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Full Length Research Paper

Exploration and visualization of highway freight flow movements in the United States using Geographical Information System (GIS)

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This paper begins with a concise national overview of the transported goods, classified by Standard Classification of Transport Goods, and their movements on the highway networks in the United States using TransCAD, a geographical information system with strong transportation planning capabilities and the freight analysis framework database version 2.2 or *FAF*$^{2.2}$. Then, the paper constructs more national views of from, to, within, and through freight flows for the 50 U.S. states and DC to highlight the spatial patterns of total freight flows by state. The local views of total freight flows focus on Oklahoma, the so called "cross-road" state of America. A linear regression model is established by linking state freight flows to state major socio-economic indicators, such as employment, revenue, income, and payroll for the year 2002. State total freight flows in tonnage or by commodity are calculated to reveal top or bottom states in handling from, to, within, and through freight flows.

Key words: Highway, freight, flow, regression, geographical information system (GIS), visualization.

INTRODUCTION

Freight transportation is an important aspect of transportation and is essential to the national and local economy. Today, most consumable goods worldwide are transported on multi-modal networks involving waterways, railways, highways, and airways to their demand markets, such as cities, distribution centers, or retail stores, and finally to the consumers.

Freight is also an important factor for transportation decisions and policies on infrastructure, investment, safety, and security. Various transportation policies have been formed and implemented based on freight research. Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 requires all Metropolitan Planning Organizations (MPOs) and other regional or local planning agencies to include freight transportation issues in state and metropolitan transportation plans (Siwek, 1996). This requirement was further continued with the Transportation Equity Act for the 21st Century (TEA-21) and the Safe, Accountable, Flexible, Efficient Transportation Equity Act (SAFETEA-LU) of 2005 (FHWA, 2005; 2010, 2011).

Freight movement can be realized by single mode (i.e., by waterway) or multi-mode (i.e., by railway and highway) transportation from an origin to a destination. However, most import and export freight are often moved by multi-mode involving water, rail, and truck. Multi-mode freight is processed at inter-modal facilities where one mode is transferred to another. For example, the freight from Shanghai, China may enter Los Angeles or Long Beach ports by ocean waterways, then is loaded on a rail to an inland city (that is, Fort Worth, TX), and is finally trucked to its final destination (i.e., Oklahoma City).

Freight movement is often analyzed at a spatial scale, which, for this study, is at the state level. Freight coming into a state is named "to freight" or "freight attraction",

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which is regarded as the demand of goods by a spatial unit that is positively correlated to the total population and income of the state. The higher the total population and income, the higher the attraction of goods are expected to be. Freight going out of a state is called "from freight" or "freight production", which is considered as the supply of goods at a state that is positively related to its total employment and revenue, implying the higher its employment and revenue, the higher its freight production. Freight movement from and to in the same state is defined as "within freight", which is considered as the freight flows between sub-spatial units, that is, metropolitan statistical areas (MSAs) or counties of the state.

For example, for the State of Oklahoma, the within freight can be thought of as the flows in Oklahoma between its major MSAs, such as Oklahoma City, Tulsa, and the Remainder of Oklahoma (non-MSA). Freight movement generated from origin states and attracted to destination states via a state's transportation network is regarded as "through freight" for the state. The "from, to, within, and through" freight can also be calculated for any smaller spatial area unit, such as MSA, county, census track, block, or ZIP. However, this research focuses on the state and MSA levels.

This paper studies the freight movement for years 2002, 2010, 2015, 2020, 2025, 2030, and 2035 in the United States using the freight analysis framework version 2.2 ($FAF^{2.2}$) database, which is produced by the U.S. Highway Administration (FHWA, 2011) under the U.S. Department of Transportation (USDOT) and is the major publically available freight database. Although $FAF^{3.0}$ is just released, it is not much different from $FAF^{2.2}$. Therefore, this research still uses $FAF^{2.2}$ to study the U.S. national freight movement in general and Oklahoma local freight movement in particular with a focus on from, to, within, and through flows and some additional freight flow measures.

After the introduction, we shall examine selected freight flow studies to inform the reader of the literature on freight movement, describe the research methodology and freight flow calculation procedures, introduce the relevant freight databases with a focus on $FAF^{2.2}$, highway networks, and data processing, provide key results and highlights freight flow movements in the United States and Oklahoma and draw conclusions and illustrates future research options.

LITERATURE REVIEW

Moving of goods perhaps began as early as human traveling from one place to another. In the United States, the first railway was built for transporting commodities in 1799 in Boston (Whitehill, 1959), and transcontinental railroads began construction in 1863. The freight movement networks were further transformed when the highway system was introduced in 1924 and the interstate highway system began in 1950s. The highway network as a whole carries the most freight and is still expanding quickly in the United States (McNichol, 2006).

Today, the movement of agricultural and mining goods such as grains, coal, and ores comprises a large share of the tonnage moved on the U.S. freight network. However, lighter and more valuable manufactured goods, such as computers, electronics, and office equipment, now make up an increasing proportion of commodities. Moreover, goods are being transported over longer distances in contrast to a few decades ago because of changes in the makeup of the United States economy and the dramatic growth in international trade.

The total domestic freight tonnages and values on U.S. highways in 1998 are shown in Figure 1, which clearly illustrates the dominance of freight tonnage and value shipped by highway networks. For example, the highways carried 10,850 million tons of goods or $7,429 billion worth of goods vs. the distant second, railroads, which shipped 2,311 million tons or $163 billion of goods in 1998.

In 2002, the U.S. transportation industry employed about 20 million people - 11 million in direct transportation and transportation-related industries (that is, train operators, highway construction workers) and 9 million in non-transportation industries (that is, truck drivers for retail stores, distribution managers for manufacturing firms). 10% of U.S. Gross domestic product (GDP) in 2002 is related to transportation activities (BTS, 2011). The United States freight transportation network moves a large volume of goods each year. The economic impacts of freight transportation are manifold. Freight transportation increases the value of goods, extends the spatial boundaries of commodity and markets, encourages competition, and stimulates demand for goods and services. The imported goods to U.S. gateway ports then to U.S. final destinations or the exported commodities from U.S. origins to U.S. gateway ports then to global destinations are relatively small in quantity when compared to the total U.S. domestic freight. Table 1 summarizes the 2002 and 2007 total freight by mode in USA. Some special types of freight, such as crude oil or natural gas movement by pipeline systems, are important, but not considered in this paper.

Research and practice on freight transportation have steadily grown over the past 20 years and dramatically in the past two decades (Hoel et al., 2011). This growth can be witnessed at national and local levels and in recent academic research. First at the national and regional levels, the U.S. Department of Transportation, the Bureau of the Census, the Bureau of Transportation Statistics (BTS), (2002). Federal Highway Administration (FHWA), and Maritime Administration all conduct activities on freight research, databases, and statistics. United States Department of Transportation (USDOT) has also developed and implemented some key transportation

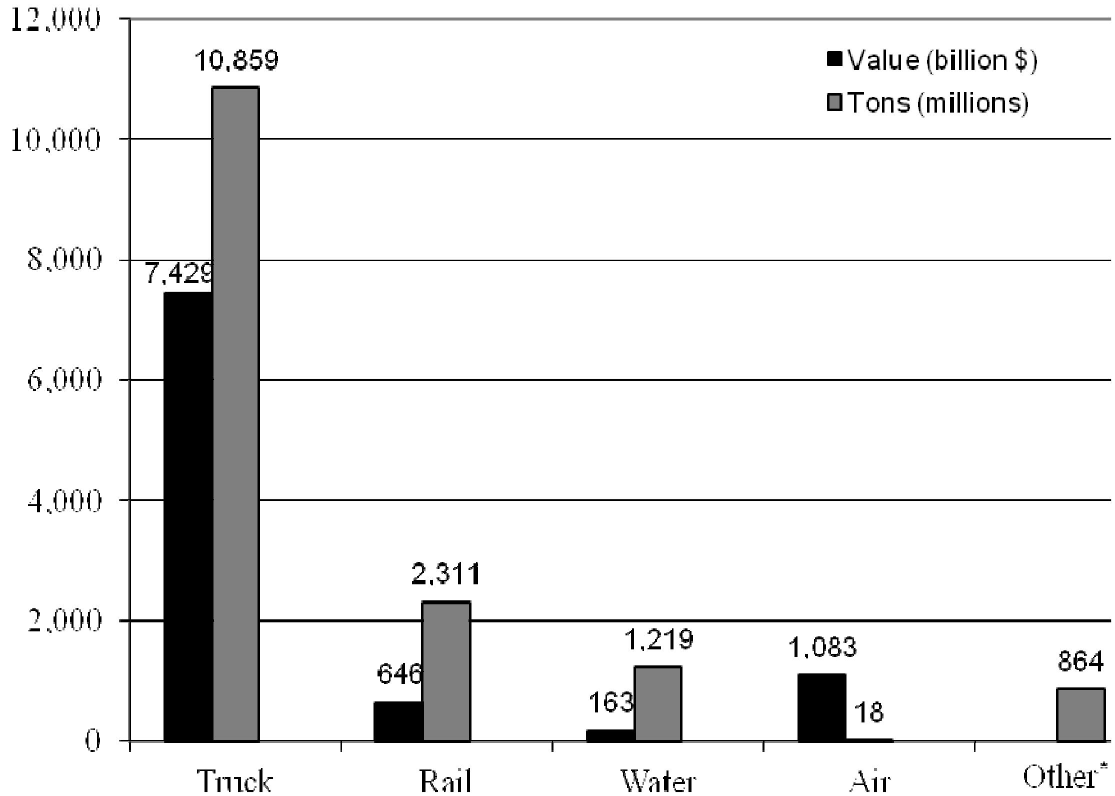

Figure 1. U.S. domestic freight by mode, value and tonnage, 1998.
*Includes international shipments through pipelines and other facilities. Source: U.S. Federal Highway Administration (FHWA), *FAF*[2.2], 2011.

Table 1. U.S. domestic, import and export freight by mode and tonnage(in million tons), 2002 and 2007.

Variable	2002				2007			
	Total	Domestic	Exports[3]	Imports[3]	Total	Domestic	Exports[3]	Imports[3]
Total	19,328	17,670	525	1,133	21,225	19,268	619	1,338
Truck	11,539	11,336	106	97	12,896	12,691	107	97
Rail	1,879	1,769	32	78	2,030	1,872	65	92
Water	701	595	62	44	689	575	57	57
Air, air and truck	11	3	3	5	14	4	4	6
Intermodal[1]	1,292	196	317	780	1,505	191	379	935
Pipeline and unknown[2]	3,905	3,772	4	130	4,091	3,934	6	151

Source: Federal Highway Administration (FHWA), Freight Facts and Figures 2008, http://ops.fhwa.dot.gov/freight/freight_analysis/nat_freight_stats/docs/08factsfigures/index.htm, retrieved on Oct. 20, 2011.

policies, such as ISTEA and TEA-21 that requires all MPOs and other planning agencies to include freight transportation in their long-term transportation plans. The attention to freight transportation continues with the recently passed SAFETEA-LU. With these policies, the importance of freight transportation is clearly made at the national and regional level.

Second, at the local level, many states have recently conducted their own freight movement studies or developed their own state-wide freight flow models. A sample selection of these freight models includes the Florida model, which is capable of identifying and measuring truck activity on the proposed Florida Intrastate Highway System corridors; the Iowa commodity based freight transportation demand model, which "analyzes the potential impacts of policy and industry changes on freight transportation within the State" (Souleyrette et al., 1996); the Ohio freight model, which uses regional, industry, and commodity models to forecast patterns of goods movement by commodity and by mode for the corridors; the Wisconsin model for state-level heavy truck movements of major manufacturing commodities from 28 economic sectors (Sorratini and Smith, 2000) and the Oklahoma model, which can estimate freight flows for all states and counties for Oklahoma by commodity and by mode (Ingalls et al., 2003). The uniqueness of the Oklahoma model was a development of full code mapping linking commodities and industries. The Oklahoma model has been extended to apply for a MSA-level 5-county regional freight study in Tulsa, OK by Shen and Pulat (2006). Interestingly, most of these applied state models were done by private transportation consultants, such as Cambridge Systematics with its popular quick response freight manual II (Cambridge Systematics, 2007) and ReBees Associates (now with global insights specializing in economic and business forecasting in the United States) for its well known freight database TranSearch.

Third, in academic research of freight movement, early freight network models were developed in the late 1960s (Bronzini, 1980). The Harvard-Brookings model, considered the first freight network model, was developed by Roberts in 1966 and later modified by Roberts and Kresge in 1971 (Friesz and Harker). This model explicitly related transportation decisions to economic and spatial factors. The theoretical component in the model presented an innovative way of estimating freight flows. Chin et al. (1998, 2001), using the 1993 commodity flow survey (CFS) database (BTS, 2011), studied the freight flows "originating from, destined to, passing through, or occurring entirely within a state" and found that the freight flows "vary significantly from state to state". They reported about 73% of ton-miles and 55% value of goods in 1993 and 76% of ton-miles and 60% value of goods in 1997 were shipped by highway. They concluded that the freight flows "could have important implications for highway revenue allocations because trucks carrying freight play a significant role in damage to highway pavements and structures". Built up the work by Gordon and Pan (2001), Giuliano and Gordon et al. (2007), based on a critical review of the modeling limitations by Johnston (2004), Miller (2003), Waddell et al. (2003), and Echenique and Partners (1994), developed unique estimation procedure secondary data sources, including small-area employment data and spatial input-output transaction tables, to estimate commodity specific intra-metropolitan freight flows on highway networks for the Los Angeles region. The distinctive features of these two studies are their focuses on finer spatial level freight flows (that is, intra-metro by traffic analysis zone), integration of various databases (that is, CFS, I-O tables), and regression comparisons of estimated and actual freight flows.

This paper improves the models by Chin et al. (1998, 2001) and Shen and Pulat (2006) by not only looking at from, to, within, and through commodity flows at the national and local levels, but also using some flow performance measures for each of these flows with respect to the total flows, hence making possible the cross-comparisons or states rankings with these measures. Also, linear regression models for the freight transportation industry were established and estimated by linking freight flows to economic factors at the state level in 2002.

METHODOLOGY

This research analyzes all commodities of freight movement from several perspectives in order to capture the main features of freight movement. The first perspective is to look at flows (that is, freight from, to, through, and within) by geographic unit (that is, state) and by time horizon (that is, base year 2002 and future years 2010 to 2035) of freight movement. States are compared and ranked according to each flow type and percentage change from 2002 to 2035. The second perspective is to measure the composition of these flows at the state level to uncover their relative importance in freight carrying capacity in the United States. The third perspective is to investigate the relationship between state level freight flows and economic factors for the transportation industry in the base year 2002.

Freight flow types

By denoting X_{mt}^{od} as the freight flow from state *o* to state *d* for commodity *m* and in year *t*, we develop the following measures:

The total "from flow" (or freight production) FF_t^o of state *o* and in year *t*:

$$FF_t^o = \sum_{d,m} X_{mt}^{od} \tag{1}$$

The total "to flow" (or freight attraction) TF_t^o of state *o* and in year *t*:

$$TF_t^o = \sum_{d,m} X_{mt}^{do} \tag{2}$$

The estimated total "within flow" WIF_t^{od} of state *o* and in year *t*:

$$WIF_t^o = \sum_{o=d,m} X_{mt}^{od}, \text{ where } o = d \tag{3}$$

The total "through flow" THF_t^o of state *o* in year *t* can be thought of as the total assigned flows between states *i* and *j* on the shortest paths linking *i* and *j* and passing through state *o*:

$$THF_t^o = \text{assigned} \left(\sum_{j,m} X_{mt}^{ij} \delta_{mt}^{ioj} + \sum_{i,m} X_{mt}^{ij} \delta_{mt}^{ioj} \right) \quad (4)$$

The total "through flow" is based on the all-or-nothing assignment, where $i \neq j \neq o$ and δ_{mt}^{ioj}=1 if state *o* is on the shortest path linking states *i* and *j*, otherwise, δ_{mt}^{ioj} =0.

Freight flow measures

The portion (%) of a state's freight production vs. the state's total freight production and attraction is a good indicator of the state's dependency on other states for its commodities. This production portion (%), FFP_t^o , and its attraction counterpart, TFP_t^o, can be measured by:

$$FFP_t^o = FF_t^o / (FF_t^o + TF_t^o) \quad (5)$$

$$TFP_t^o = 1 - FFP_t^o \quad (6)$$

Similar measures can be designed for within flows and through flows for a state. The within flow portion (%), $WIFP_t^o$, indicates the state's self sufficiency in its goods supply while the through flow portion (%), $THFP_t^o$, shows the relative contribution of the state's network to the freight supply and demand of other states.

$$WIFP_t^o = WIF_t^o / (WIF_t^o + TF_t^o) \quad (7)$$

$$THFP_t^o = THF_t^o / (FF_t^o + TF_t^o + THF_t^o) \quad (8)$$

Regression linkage of freight flows and economic factors

It is hypothesized that there is a linear regression relation between the economic factors of employment (EMP_t^o), establishment (EST_t^o), revenue (REV_t^o), and payroll (PAY_t^o) of the transportation sector (NAICS code = 48-49), and the total from, to, within and through freight flows of the state *o* in year *t*. It is anticipated that the total from and within flows are positively correlated to the state total transportation workforce, but negatively associated with total to and through flows since it makes common sense that to and through flows are most likely transported by firms of other states. Mathematically, we can write the regressions as follows:

$$EMP_t^o = a_0 + a_1 FF_t^o + a_2 TF_t^o + a_3 WIF_t^o + a_4 THF_t^o + e_{EMP} \quad (9)$$

$$EST_t^o = b_0 + b_1 FF_t^o + b_2 TF_t^o + b_3 WIF_t^o + b_4 THF_t^o + e_{EST} \quad (10)$$

$$REV_t^o = c_0 + c_1 FF_t^o + c_2 TF_t^o + c_3 WIF_t^o + c_4 THF_t^o + e_{REV} \quad (11)$$

$$PAY_t^o = d_0 + d_1 FF_t^o + d_2 TF_t^o + d_3 WIF_t^o + d_4 THF_t^o + e_{PAY} \quad (12)$$

Where e_{EMP}, e_{EST} , e_{REV}, and e_{PAY} are the error terms for the regressions.

DATABASE AND PROCESSING

The freight movement model requires careful data processing and coding of several databases, including the standard classification of transportation goods (SCTG) by Statistics Canada (2010), North American Industry Classification System (NAICS), $FAF^{2.2}$, and U.S. highway networks in GIS system. For this research, we used TransCAD to integrate databases and perform state-level freight flows and their assignments on the U.S. highway network.

Freight database

The freight analysis framework version 2.2 ($FAF^{2.2}$) provides a comprehensive freight database for regions, states, and major transportation gateways. The original version, FAF^{1}, provides freight estimates for 1998 and forecasts for 2010 and 2020. The new version $FAF^{2.2}$ provides estimates for 2002 to 2035. $FAF^{2.2}$ helps identify areas in need of capacity improvements and highlights states and regions with mismatched freight demand and supply. Since it is estimating commodity flows, SCTG coding system is used. SCTG is based upon a set of transportation characteristics, commodity similarities, and industry-relevant statistically significant categories that better reflect goods transported by all modes. The structure of the SCTG is a hierarchy consisting of four levels that contain groupings based on harmonized commodity description and coding system[1] (HS) or the "building blocks" in standard classification of goods[2] (SCG). These levels range from a minimum of 43 to a maximum of 512 categories.

[1] Harmonized System (HS): In 1988, Canada replaced its uniquely Canadian export (XCC) and import (MCC) commodity classification systems with the internationally recognized Harmonized System of Commodity Description and Coding. Structured on chapters of goods with common features, the first 6-digits of the code are used internationally.

[2] SCG is Canada's extension of the HS

Freight network database

The highway network database used in this research is taken from the $FAF^{2.2}$ database. $FAF^{2.2}$ database was developed from the National Highway Planning Network (NHPN) Version 3 database, which in turn was developed by the Federal Highway Administration to support GIS-based traffic modeling and mapping. The NHPN's highway network has approximately 452,000 miles of public roadways including the interstate system (IS), National Highway System (NHS), National Network (NN), and other state highways while the Highway Planning and Monitoring System (HPMS) records only approximately 350,000 miles of public roadways. Also, less than 70% of links recorded in the HPMS database matches those recorded in NHPN Version 3.

The $FAF^{2.2}$ database has 170,773 links, of which a small number of links connecting Canadian/Mexican Highway networks and the Alaska Highway network was removed. Hawaii highway network was removed as well. The attribute table of the remaining highway network records the length, state name, functional classification, rural/urban classification, link name, signage (like "I" for interstate, "S" for state highway, etc.), and link status.

Each state is represented by a set of metropolitan statistics areas (MSAs) and the remainder (or Non-MSA). These MSAs or Non-MSAs are treated as centroids, which are connected to the U.S. highway network through centroid connectors and assumed as points of sending or receiving freight flows. The centroids are then linked to freight flow data for a complete geographic information system (GIS) database in TransCAD.

RESULTS AND DISCUSSION

National freight flows

Freight production (from flow), attraction (to flow), and within flow data were retrieved from the $FAF^{2.2}$ database for all MSAs and Non-MSAs in a state by summarizing up all commodities in thousands of tons and aggregating to the state level for 2002 to 2035. For each year, a state's through flows were calculated by summing up all the centroid-to-centroid flows on the shortest paths that go through the state. These four types of flows were then ranked and compared to highlight the freight flow movement at the national and local levels.

From flow (freight production)

The national total and top 10 states with freight production in thousand tons (Ktons) are given in Table 2. At the national level, the total from freight flows more than doubled from 2,505 Ktons in 2002 to 5,764 Ktons in 2035. Seven of the top ten states are located in the North or Northeast with only three states (TX, GA and MO) in the South. Midwestern states have four on the list of top ten states, including IL, OH, PA and IN. Also, the freight production of the top ten states over the national total freight production decreases consistently from 44.19 to 37.34%, with the period of 2002 to 2010 dropping the most. Moreover, the top eight states have steady growth in freight production during 2002 to 2035 while WI and NY have slight fluctuations in total from flow. IN, TX, and NJ have the highest freight production growth in the same period.

Between 2002 and 2035, production freight flow changes range between -12% (NY) to 365% (KY), and the national average is 137%. ID (359%), MI (346%), CA (328%), and OR (308%) are the other fastest growing states in terms of freight production. The top and bottom ten freight production increases or decreases in percentage are given in Table 3. In 2002 IL, OH, IN, TN, and MO occupied the top 5. On the contrary, it is predicted that in 2035 some of these states decline and move down the ranking. KY, the state with the highest percentage increase in production freight flow, is estimated to achieve the 3rd ranking in 2035. The total production freight flow has an increasing trend in general for the top ten states, but a decreasing trend for the bottom ten states, as shown in Table 4. Also, the fact that 28 of the 51 states have below average increase suggests a possible decline in national and state manufacturing employment. NY (-12%) and WA (-4%) are the fastest declining states in freight production. NY decreases until year 2025. Although the state increases its freight production afterwards, in year 2035 the state cannot reach 2002 levels. In addition, NY, DC, NJ, and WA decrease between 2002 and 2010. Although DC and NJ reach and pass their 2002 levels, WA has more fluctuations and increases till 2015 but faces a steep decrease afterwards. AK is the other fluctuating state, having an increase between 2002 and 2010; it keeps the same level until 2020 and experiences more fluctuations afterwards.

To flow (freight attraction)

The national total and the top ten states in freight attraction are listed in Table 4. The national total freight attractions from 2002 to 2035 are the same as their national total freight productions, increasing from 2,505 Ktons in 2002 to 5,764 Ktons in 2035. This national total growth is similar to the increasing pace of the total of the top ten states. However, the share of the top ten states vs. the national total is almost flat from 2002 to 2035, for example, 38.75% in 2010 to 38.22% in 2035, indicating that other states also experienced a similar growth in the period. IL, the top state in Table 4, has a stable increasing trend, and the change between years 2002 to 2035 is 181%. Interestingly, each of the top ten states had a steady freight attraction growth from 2002 to 2035, with higher ranked states growing at a somewhat faster speed.

The states with the fastest and the slowest growth in freight attraction are in Table 5. The top four states IL, OH, PA, and IN ranked in 2002 attraction magnitude and percentage are amazingly ranked in the same order to 2035, indicating their dominancy in total freight attraction. IL, VA, and FL are the only three states in the top ten that have larger percentages in the same period, such as 5.95

Table 2. Sample freight production table (thousand tons or Ktons).

State	2002	2010	2015	2020	2025	2030	2035
IL	207	222	235	253	281	312	345
OH	138	181	191	199	210	226	243
PA	116	113	116	122	131	143	158
IN	102	131	152	175	209	246	291
NJ	100	114	130	149	174	206	244
TX	97	118	136	162	193	229	263
GA	89	111	121	136	157	185	220
MO	88	107	121	140	162	188	218
WI	87	60	60	62	66	70	77
NY	83	76	77	77	79	87	93
Top 10 sum	1,107	1,233	1,339	1,475	1,662	1,892	2,152
Total	2,505	2,960	3,288	3,706	4,263	4,961	5,764
Top 10/National	44.19%	41.66%	40.72%	39.80%	38.99%	38.14%	37.34%

Table 3. Top and bottom ten percentage changes in freight production, 2002 to 2035.

State	2002 (%)	2010 (%)	2015 (%)	2020 (%)	2025 (%)	2030 (%)	2035 rank (%)	2002 rank
IL	8.26	7.52	7.15	6.83	6.60	6.29	5.98	1
MI	2.96	3.12	3.62	4.15	4.74	5.20	5.74	12
KY	2.79	3.30	3.65	4.09	4.65	5.15	5.63	14
IN	4.05	4.42	4.61	4.74	4.91	4.97	5.06	4
MO	3.89	4.00	4.14	4.38	4.53	4.63	4.56	6
CA	2.34	2.88	3.13	3.38	3.64	3.95	4.34	18
TN	4.00	3.86	3.95	4.02	4.07	4.15	4.24	5
OH	5.52	6.10	5.81	5.36	4.94	4.56	4.22	2
TX	3.57	3.75	3.68	3.67	3.68	3.73	3.82	7
MD	2.41	2.82	2.91	3.16	3.39	3.68	3.80	17
Top 10 sum	39.78	41.77	42.65	43.78	45.14	46.31	47.39	
ME	0.59	0.51	0.52	0.56	0.57	0.58	0.57	42
NM	0.36	0.42	0.44	0.46	0.48	0.49	0.52	46
WY	0.56	0.51	0.51	0.51	0.51	0.51	0.52	44
NV	0.56	0.53	0.52	0.51	0.51	0.51	0.51	43
RI	0.47	0.43	0.49	0.51	0.52	0.49	0.48	45
WA	1.00	0.88	0.78	0.68	0.58	0.49	0.42	34
VT	0.33	0.35	0.34	0.34	0.35	0.35	0.37	47
MT	0.27	0.25	0.25	0.25	0.25	0.25	0.25	48
DC	0.09	0.07	0.06	0.06	0.05	0.05	0.05	49
AK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50
Bottom 10 sum	4.24	3.95	3.93	3.89	3.82	3.73	3.69	

to 7.26% for IL, 2.18 to 3.66% in FL, and 2.86 to 3.33% in VA. Other top ten states slightly decrease, or fluctuate, or increase in percentage changes from 2002 to 2035. Each of the bottom ten states has less than 0.65% in freight attraction change from 2002 to 2035.

Figures 2 and 3 are sample maps of top from-to freight flows, depicted either in direct lines linking state centroids or assigned to the U.S. highway networks, for the United States. Given that the study is at the national and local (state and metro) levels, the freight flows are assigned to the highway network using the shortest paths between the origins and destinations without considering the network link capacity. Figures 2 and 3 clearly show the from-to interacting freight flows between key states, for example, CA; New England states, such as NY, NJ, MA; Mid-American states, such as OH, MI, IL, TX and FL.Figures 4 and 5 show the from-to freight flows, depicted either in direct lines linking state centroids or

Table 4. Sample freight attraction table (thousand tons or Ktons).

State	2002	2010	2015	2020	2025	2030	2035
IL	149	195	229	265	310	362	419
OH	130	150	168	190	221	258	304
PA	123	149	166	187	214	249	289
IN	116	127	140	157	183	214	244
NJ	107	108	115	125	139	153	171
TX	103	120	135	153	176	204	235
GA	95	102	110	122	138	159	184
MO	90	93	99	108	123	141	164
WI	87	103	116	130	146	170	193
Top 10 Sum	1,000	1,147	1,278	1,437	1,650	1,910	2,203
Total	2,505	2,960	3,288	3,706	4,263	4,961	5,764
Top 10/National (%)	39.92	38.75	38.87	38.77	38.71	38.50	38.22

Table 5. Top and bottom ten percentage changes in freight attraction, 2002 to 2035.

State	2002 (%)	2010 (%)	2015 (%)	2020 (%)	2025 (%)	2030 (%)	2035 (%)	2002 rank
IL	5.95	6.59	6.95	7.16	7.27	7.30	7.26	**1**
OH	5.21	5.08	5.12	5.14	5.19	5.19	5.27	2
PA	4.91	5.03	5.04	5.04	5.02	5.03	5.01	3
IN	4.61	4.30	4.26	4.24	4.29	4.30	4.24	4
TX	4.12	4.06	4.10	4.12	4.12	4.11	4.08	6
NY	3.33	3.06	3.17	3.28	3.42	3.60	3.80	10
FL	2.18	2.92	3.10	3.25	3.38	3.51	3.66	20
WI	3.46	3.48	3.53	3.52	3.43	3.43	3.36	9
VA	2.86	2.77	2.85	3.01	3.12	3.28	3.33	13
GA	3.80	3.45	3.36	3.28	3.24	3.21	3.20	7
Top 10 sum	40.43	40.72	41.48	42.03	42.49	42.97	43.20	
NH	0.55	0.58	0.58	0.58	0.59	0.59	0.59	42
NM	0.65	0.67	0.64	0.61	0.60	0.59	0.57	39
ID	0.63	0.60	0.57	0.53	0.51	0.49	0.48	40
SD	0.43	0.45	0.47	0.47	0.47	0.45	0.42	43
ND	0.31	0.36	0.37	0.37	0.38	0.39	0.40	46
MT	0.28	0.32	0.33	0.34	0.35	0.37	0.37	49
RI	0.33	0.33	0.34	0.35	0.35	0.35	0.35	44
VT	0.28	0.29	0.29	0.29	0.29	0.28	0.27	48
ME	0.33	0.30	0.28	0.27	0.26	0.26	0.26	45
AK	0.07	0.07	0.07	0.08	0.09	0.10	0.11	50
Bottom 10 sum	3.86	3.97	3.93	3.89	3.87	3.85	3.82	

assigned to the U.S. highway networks, for the State of Oklahoma. Although OK exchanges freight with all other U.S. states, Figures 4 and 5 illustrate the impact flows are with CA, New England States, TX, Mid-American States, and States in the Northwest.

Figure 6 is a map showing the freight flows between centroids of 114 major U.S. metropolitan statistics areas (MSAs). The freight patterns are disaggregated with respect to the more aggregated patterns in Figure 2. However, key patterns between metros are still apparent, for example, the interacting from-to freight flows between Mid-American state metros, that is, OH, MI, IL, WI, IN, are the most intensive, followed by New England state metros (that is, NY, NJ, MA, PA), Southern state metros (that is, GA, TX, NC, AL, TN), and Pacific and Pacific Northwest state metros (that is, CA, WA, OR). Freight flows among key metro partners, such as CA, FL, New England state metros, Mid American state metros, and

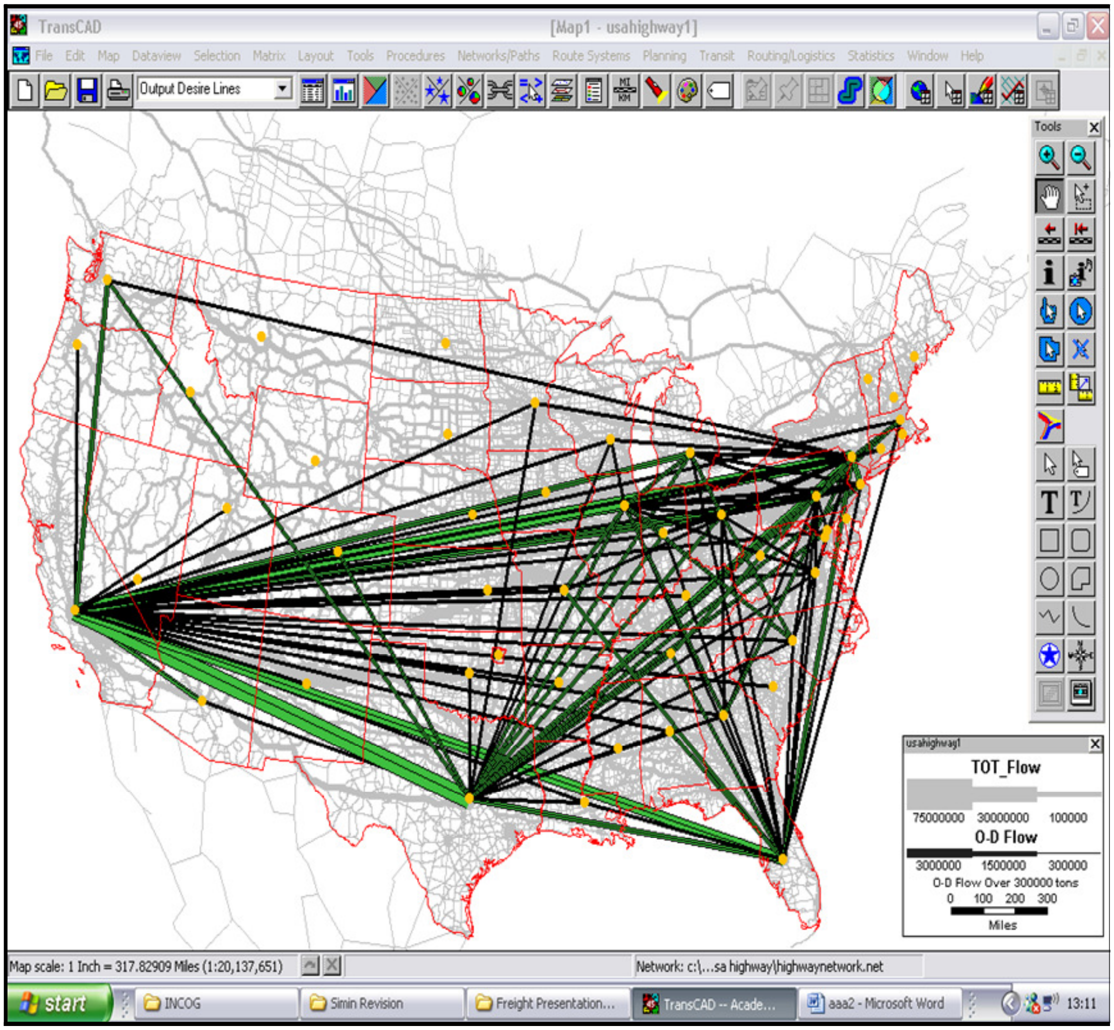

Figure 2. USA sample top state-level from-to freight flows shown in direct lines, 2002.

Southern state metros, are strong regionally as well.

Within flows

Table 6 shows the within freight flow, which changes by 85% on average with a minimum of -16% (DC) and a maximum of 232% (WY) between 2002 and 2035. California, Texas, Illinois, and Florida are not only the top four states having the highest within freight flows, but their within freight flows are also very high compared to others. These four states have a total of more than 30% of the total within flow. The top ten states having the highest and least within flows are listed in Table 8, where there is not much change seen between years 2002 and 2035. However, the top five states (i.e., CA, TX, IL, FL, GA) have within flow gains while the bottom 5 states (that is, HI, VT, DE, RI, and DC) have within flow losses in 2002 vs. 2035.

Most of the states follow an increasing within freight flow pattern through 2002 to 2035. NY and LA have a steep decline at 2010, and then have a steady increase until 2035. Likewise, DC, the last state in the within freight flow list, has a steep decline; however, the state cannot reach its 2002 levels by 2035. 70% of all states face a decrease in their yearly within freight flow between 2010 and 2015.

Figures 7 and 8 depict the within freight flows by state for 2002 and 2035. The overall pattern is not surprising, with top states in 2002, such as CA, TX, IL still holding the top spots in 2035 and with bottom states being virtually the same in 2002 and 2035. Although, Pacific Northwest states (that is, WA, OR), Mid-American states (that is, OH, MI, MN, IN), Southern states (that is, TN, NC, GA and FL), and Southwestern states (that is, CO, OK, MO, IA) have increases within freight flows, their percentage rankings at the national levels may be higher (that is, MN, IN, FL, GA, OK) or lower (that is, OH, NC)

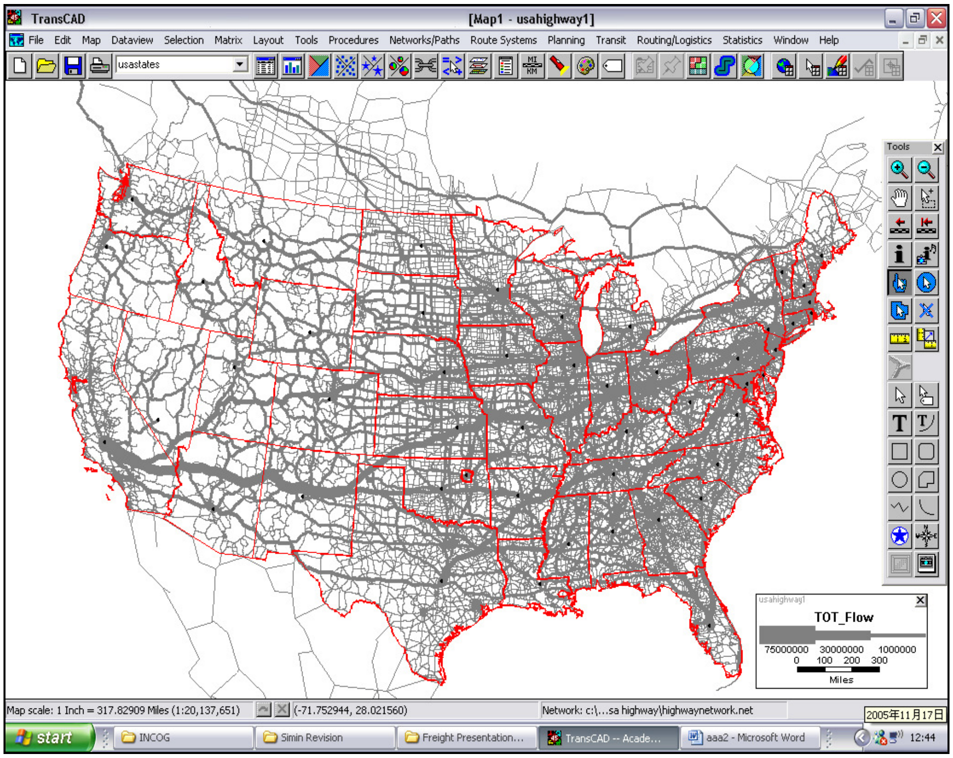

Figure 3. USA sample top state-level from-to freight flows assigned to the highway networks, 2002.

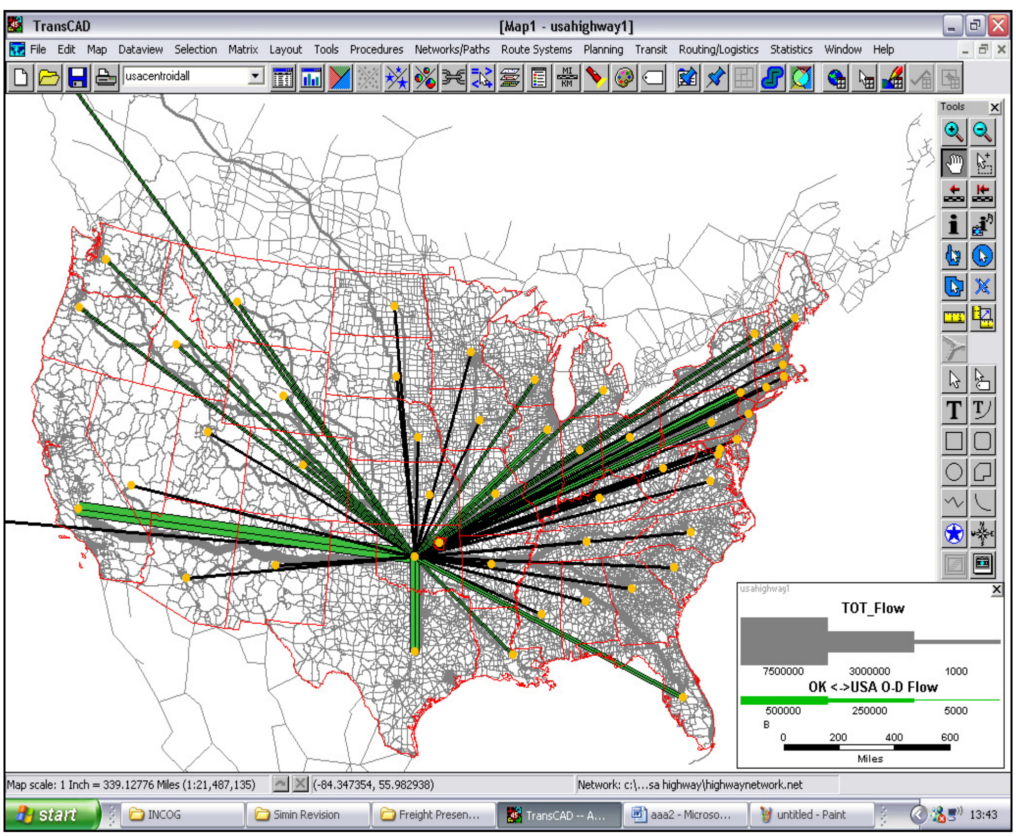

Figure 4. Oklahoma from-to freight flows with other states shown in direct Lines, 2002.

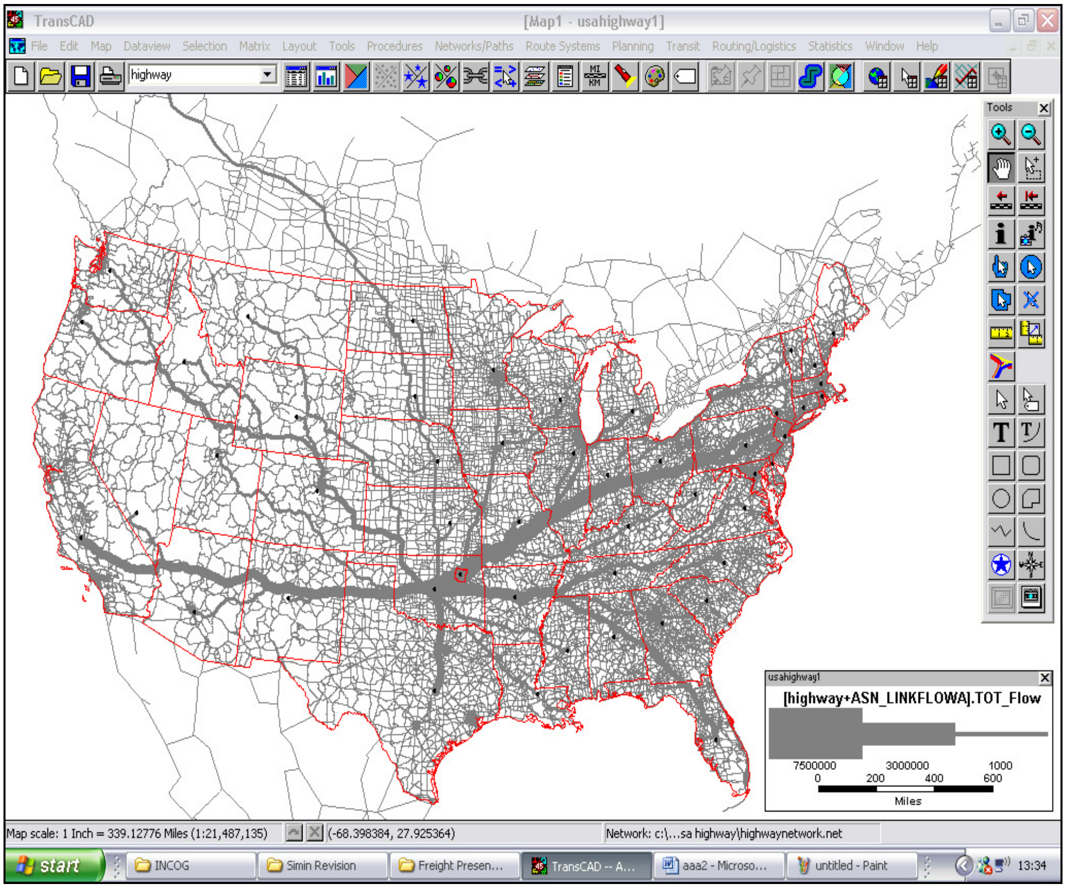

Figure 5. Oklahoma from-to freight flows with other states assigned to the highway network, 2002.

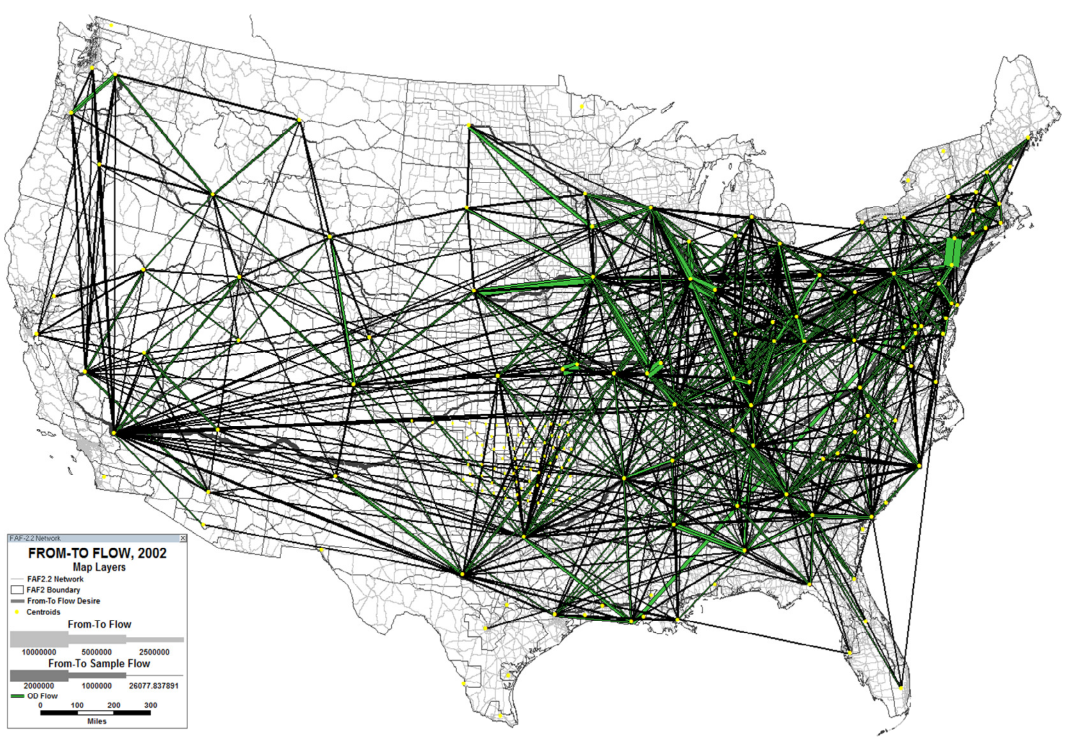

Figure 6. USA from-to freight flows shown in direct lines at the MSA level, 2002.

Table 6. Top and bottom ten changes in within freight flows, 2002 to 2035.

State	Within freight percentages							2002 rank
	2002 (%)	2010 (%)	2015 (%)	2020 (%)	2025 (%)	2030 (%)	2035 (%)	
CA	11.00	11.39	11.72	12.05	12.46	12.88	13.24	1
TX	7.88	8.18	8.25	8.33	8.48	8.80	9.34	2
IL	7.51	7.45	7.19	6.95	6.72	6.51	6.28	3
FL	5.51	5.75	5.71	5.73	5.71	5.69	5.63	4
GA	3.61	3.61	3.64	3.69	3.71	3.69	3.63	6
OH	3.90	4.17	4.10	4.01	3.87	3.71	3.52	5
IN	3.00	3.24	3.29	3.30	3.25	3.17	3.09	9
MI	3.12	2.95	2.96	3.02	3.05	3.06	3.06	7
MN	2.72	2.80	2.86	2.90	2.93	2.95	2.93	11
NC	3.08	2.84	2.80	2.76	2.70	2.64	2.57	8
Top 10 sum	51.34	52.39	52.52	52.73	52.88	53.10	53.28	
WY	0.28	0.31	0.35	0.38	0.42	0.46	0.50	45
WV	0.49	0.49	0.45	0.42	0.40	0.39	0.36	39
NH	0.33	0.33	0.32	0.32	0.31	0.30	0.29	44
ME	0.41	0.35	0.34	0.33	0.31	0.30	0.29	42
AK	0.21	0.25	0.23	0.23	0.22	0.22	0.22	46
HI	0.21	0.20	0.19	0.19	0.18	0.18	0.18	47
VT	0.18	0.18	0.18	0.18	0.18	0.17	0.17	48
DE	0.18	0.18	0.18	0.18	0.17	0.17	0.17	49
RI	0.15	0.14	0.14	0.14	0.14	0.14	0.13	50
DC	0.02	0.00	0.01	0.01	0.01	0.01	0.01	51
Bottom 10 sum (%)	2.45	2.42	2.40	2.37	2.34	2.34	2.32	

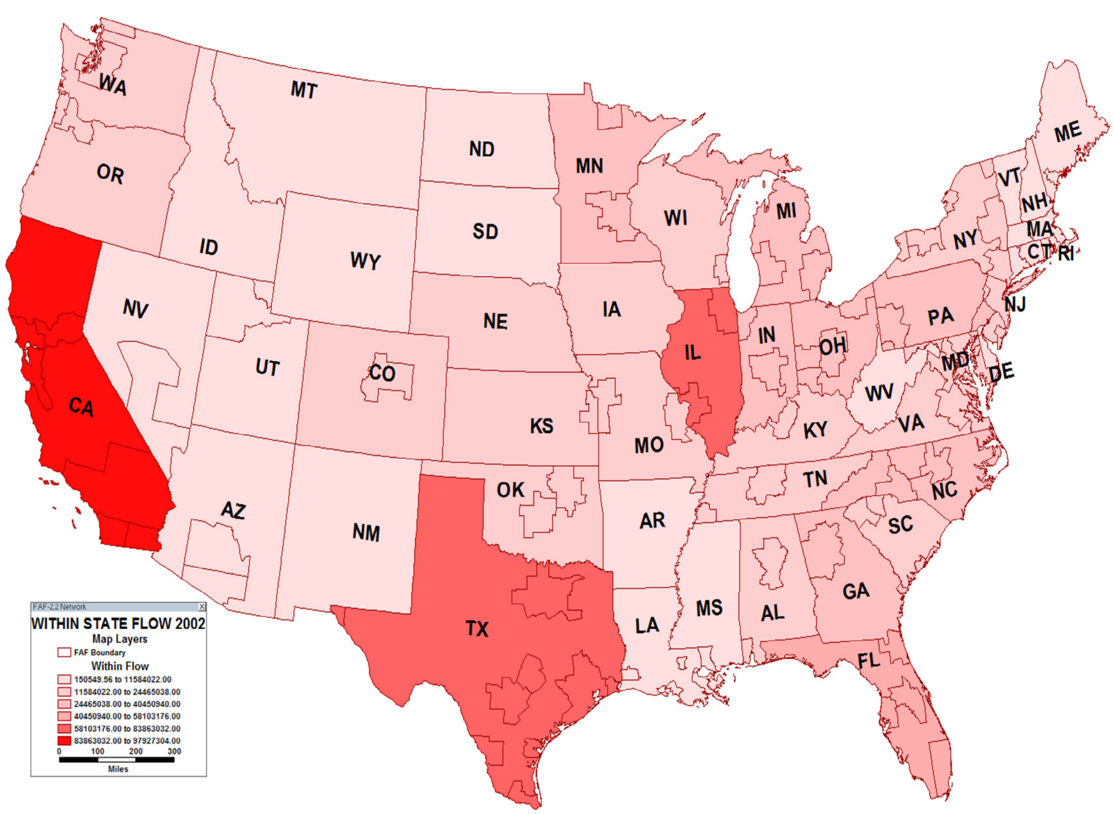

Figure 7. Within freight flows by state, 2002.

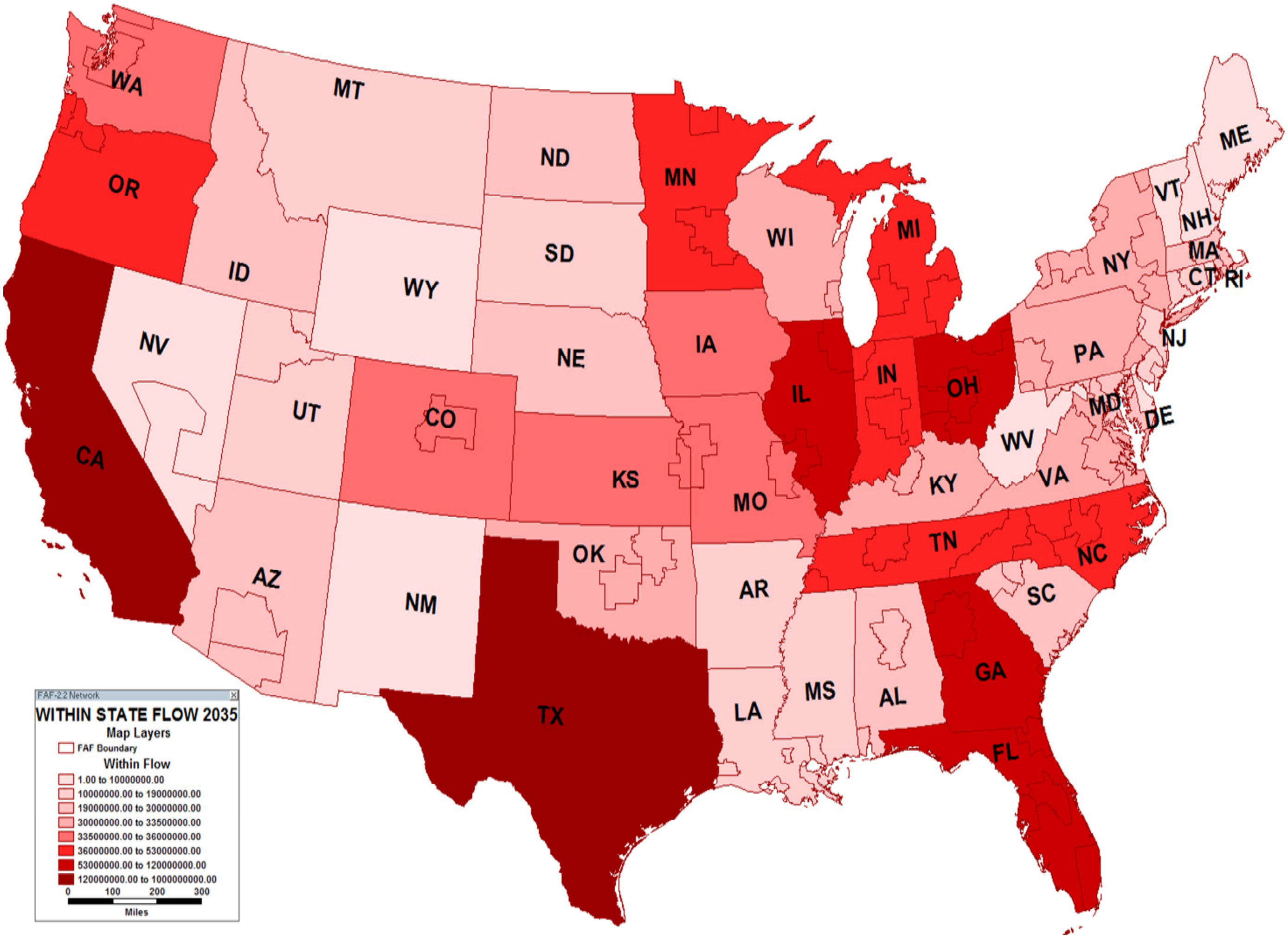

Figure 8. Within freight flows by state, 2035.

in 2002 vs. 2035.

Through flows

For each state several O-D pairs passing through the corresponding state (that is, OK) were identified using TransCAD. Table 7 shows the highest twenty through flow passing states. IN, KY, and IL are the top three states that carried the highest through flows on their transportation networks. The top 20 states carried the highest through flows are 75% of all through flows. The average change from year 2002 to 2035 was 126% (the lowest being 31% with FL, and the highest being 204% with NV).

Figures 9 and 10 shows a map of the United States for years 2002 and 2035, respectively. The red indicates the high through flows, and the white represents no through flow. The highest through flow passing states are concentrated towards the east coast, which suggests that there is a higher demand for freight on the east coast.

Through flow for Oklahoma is shown in Figure 11. In the figure, shortest paths between origin and destination pairs are shown. Figure 11 also represents how Oklahoma is a cross road. Texas-Kansas, Texas-Ohio, Texas-Missouri, California-Illinois and California-Ohio are the pairs having highest freight flow passing through Oklahoma. California, Texas, Illinois, Indiana and Ohio are the top five states that are producing freight flows. Texas, California, Kansas, Illinois and Colorado are the top five states that have the highest attraction. Rankings do not change for manufacturing freight flow. These listed are states that pass through Oklahoma most frequently.

Local freight flows

Local from, to, within, and through freight flows focus on the State of Oklahoma. While Figures 12 to 15 visually show the highway networks carrying freight flows in

Table 7. Top twenty states with through flows.

State	2002	2010	2015	2020	2025	2030	2035	2002 Rank	% Change
IN	206,004	244,198	273,239	308,289	357,600	418,346	493,252	2	139
KY	209,526	244,929	273,771	308,819	355,432	413,090	480,696	1	129
IL	198,867	231,445	257,254	289,671	333,633	390,602	459,943	3	131
TN	156,777	181,995	200,403	223,596	255,073	296,864	348,067	6	122
OH	141,728	157,761	176,766	202,933	239,450	286,523	346,717	7	145
MO	139,990	169,051	187,800	211,760	243,074	283,956	332,044	8	137
PA	163,512	173,633	188,036	207,322	235,735	274,231	321,311	4	97
WV	159,029	176,962	191,770	209,102	233,053	264,278	304,489	5	91
GA	122,348	153,547	170,197	187,871	210,830	241,430	277,563	9	127
VA	121,465	132,129	142,627	155,123	171,909	194,901	221,624	10	82
MD	113,340	124,627	134,178	145,031	160,349	181,445	206,330	11	82
NM	75,686	92,948	104,055	118,523	139,017	165,960	199,169	16	163
AZ	70,639	86,339	97,635	112,343	133,039	160,728	197,839	17	180
IA	81,049	96,480	107,237	120,563	138,658	161,988	190,245	13	135
OK	79,162	93,954	103,716	115,838	133,606	156,919	186,489	15	136
MS	83,335	98,379	109,495	123,224	138,976	158,554	181,950	12	118
AL	80,752	91,818	99,916	110,578	125,105	144,086	167,599	14	108
NJ	70,364	74,168	82,451	93,085	107,927	127,715	153,054	18	118
AR	64,827	75,342	83,718	94,395	108,829	127,275	149,787	20	131
TX	56,773	67,646	75,359	85,720	100,396	119,803	144,531	24	155
Top 20 sum	2,395,173	2,767,352	3,059,621	3,423,783	3,921,689	4,568,691	5,362,699		
Total (46)	3,209,160	3,715,933	4,107,803	4,599,917	5,269,487	6,146,558	7,210,833		
Top 20 sum (%)	74.64	74.47	74.48	74.43	74.42	74.33	74.37		

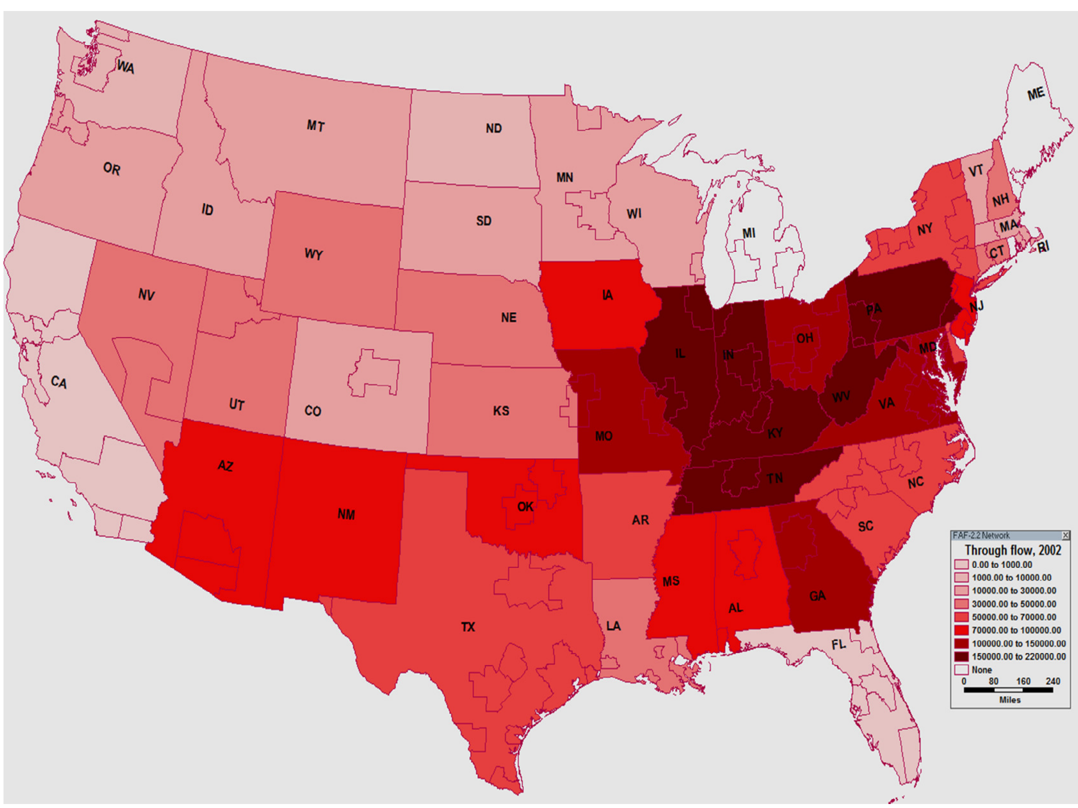

Figure 9. Through flows by state, 2002.

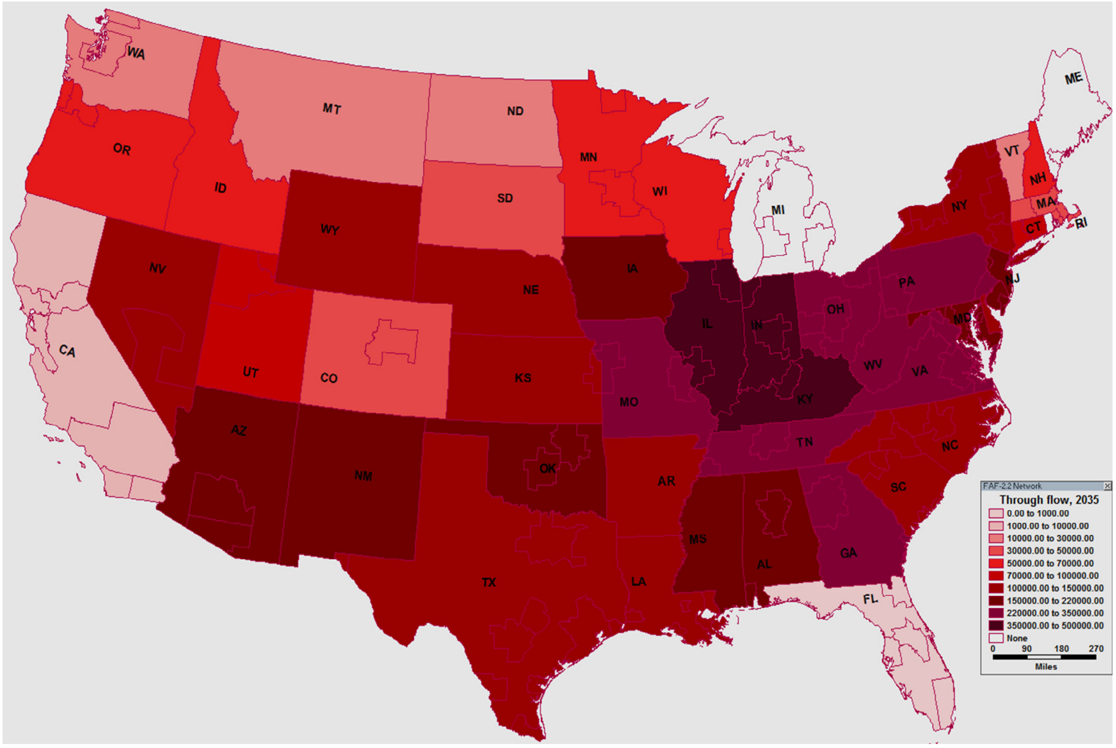

Figure 10. Through flows by state, 2035.

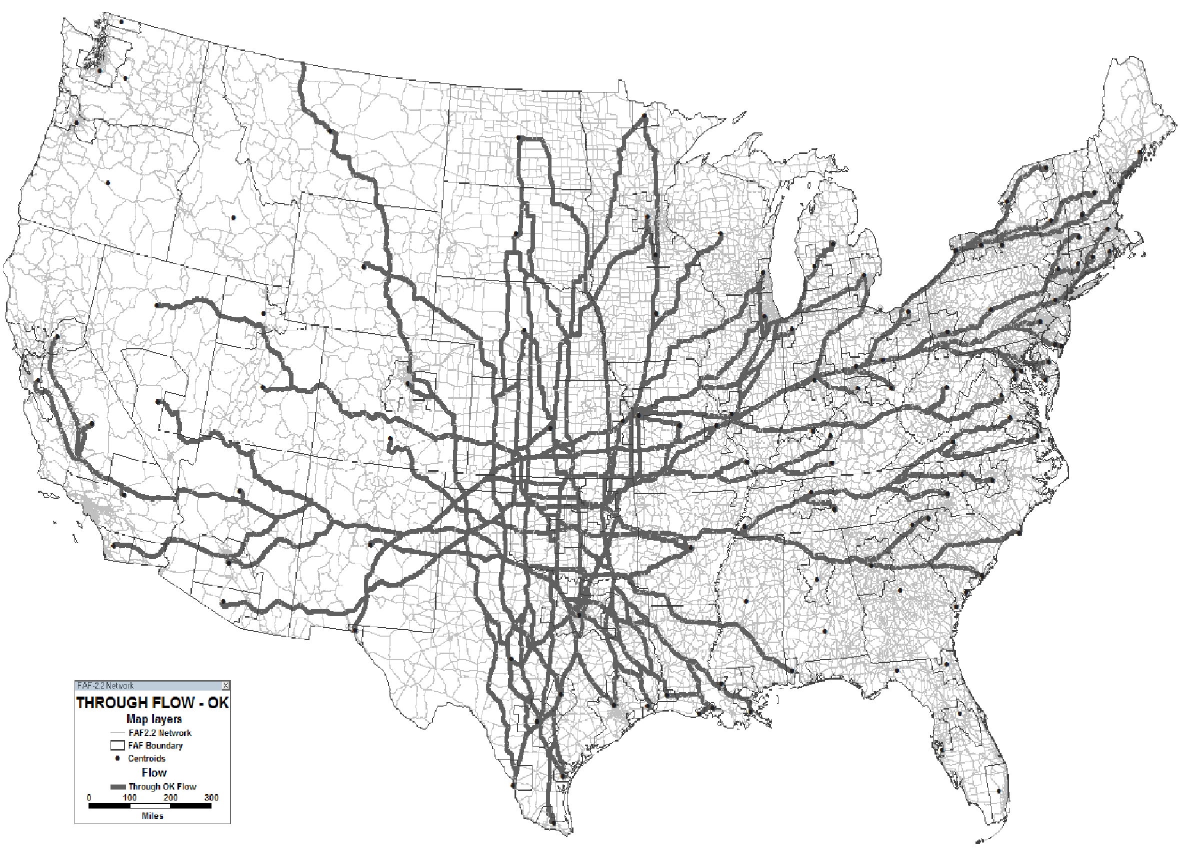

Figure 11. Oklahoma through freight flows generated by all other states, 2002.

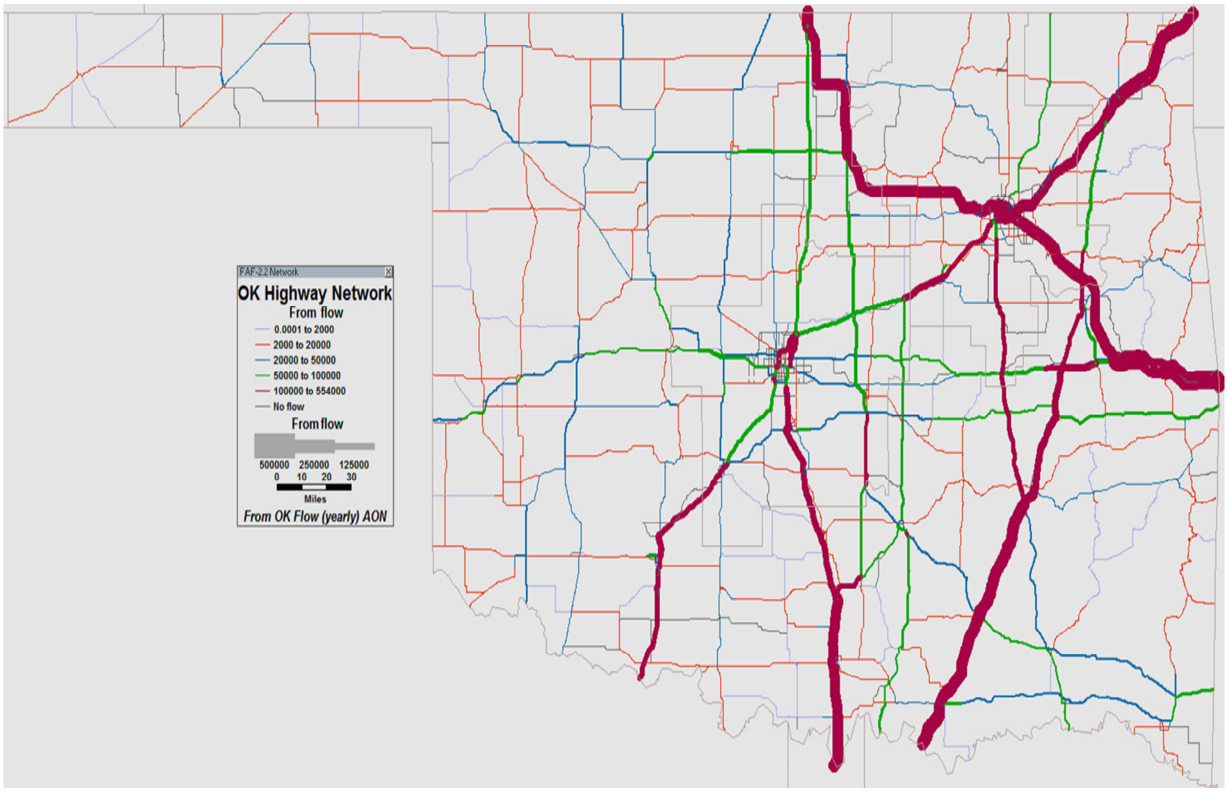

Figure 12. From flows assigned to Oklahoma highway networks, 2002.

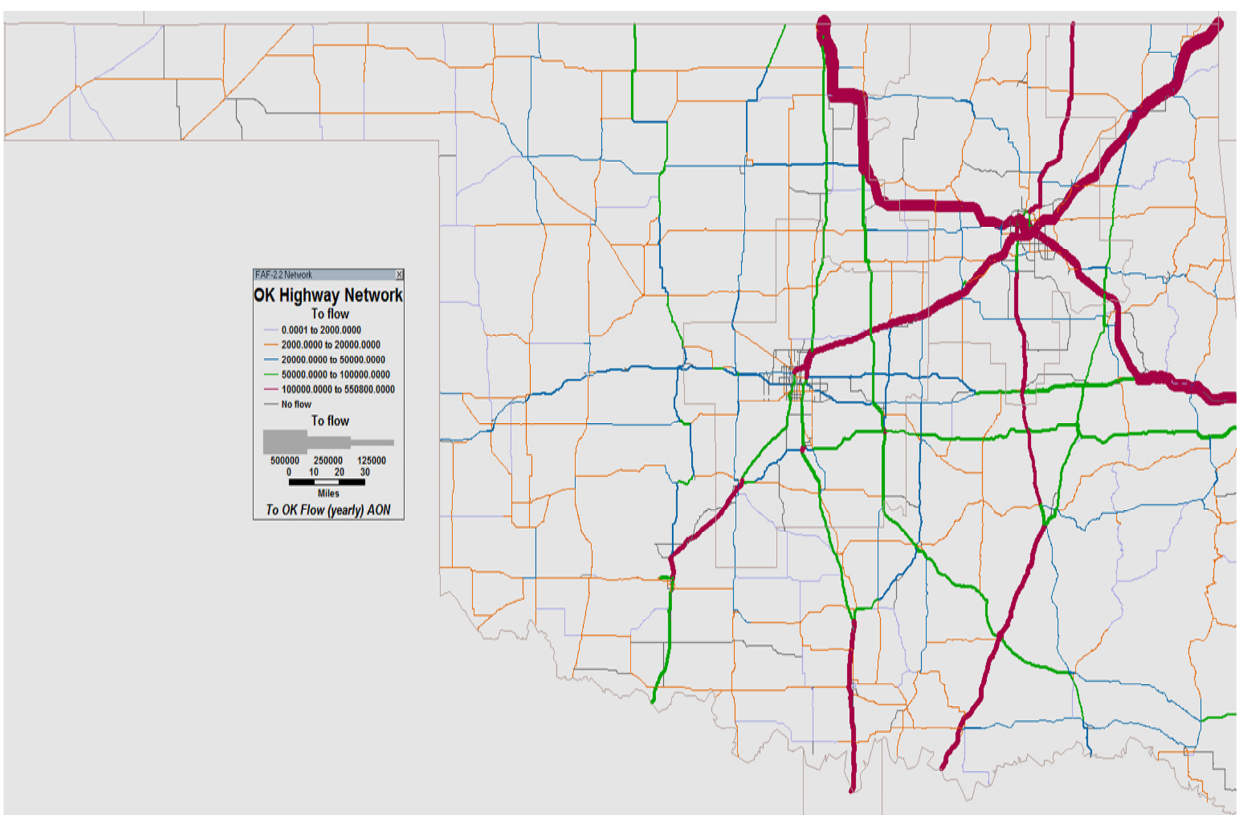

Figure 13. To flows assigned to Oklahoma highway networks, 2002.

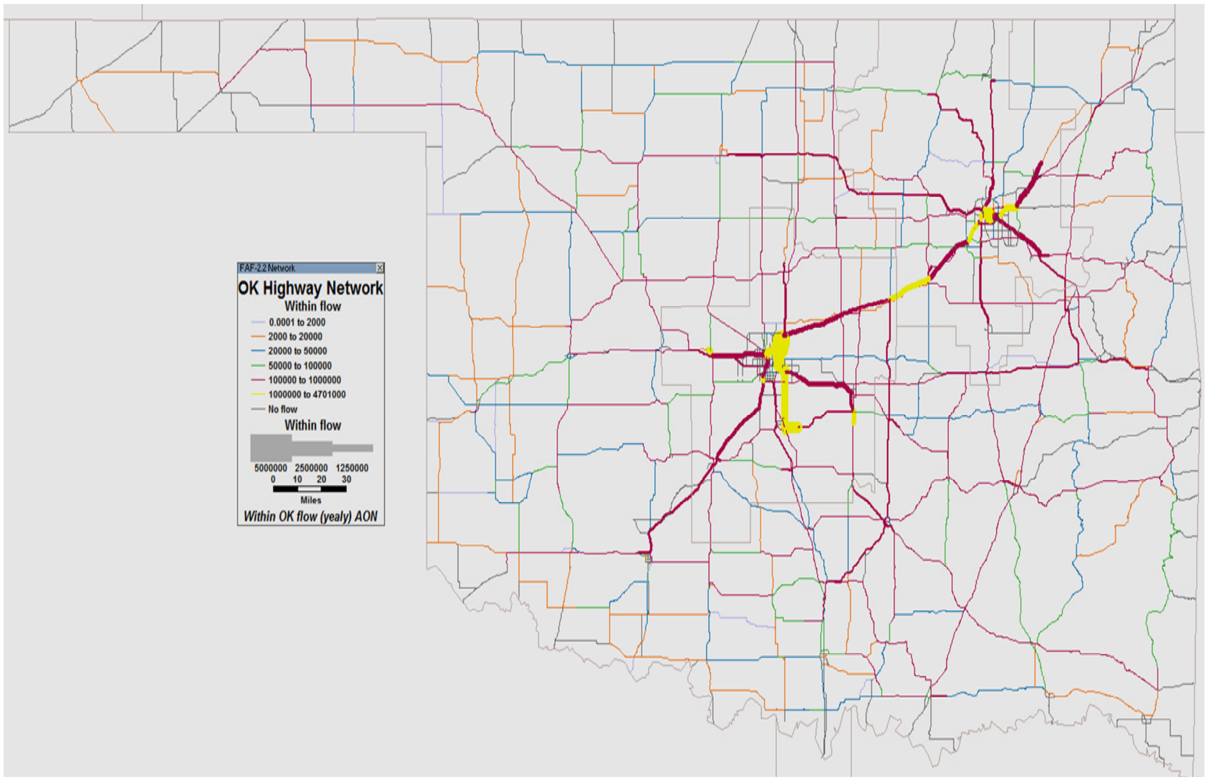

Figure 14. Within flows assigned to Oklahoma highway networks, 2002.

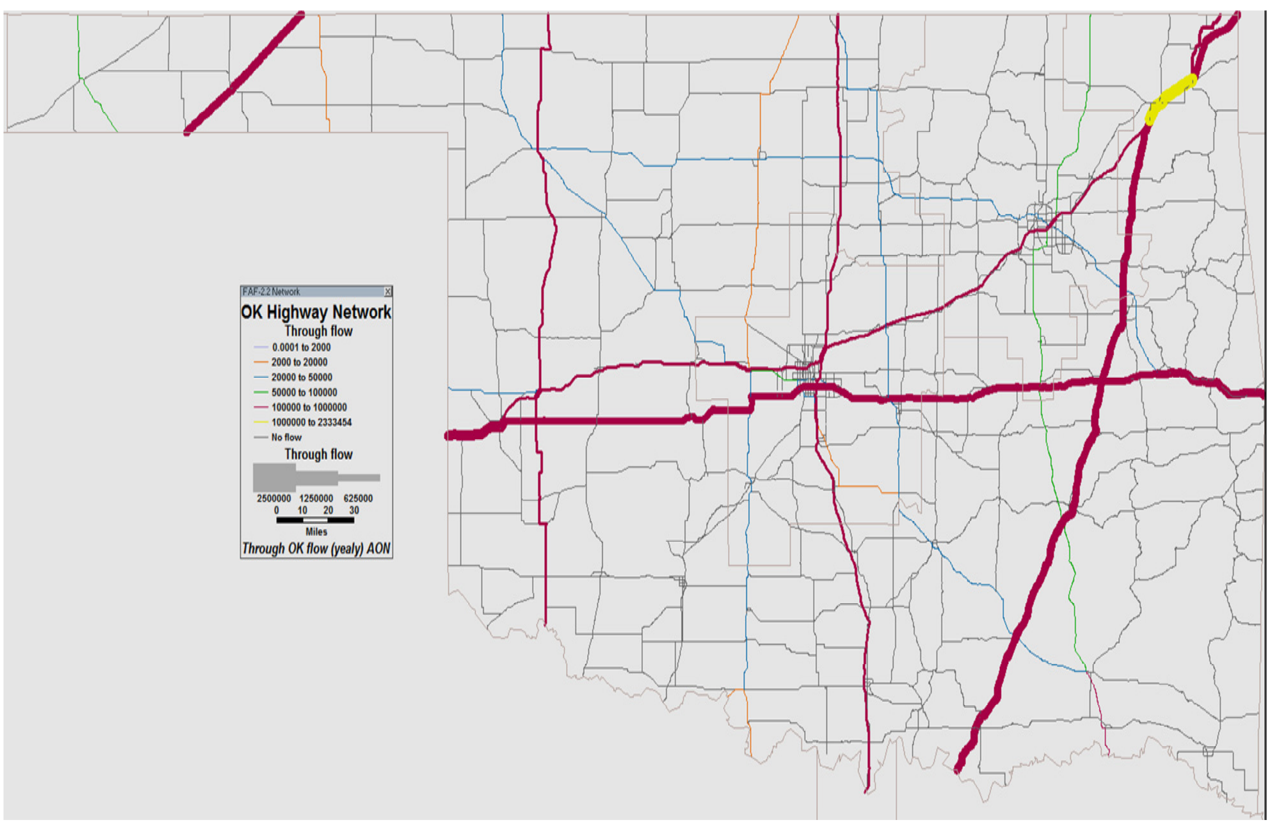

Figure 15. Through flows assigned to Oklahoma highway networks, 2002.

Table 8. Oklahoma from, to, within, and through flows and percentages, 2002 to 2035.

Flow type	2002	2010	2015	2020	2025	2030	2035
From	45,772	50,713	54,488	60,773	69,219	78,660	88,551
To	37,004	42,680	47,440	53,118	60,653	70,592	83,092
Within	235,118	240,151	256,074	278,577	306,883	338,645	370,764
Through	86,021	101,688	111,920	124,796	143,304	167,130	195,348
Flow Type	2002	2010	2015	2020	2025	2030	2035
From (%)	11	12	12	12	12	12	12
To (%)	9	10	10	10	10	11	11
Within (%)	58	55	54	54	53	52	50
Through (%)	21	23	24	24	25	26	26

Table 9. Top twenty trading partners for freight flows through Oklahoma.

Origin	Destination	2002	2035	2002 rank
CA	NY	116,472	531,250	3
CA	PA	101,971	511,371	7
CA	MD	92,660	446,035	10
CA	MA	107,468	341,613	4
CA	OH	99,078	340,667	8
CA	NJ	90,511	331,781	11
CA	FL	50,424	315,399	25
MA	FL	74,015	291,998	17
CA	GA	62,035	289,232	21
OH	CA	175,033	268,222	1
ME	FL	84,832	263,965	13
CA	IL	78,673	240,657	16
MI	CA	73,906	226,660	18
NJ	FL	94,092	224,216	9
OR	FL	40,177	219,657	32
IN	CA	102,366	218,073	6
AZ	NY	36,840	196,639	34
MI	TX	37,373	182,371	33
OH	FL	47,909	180,872	28
TX	NJ	50,952	176,946	24
Top 20 sum		1,616,787	5,797,622	
Top 20 %		11.95	18.92	
Total		13,524,100	30,641,974	

Oklahoma, Table 8 shows numerically the volumes and percentages of from, to, within, and through flows in Oklahoma. Clearly, Oklahoma, as many other states, generates and receives most freight flows itself, as demonstrated by the 50 to 58% within flows, although the within percentage steadily decreases from 2002 to 2035. However, Oklahoma's through flow increases from 21to 26% in 2002 to 2035, making Oklahoma to be even more the cross-road of America in the future. Also, Oklahoma is fairly balanced with the difference between freight production and attraction to be within 1 to 2% from 2002 to 2035.

Table 9 shows the top twenty trade partners of Oklahoma. CA-NY ranked first in 2035, while occupying the 3rd ranking in 2002. OH-CA ranked first in 2002, but ranked 10th in 2035. The top twenty trading partners contribute to almost 12% in 2002 to 19% in 2035 Oklahoma's total through flows. West coast CA, East coast NY, PA, MA, NJ, FL, Mid-Western MI, Southwest TX, and Southeast FL, GA contributes the most to

Table 10. Top, middle, and bottom five states by producing percentage change, 2002 to 2035.

State	2002 (%)	2010 (%)	2015 (%)	2020 (%)	2025 (%)	2030 (%)	2035 (%)	2035-2002 (%)
KY	47.4	49.0	53.2	58.8	64.4	68.5	71.9	24.5
MI	51.5	52.7	58.3	63.8	68.3	72.1	75.8	24.3
ID	54.9	59.6	63.5	67.4	71.6	74.9	76.2	21.3
OR	48.7	53.0	57.5	61.6	64.3	66.8	69.4	20.6
CA	43.5	51.3	54.0	56.4	58.1	59.9	61.2	17.6
…	…	…	…	…	…	…	…	…
NC	51.8	52.3	52.4	53.0	52.9	52.9	53.6	1.8
NH	51.8	57.2	55.6	55.0	53.6	53.1	53.2	1.4
LA	51.3	52.3	54.5	55.7	55.1	53.5	52.3	1.0
CT	43.5	43.4	43.8	44.1	44.2	44.0	43.9	0.3
SC	54.0	53.6	53.6	53.2	53.5	53.7	53.1	-0.9
…	…	…	…	…	…	…	…	…
AR	49.1	43.8	41.6	39.1	36.6	34.3	32.1	-17.0
KS	55.9	49.1	46.7	43.4	40.9	39.2	38.1	-17.8
FL	40.9	30.0	27.1	24.4	21.8	19.5	17.2	-23.7
NY	51.1	40.0	36.6	33.9	31.2	28.1	25.9	-25.2
WA	44.1	37.0	32.2	27.1	22.8	18.6	15.4	-28.6

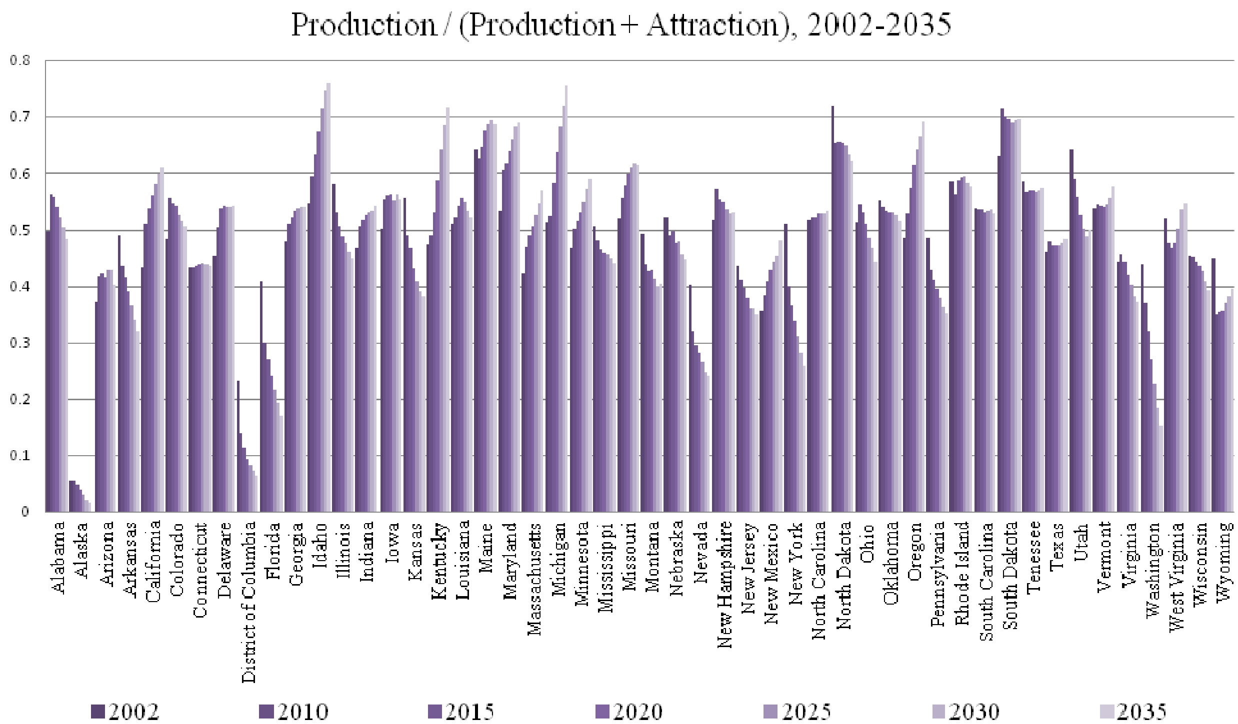

Figure 16. Changes in freight producing status by state, 2002 to 2035.

Oklahoma's through flows.

Freight flow measures

The ratio of a state's production to its production and attraction defines whether the state is a freight production state or not. If the ratio is greater than 50%, the state is classified as a producing state. Results of this analysis are summarized in Table 10, Figures 16 and 17. There are 24 states with an average of 55.78% and 27 states with an average of 59.73% classified as producing states

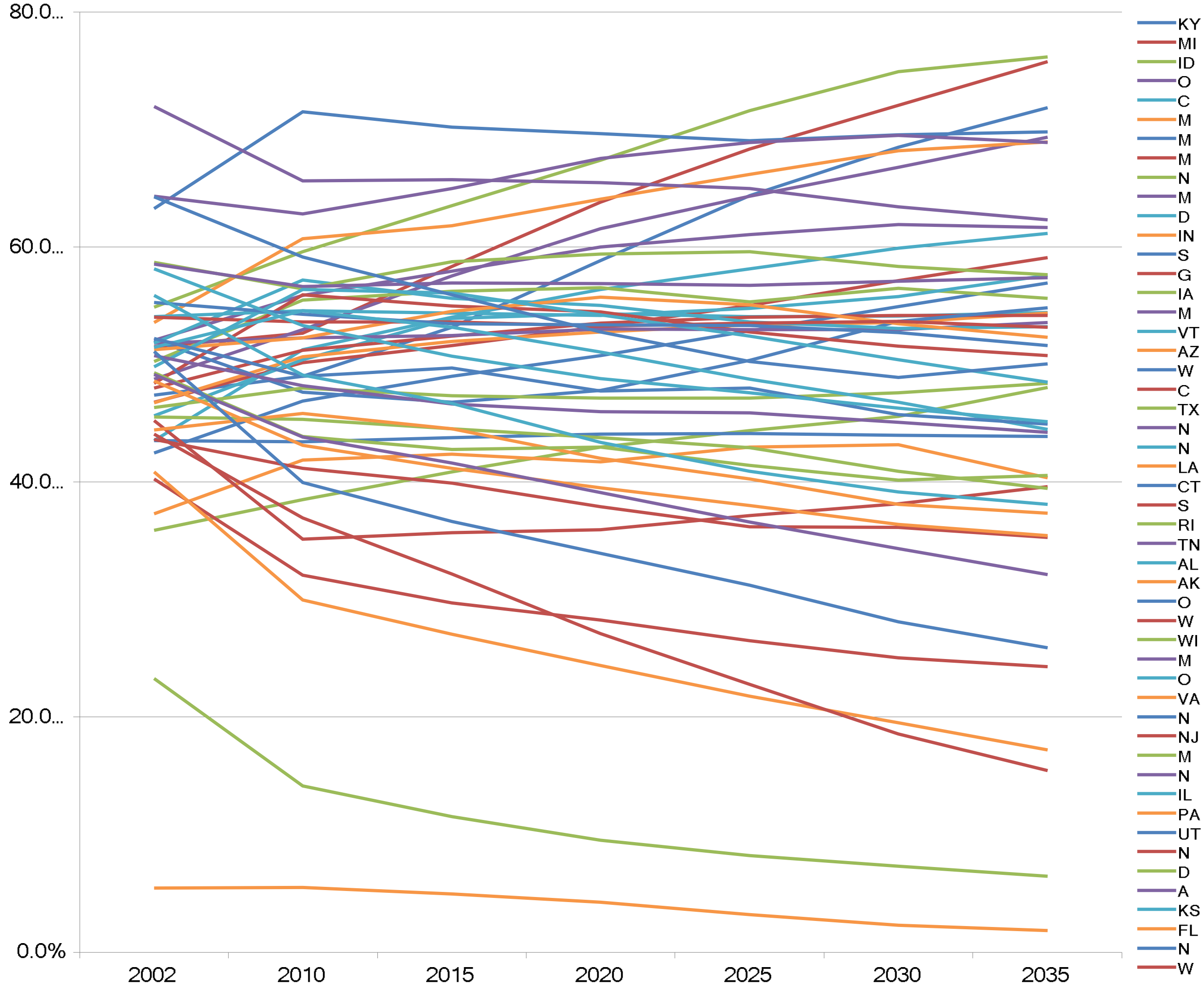

Figure 17. Producing status by state, 2002 to 2035.

in 2002 and 2035, respectively. States like ID, MI, KY, and OR have the highest percentage changes during 2003 to 2035 with an increase of their percentages of production freight flow by more than 20%, whereas states like WA (-28.62%), NY (-25.20%), and FL (-23.68%) have a decrease and move down the list from producing states to attracting states.

Generally, states tend to move either to the low freight production or the high freight production groups. Freight production range in 2002 is 48.67% (minimum: 23.30%, maximum: 71.98), whereas in 2035 it changes to 69.74% (minimum: 6.44% maximum: 76.19%). A higher range indicates the increased gap between states in freight production. AK, DC, FL, NH, and WA have an average 30-% freight production. Interestingly, with respect to a state's population size, some smaller states, such as ID, ME, ND, and SD, are the strongest production states (60+%) while some larger states, such as, NY, NJ, and FL, are the strongest attraction states (30-%). Oklahoma as a whole is a freight production state with a small production variation during 2002 to 2035, similar to the states of IA, SC, NC, RI, and VT. While WA, UT, PA, NY, NV, KS, AR, DC, and FL have the largest drops, CA, ID, KY, MD, MA, MI, MN, NM, and OR have the largest growths in freight production during 2002 to 2035.

Figure 17 lists all the states by the ratio of production vs. total production and attraction. Clearly, most states have their ratios within 40 to 60%, with only a few states below 40 or above 60% during 2002 to 2035; hence most states are balanced in terms of production and attraction in total freight. While the production ratios change over the period, most of them are quite stable. Interestingly, some state ratios (that is, KY, MI, ID, OR, and CA) consistently increase or decrease (that is, AR, KS, FL,

Table 11. Top, middle, and bottom five ratios of within flows, 2002 to 2035.

State	2002 (%)	2010 (%)	2015 (%)	2020 (%)	2025 (%)	2030 (%)	2035 (%)	2002 rank
CA	92.7	93.5	93.7	93.8	93.7	93.5	93.2	1
ND	89.7	89.1	89.2	89.1	88.8	88.4	88.1	4
OR	84.3	84.9	85.7	86.7	87.1	87.4	87.8	8
ID	81.8	84.2	85.0	85.6	86.2	86.7	87.0	12
TX	87.1	87.5	87.2	86.9	86.5	86.4	86.7	5
WA	85.6	84.6	82.7	80.5	78.0	75.0	72.0	7
IL	81.6	79.6	77.7	76.0	74.3	72.6	71.2	13
KY	62.6	62.4	64.5	66.9	69.1	69.9	70.5	44
IA	71.0	73.2	72.7	72.4	71.3	70.7	69.7	29
TN	73.9	72.9	72.6	71.9	70.9	70.0	69.2	24
NJ	60.0	60.8	59.6	57.5	55.0	52.9	50.3	46
AR	64.5	61.8	59.6	56.9	53.9	51.1	48.2	42
NV	66.6	60.9	58.1	56.0	52.6	49.6	47.7	40
DE	44.9	46.5	49.4	48.3	45.8	44.2	43.2	49
DC	15.3	3.6	3.5	3.1	3.0	2.9	2.8	50
Average	73.3	72.3	71.9	71.3	70.3	69.3	68.4	

NY, and WA) from 2002 to 2035.

Table 11 shows the within flow measures for the top and bottom five states listed in descending order by 2035 percentage. While the rankings and percentages vary from 2002 to 2035, most states have a percentage of 50% or higher, meaning most states during the period are self-sufficient in that whey a state's demand is met by the state's supply by at least 50%. In fact, only 17 out of 51×7=357entries in Table 13, or specifically DE and DC from 2002 to 2035, AR in 2035, and NV in 2030 and2035, have a within flow percentage smaller than 50%. CA is the only state that consistently produces over 92% of its demand while DC is the only state that consistently depends more outside supply over 85% to operate. Also, the state within flow percentages range from virtually no change (that is, SC at 73.3% in both 2002 and 2035) to a large change (that is, NV at 66.6% in 2002 and 47.7% in 2035).

Table 12 illustrates the through flow percentages by state ranked by 2035 through flow percentage. While DC and CA have the lowest or highest within flow percentages as shown in Table 11, here DC and CA have the top or bottom percentages in through flows. Almost all states have a through flow percentage over 66%, meaning that most the highway networks of most states carry more through flows, except WA, FL, CA and four other states (AK, ME, MI, and RI), whose through flows are zero due to the all-or-nothing assignment used for each state's through flows. Spatially, the states with higher through flow percentages are inner states while those coastal or border states have smaller through flow percentages. As the "cross-road" of America, Oklahoma ranks 31st state in handling through flows with 88.1% in 2002 and 91.3% in 2035. Some states have increasing percentages while other states have decreasing percentages from 2002 to 2035; however, the variations are small in the range of -4.8% (ND) to 8.3% (WA).

Regression linkage of freight flows and socio-economic factors

Linear regressions were run with the 2002 base-year economic factors such as employment, establishment, payroll, and revenue (or sales) as dependent variables and the total from, to, within, and through flows at the state level as the independent variables. The back elimination process was used to identify the best regression and the results were summarized into Table 13.

Here, the results from initial runs with all variables included are summarized in Table 13. The variable Through Freight in all cases is not insignificant, as indicated by *P*-values of more than 41%. The numbers in bold show the significant model results for the four regression models without the through flow variable. These significant models with good *R*-square values ranging from 87.8% to 89.9% all have *P*-values at 95% or more. Also, as expected, the signs of independent variables from freight and within freight are all positive since they contribute directly to the employment, establishment, payroll, and revenue of the transportation industry. Since the To Freight of a state is more likely shipped by transportation firms outside that state, the independent variable To Freight has a negative sign.

Table 12. Top and bottom ten state through flow percentages, 2002 to 2035.

State	2002 (%)	2010 (%)	2015 (%)	2020 (%)	2025 (%)	2030 (%)	2035 (%)	2002 rank
DC	99.6	99.5	99.5	99.4	99.4	99.4	99.3	1
WV	98.4	98.3	98.4	98.5	98.5	98.5	98.6	2
DE	98.1	98.1	98.1	98.1	98.1	98.1	98.1	3
NM	97.9	97.9	97.9	97.9	97.9	97.9	98.0	4
KY	97.2	96.9	96.9	96.9	96.8	96.8	96.8	5
MS	95.6	95.8	96.0	96.2	96.3	96.4	96.5	7
WY	96.7	96.4	96.2	96.1	96.1	96.1	96.1	6
NV	95.1	95.0	95.1	95.2	95.4	95.6	96.0	9
NH	95.4	94.9	95.1	95.3	95.5	95.8	95.9	8
AR	93.1	93.3	93.6	94.0	94.5	94.9	95.4	16
MN	73.2	74.1	75.2	75.6	75.3	75.9	75.7	41
TX	68.1	67.9	68.3	68.8	69.7	70.3	70.7	43
ND	71.5	68.5	67.7	67.2	66.9	66.9	66.7	42
WA	42.6	40.5	41.9	43.4	45.6	48.2	50.9	44
FL	2.3	1.8	1.8	1.7	1.6	1.6	1.5	45
CA	1.2	1.3	1.3	1.3	1.3	1.4	1.3	46
AK	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47
ME	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47
MI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47
RI	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47

Conclusions

Freight flow movements provide a unique perspective of understanding the national and local economies. This research develops a set of measures for mainly state-level or MSA-level freight flows for the United States, namely from, to, within, and through freight flows, which can be used to classify a state or MSA as: production, attraction, or through state or MSA. In production freight flow, the states IL, MI, and KY are the top 3 in all commodities, whereas DC and AK are the lowest freight flow states. In attraction freight flow, IL, OH, and PA share the top three spots. States that have the lowest attraction figures are VT, ME, and AK. For the period of 2000 to 2035, production and attraction freight flows fluctuate for many states, although the totals for the United States are increasing in the same period. One particular finding is that some producing states are becoming less productive, whereas other states are becoming significantly more productive during 2000 to 2035, which clearly shows the ups and downs of state economic dynamics. In general, we can say that an attraction state is less self-sufficient than a production state.

Similarly, within freight flows typically increase over time as their population increases. Large states, such as CA, TX, IL, and FL, typically have very high within freight flows compared to other smaller states, such as DC, AK, and RI. The more within freight flows a state has, the more independent the state is.

The highest through flow carrying states are IN, KY, and IL. Clearly, these states are used to satisfy the high productions and attractions from other state pairs who have freight interactions. Typically, the higher the through flow a state has, the more it is used as the "cross-road of America". States contributing more through flows can be regarded as benefiting from other states. States with a higher through flow may need to consider more federal funding to upgrade their highway networks or they may consider charging through traffic tolls for out of state through freight, though this is a politically sensitive topic worthy of further research.

Freight flows are good reflections of national and local economies. Indeed, the regression models explaining freight flows by employment, establishment, revenue, and payment are statistically sound, particularly for state-level production, as shown by attraction and within flows with R-square values between 87.8 to 89.9%. The regression results for state through flows are not significantly explained by the same set of state economic indicators, opening the door for future models with better variables.

This research is limited to all-or-nothing assignment using the shortest paths without taking into account the network capacity, and is determined for the U.S. highway only. Further research considering highway capacity and other freight modes such as rail, air, and water or intermodal will certainly provide better results. In addition, a study on the socioeconomic relationship between

Table 13. Results of regression of freight flows and socio-economic indicators, 2002.

Dependent variable	Statistics	From freight	To freight	Within freight	Through freight	*R*-square /intercept
Establishment (EST)	Coefficient	0.059729	-0.04362	0.01645	-1.5E-05	
	t-stats	3.587786	-2.88304	6.231616	-0.00014	0.898615/292.7481
	P-values	0.000899	0.00631	2.23E-07	0.999888	
	Coefficient	**0.059729**	**-0.04362**	**0.01645**		
	***t*-stats**	**3.651052**	**-2.98794**	**12.0761**		**0.898615/292.7547**
	***P*-values**	**0.000732**	**0.004727**	**4.38E-15**		
Employment (EMP)	Coefficient	1.413703	-1.05716	0.33953	-0.52466	
	t-Stats	3.813788	-3.13835	5.776454	-0.22937	0.881085/-1585.11
	P-values	9.74E-07	0.000464	0.003186	0.819752	
	Coefficient	**1.405107**	**-1.04064**	**0.328034**		
	T-stats	**3.85492**	**-3.19965**	**10.80815**		**0.880929/-1347.29**
	P-values	**0.0004**	**0.002655**	**1.43E-13**		
Payroll (PAY)	Coefficient	43.7947	-33.8928	11.17931	-3.48239	
	t-stats	-3.02048	3.546721	5.709594	-0.0457	0.878229/-79816.5
	P-values	0.001012	0.004383	1.21E-06	0.963775	
	Coefficient	**43.73764**	**-33.7831**	**11.10301**		
	***t*-stats**	**-3.12021**	**3.604481**	**10.98889**		**0.878223/-78238**
	***P*-values**	**0.000839**	**0.003304**	**8.58E-14**		
Revenue (REV)	Coefficient	125.7497	-110.002	36.37945	188.8557	
	t-stats	3.378533	-3.25225	6.163994	0.822261	0.900412/20996.09
	P-values	0.001635	0.002329	2.78E-07	0.415803	
	Coefficient	**128.844**	**-115.949**	**40.51745**		
	***t*-stats**	**3.493327**	**-3.52322**	**13.19298**		**0.898729/-64610.4**
	***P*-values**	**0.001158**	**0.001063**	**2.41E-16**		

freight and freight movement could offer a deeper understanding of freight flow dynamics at the national, regional, and local levels for better decisions and policies regarding freight transportation.

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