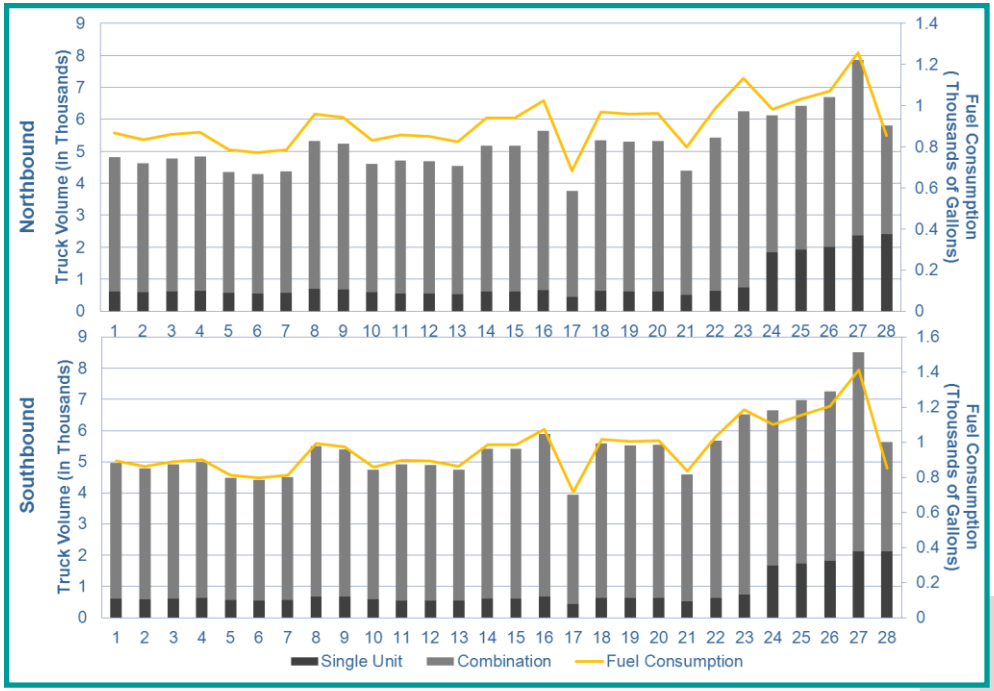
Level 2 Aggregation : Example Major Trucking Corridor Analysis

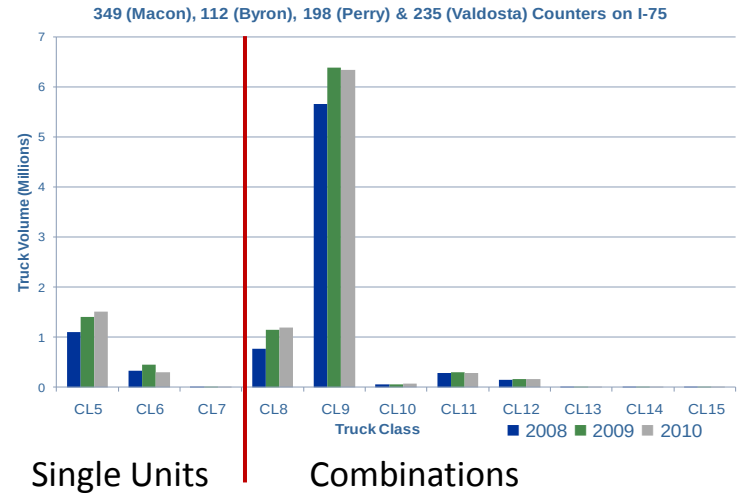


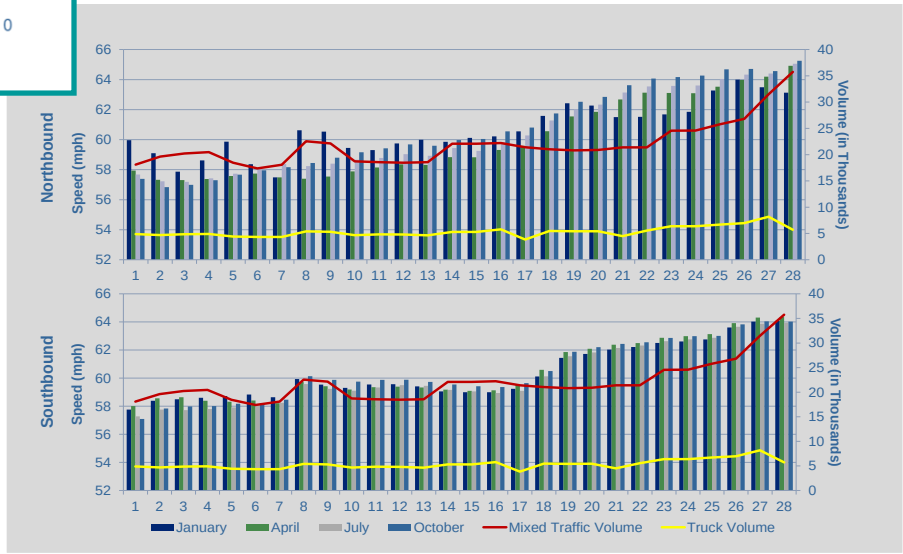


* Source: Southworth F. and Gillett, J. *Trucking in Georgia: Freight Performance Measures.* Report 10-16. Georgia Transportation Institute. Oct. 2011.

Example Link Specific Performance Measurement: Average Daily Truck Traffic & Associated Fuel Consumption







Note: Use of empirical data on truck speeds shows that traditional speed/volume relationship does not necessarily hold for low mixed volume corridors

* Source: Southworth F. and Gillett, J. *Trucking in Georgia: Freight Performance Measures.* Report 10-16. Georgia Transportation Institute. Oct. 2011.

Level 3 Aggregation : Metropolitan Area Wide Energy and CO2 Emissions Estimation*

Figure 1: Highway (Automobile, Truck) Methodology

Highway

Step 1: Estimate DVMT Within Each Metro

Data: HPMS, Highway Statistics

On HPMS Network:

$DVMT_{Total,\ section}$ = Section length *AADT * Std. Expansion Factor

$DVMT_{Single\ Unit,\ section} = DVMT_{Total,\ section}$ * % Single Unit Trucks

$DVMT_{Combination,\ section} = DVMT_{Total,\ section}$ * % Combination Trucks

$DVMT_{Car,\ section} = DVMT_{Total,\ section} - (DVMT_{Single\ Unit} + DVMT_{Combination})$

Aggregate sections in each Metro to get $DVMT_{METRO,\ TOTAL}$, $DVMT_{METRO,\ CAR}$, $DVMT_{METRO,\ SINGLE\ UNIT}$, $DVMT_{METRO,\ COMBINATION}$

Off HPMS Network (local) :

$DVMT_{local,\ METRO,\ CAR} = (DVMT_{METRO,\ CAR}/DVMT_{METRO,\ TOTAL}) * DVMT_{local,\ URBAN} * (DVMT_{METRO,\ TOTAL}/DVMT_{URBAN})$

$DVMT_{local,\ METRO,\ SINGLE\ UNIT} = ((DVMT_{METRO,\ SINGLE\ UNIT} + DVMT_{METRO,\ COMBINATION})/DVMT_{METRO,\ TOTAL}) * DVMT_{local,\ URBAN} * (DVMT_{METRO,\ TOTAL}/DVMT_{URBAN}) * 0.9$

$DVMT_{local,\ METRO,\ COMBINATION} = ((DVMT_{METRO,\ SINGLE\ UNIT} + DVMT_{METRO,\ COMBINATION})/DVMT_{METRO,\ TOTAL}) * DVMT_{local,\ URBAN} * (DVMT_{METRO,\ TOTAL}/DVMT_{URBAN}) * (1 - 0.9)$

Step 2: Convert to Fuel Consumption (in gallons)

Data: Transportation Energy Data Book, Highway Statistics , VIUS

Cars:

Fuel Shares:

Gasoline	*0.669*
Gasohol	*0.326*
Diesel	*0.005*

Average Mileage 2005: *19.7 miles per gallon*

Trucks:

Fuel Shares: *Share of Fuel Type X = Reported Truck Miles Using Fuel Type X / Total Reported Truck Miles*

Average Mileage (VIUS, 2002): *Avg MPG Fuel Type X = ((Miles 'mpg class 1'/Total miles fuel type X)* Middle value 'mpg class 1') + ((Miles 'mpg class 2'/Total miles fuel type X)* Middle value 'mpg class 2') + ... etc.*

Adjustment factors for 2005: *8.8/8.6 for Single Unit and 5.9/6.1 for Combination*

Step 3: Convert to BTU and Carbon Emissions

Heat Content and Carbon Coefficients:

FUEL:	*Gasoline*	*Diesel*	*Gasohol*	*LPG/Propane*
Heat Content (Btu/gal)	*125,000*	*138,700*	*120,900*	*91,300*
Carbon Coeff (Tg/Qbtu)	*19.34*	*19.95*	*19.34*	*16.99*

Step 4: Conversion from direct emissions to total emissions (including upstream)

Data: For Cars: Chester and Horvath (2008), for trucks: EPA *and* Chester and Horvath (2008)

*Total Emission = Direct Emissions * Multiplication Factor*

Multiplication factors: 1.56 for Auto, 1.43 for Single Unit Trucks, 1.38 for Combination Trucks

Direct (End Use) Btu and CO2 Emissions Estimation:

For Each Vehicle/Fuel /Network Type , V:

<u>Step1</u> : Estimate Daily VMT

<u>Step 2:</u> Multiply VMT by Average Gallons of Fuel/Mile = Fuel Used

<u>Step 3:</u> Multiply Fuel Used by Average per Gallon Heat Content (Btu) and CO2 Emissions.

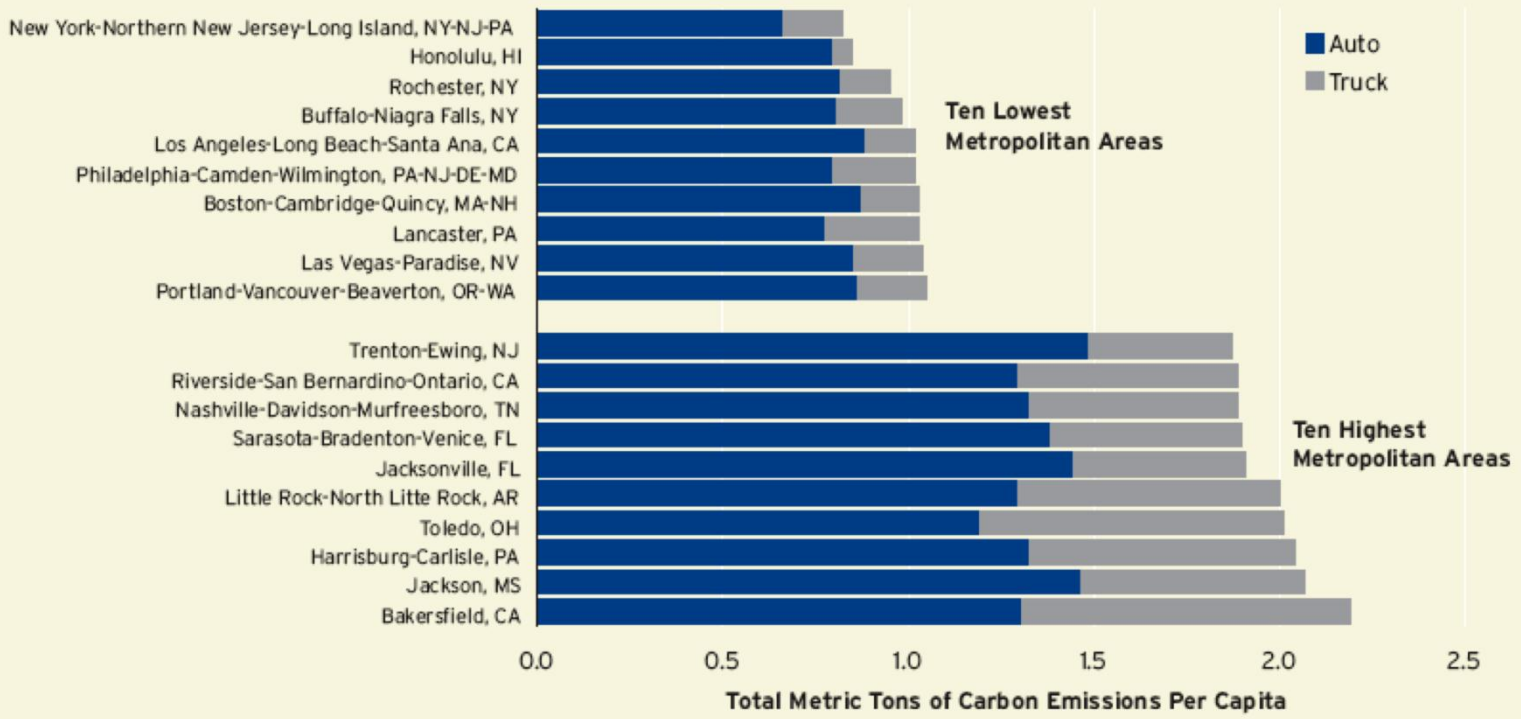
<u>Step 4</u>: Multiply Direct CO2 Emissions by [(Direct+ Indirect) /Direct] Btu and Emissions Ratios

where indirect refers principally to 'upstream' energy use and emissions production.

And sum results over all Vehicle/Fuel /Network Types, V = 1,2,...N

* See F. Southworth and A. Sonnenberg, *Set of Comparable Carbon Footprints for Highway Travel in Metropolitan America* JOURNAL OF TRANSPORTATION ENGINEERING, JUNE 2011.

High levels of freight transport characterize metros with large transportation footprints

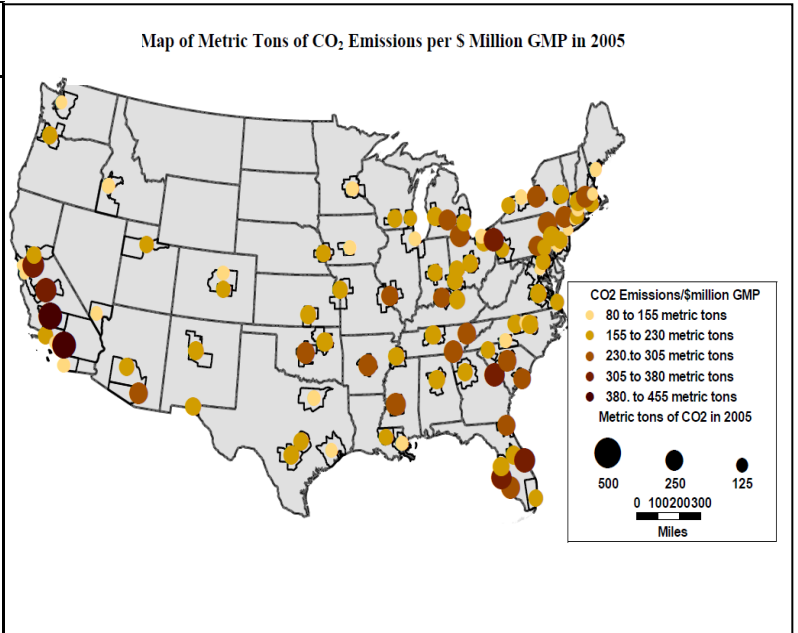


Source: Brown, Southworth, and Sarzynski, "Shrinking the Carbon Footprint of Metropolitan America," Brookings, 2008.

Large Differences in Truck Freight CO2 Emissions Rates Are Found Across The Largest 100 U.S. Metro Areas

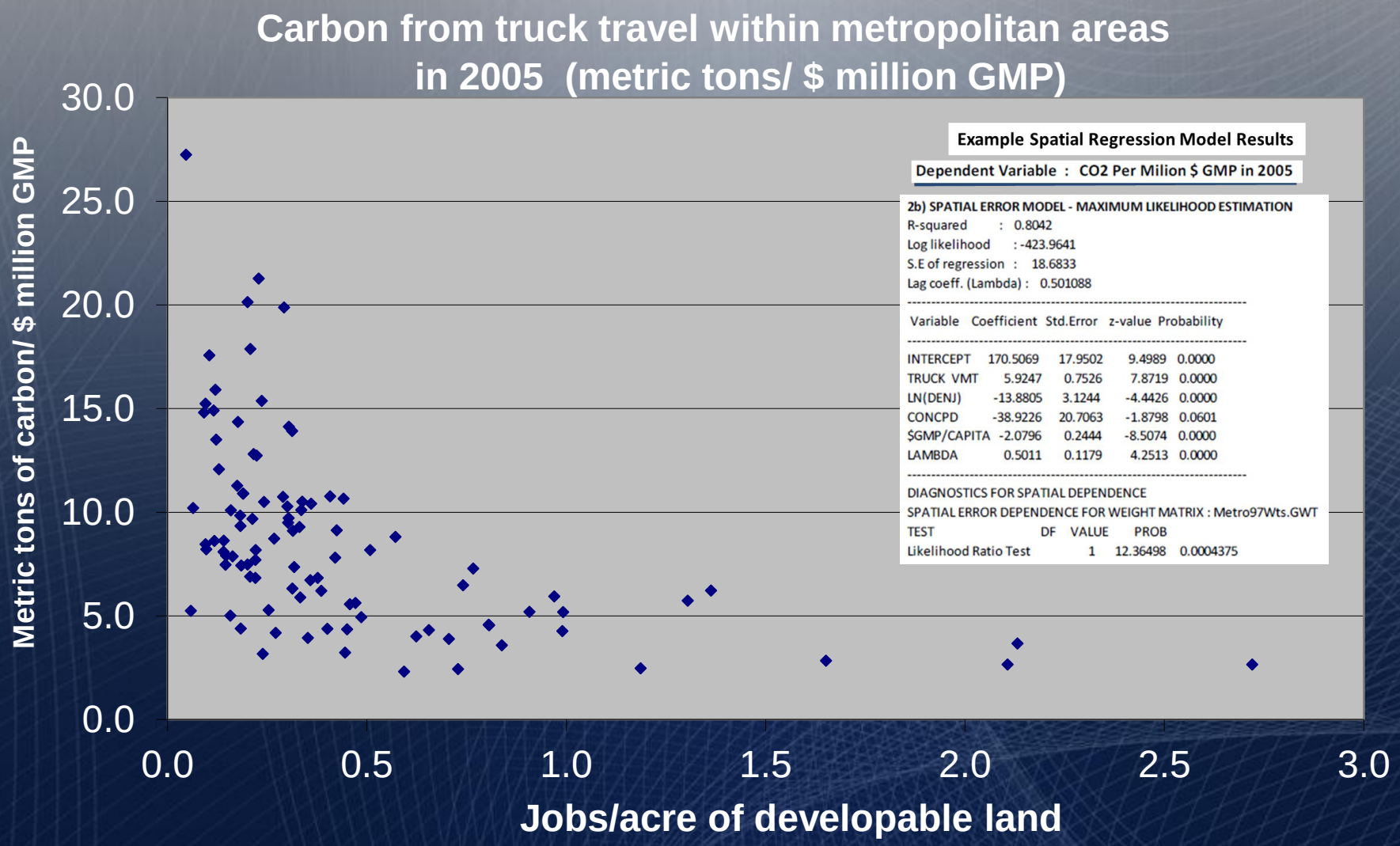
CO_2 per $Million GMP in 2005: 10 Highest and Lowest Metro Area Emitters

METRO	Auto	Public Transit	Single Unit Truck	Combination Truck	Total
1 Riverside, CA	291.23	0.69	49.27	68.49	409.68
2 Bakersfield, CA	253.51	0.52	45.23	104.95	404.22
3 Stockton, CA	239.38	1.13	34.04	76.92	351.47
4 Fresno, CA	235.46	0.8	37.6	59.51	333.37
5 Palm Bay, FL	251.58	0.46	43.01	36.26	331.31
6 Augusta, GA	229.64	0.15	33.01	51.26	314.05
7 Sarasota, FL	235.45	0.6	38.33	38.9	313.29
8 Youngstown, OH-PA	210.77	0.37	33.64	65.02	309.8
9 Jackson, MS	222.64	0.24	35.08	46.92	304.88
10 Toledo, OH	183.41	0.76	37.41	72.26	293.84
……..					
91 Seattle, WA	98.61	3.01	12.06	10.23	123.92
92 Los Angeles, CA	105.88	1.27	6.92	7.75	121.82
93 Philadelphia, PA	91.07	2.1	11.67	11.99	116.82
94 Honolulu, HI	101.49	2.47	4.62	2.32	110.91
95 San Francisco, CA	90.74	1.84	6.64	9.04	108.26
96 Boston, MA	87.15	2.06	6.87	6.81	102.88
97 Washington, DC	87.2	2.22	5.6	7.83	102.86
98 San Jose, CA	84.54	0.7	6.29	6.52	98.05
99 New York, NY-NJ	69.38	3.24	7.03	7.69	87.34
100 Bridgeport, CT	70.69	0.31	5.37	8.61	84.99



See Brown, M. A., Southworth, F., and Sarzynski, A. (2008). "Shrinking the carbon footprint of metropolitan America." ⟨http://www.brookings.edu/reports/2008/05_carbon_footprint_sarzynski.aspx⟩

Dispersed Employment Increases Truck Emissions



Example Spatial Regression Model Results

Dependent Variable : CO2 Per Milion $ GMP in 2005

2b) SPATIAL ERROR MODEL - MAXIMUM LIKELIHOOD ESTIMATION

R-squared : 0.8042
Log likelihood : -423.9641
S.E of regression : 18.6833
Lag coeff. (Lambda) : 0.501088

Variable	Coefficient	Std.Error	z-value	Probability
INTERCEPT	170.5069	17.9502	9.4989	0.0000
TRUCK VMT	5.9247	0.7526	7.8719	0.0000
LN(DENJ)	-13.8805	3.1244	-4.4426	0.0000
CONCPD	-38.9226	20.7063	-1.8798	0.0601
$GMP/CAPITA	-2.0796	0.2444	-8.5074	0.0000
LAMBDA	0.5011	0.1179	4.2513	0.0000

DIAGNOSTICS FOR SPATIAL DEPENDENCE
SPATIAL ERROR DEPENDENCE FOR WEIGHT MATRIX : Metro97Wts.GWT

TEST	DF	VALUE	PROB
Likelihood Ratio Test	1	12.36498	0.0004375