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Forecasting Freight Logistic Needs and INDOT Plans

Ananth V. Iyer, Thomas Brady, Steven R. Dunlop, Dutt J. Thakkar, Saichandar Naini, Srinath Jayan, Suraj Vasu, Sanjayraj Mohanraj, Janani Srinvasan

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This project focused on forecasting freight logistics needs and developing and analyzing capacity plans for INDOT to consider. The forecast timeframe ranges from the 2020 to 2045; the commodities considered are those used in the FHWA framework. We considered five SSP (Shared Socio-Economic Pathways) scenarios that are in sync with those used by the IPCC (International Protocol for Climate Change). We also use the IPCC forecasts of world GDP and FHWA forecasts to develop county-level freight forecasts by commodity. A survey of industry participants, primarily in manufacturing, suggests that Indiana industries are tied to the rest of the country and the world for supply of inputs as well as for demand markets. Finally, we focus on three different industries—the recreational vehicle (RV) industry in Elkhart County, the furniture industry in Dubois County, and the Honda plant in Decatur County—to illustrate the impact of bill of materials and growth forecasts on forecasted congestion and potential capacity mitigation. Our results suggest that proactive capacity planning can enable INDOT to anticipate and ease congestion and ensure continued economic competitiveness for Indiana industries.</td></tr>
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EXECUTIVE SUMMARY

Introduction

This project focused on forecasting freight logistics needs and developing and analyzing capacity plans for the Indiana Department of Transportation's (INDOT) consideration. The forecasted time frame is from 2020 to 2045, and the commodities considered are those used in the Federal Highway Administration (FHWA) framework. We considered five SSP (Shared Socio-Economic Pathways) scenarios that are coordinated with those used by IPCC (International Protocol for Climate Change). We used the IPCC's forecasts of world Gross Domestic Product (GDP), along with FHWA forecasts, to develop county-level freight forecasts by commodity. A survey of industry participants, primarily in manufacturing, suggests that Indiana industries are tied to the rest of the US and the world for a supply of inputs and for demand markets. We focused on three different industries—the recreational vehicle (RV) industry in Elkhart County, the furniture industry in Dubois County, and the Honda plant in Decatur County—to illustrate the impact bill of materials and growth forecasts have on forecasted congestion and potential capacity mitigation. Our results suggest that proactive capacity planning can enable INDOT to anticipate and ease congestion and thus ensure continued economic competitiveness for Indiana industries.

Findings

Our forecast of the SSP scenarios show a greater variance in freight forecasts than the forecasts provided by FHWA. This potential larger upside, the scenario called SSP5, is the result of a potential worldwide focus on education and growth, which may result in a potential 50% increase in world GDP. If INDOT desires to plan for opportunities related to such growth, there will be associated county-level capacity decisions. We provide forecasts similar to this by county, scenario, and future years through 2045.

This report provides analysis of strategic goals for neighboring states and associated expenditure of funds. INDOT's priorities focus on the state of good roads and easing congestion. Our survey indicates that these attributes are coordinated with industry needs to remain competitive; however, our survey suggests industry prefers to explore access to waterways and railroads too.

Implementation

Our capacity planning model focuses on case studies by industry. This industry perspective connects the bill of materials of inputs to the volume of outputs, thus quantifying the inflows and outflows for the industry. For example, the RV industry in Elkhart has been growing, and requires several inputs from out of state and ships a large portion of its outputs out of state. Thus, the projected growth of the industry increases inflows and outflows. We built a mathematical programming model with scenarios to develop optimal ramp capacity expansion and provide results. The same approach has been used to develop results for Dubois County's furniture industry cluster and for Decatur County's Honda plant. Additional models of industry clusters were added for Allen County, Bartholomew County, Gibson County, Howard County, Vigo County, and Marion County.

In summary, this report provides county-level, long-term commodity freight forecasts through 2045, a current industry survey of company preferences, and a model for INDOT's use as they consider adjusting road capacity to ensure continued economic competitiveness of the Indiana's industries.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. PROJECT OVERVIEW

1.1 Introduction

Indiana, known as the Crossroads of America, has transformed into a global center of transportation and logistics of the 21st century. Indiana's robust and multi-modal transportation infrastructure is critical to provide companies with a competitive advantage in manufacturing and distribution. Indiana has been recorded as the fifth busiest state for commercial freight traffic as it serves regional, national, and international markets due its strategic location (IN.gov, n.d.).

The Indiana Department of Transportation is responsible for maintaining and regulating transportation and transportation related infrastructure in the state (Wikipedia Contributors, 2021). INDOT plays a significant role in enabling Indiana's industry-level competitiveness by supporting freight logistics across Indiana through multi-modal freight systems. According to the *Indiana Department of Transportation 2019 Strategic Plan* (INDOT, 2019), INDOT is responsible for more than 4,000 freight railroad miles, over 110 public access airports, and maintains more than 11,000 centerline miles and observes more than 1.5 billion tons or $495 billion worth of annual freight movement throughout Indiana.

As freight logistics has a significant impact on Indiana's economy and transportation system with a forecasted increase in freight flow by 60% by 2040, INDOT aims to provide an integrated freight transportation and logistics system that ensures the efficient, reliable, safe, and secure movement of goods, materials, and services which support the state's economic growth and competitiveness (IN.gov., n.d.).

It is imperative for INDOT to stay proactive and plan for the future growth in freight truck and the corresponding impact on state's economy. In this project, we study various factors influencing freight movement across Indiana, therefore, influencing the economy of the state. The information for the analysis has been gathered through online resources made available by the state and private organizations, literature review of research papers, and articles and input from appropriate industry representatives gathered through surveys.

1.2 Objectives

The objective of this project is to identify specific industry clusters within the state of Indiana, identify their respective inbound and outbound freight flows, and, through the use of an economic model, provide INDOT with a roadmap of specific, targeted roadway projects that will enhance the competitiveness of these industry clusters. The time frame for the analysis is 20 years. A comparative analysis of neighboring states relative to their long-term transportation infrastructure projects is provided for benchmarking purposes. The analysis is presented through the use of three industry cluster cases studies: the recreational vehicle (RV) industry, the furniture industry, and the integration of an automotive assembly plant supply chain.

1.3 Project Timeline

Figure 1.1 provides a Gantt chart for the project. The Gantt chart outlines the time periods and the interface of the phases of the project. The project was divided into five phases.

Phase 1 included gathering information about the various industries, the stake holders of the freight logistics in Indiana and analyzing the volume of flow of commodities across the various industries to identify special influence on economy.

Phase 2 comprised a literature review and benchmarking analysis for states in the Midwest region as Indiana would see a lot of freight traffic from these neighboring states. Hence, it would be helpful to review the neighboring Midwestern states and the approach they have taken to stay competitive and prepare for future.

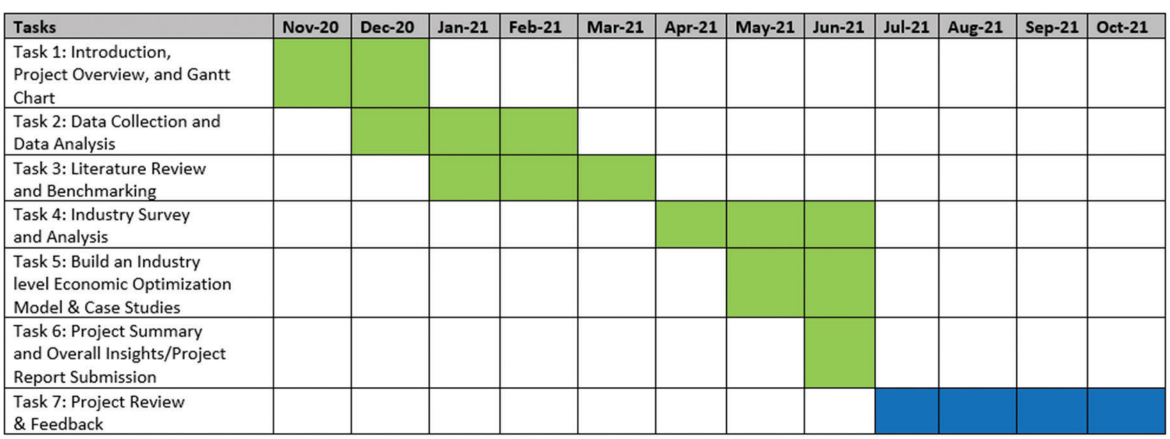

Figure 1.1 Gantt chart.

Phase 3 included the development of a survey regarding the supply chain of targeted companies in Indiana. This survey would provide important insight into the needs of companies around Indiana and their perception of freight logistics.

Phase 4 included the development of an industry-level economic model that analytically optimizes inbound and outbound freight mobility, reliability, cost effectiveness, and overall mobility for specific industry clusters on the INDOT road network. Furthermore, the objective of the model would be to exhibit the benefits of an improved freight flow on enhancing select industry cluster competitiveness.

Phase 5 included presenting the overall insights gained from the project incorporating INDOT and industry personnel feedback. This phase also included preparing the final draft report with recommendations made to INDOT on future freight growth and its impact on economy and competitiveness.

2. DATA COLLECTION AND ANALYSIS

2.1 Freight Analysis Framework (FAF)

The United States Department of Transportation (USDOT), Federal Highway Administration (FHWA) through a partnership with Bureau of Transportation Statistics (BTS) integrates data from a variety of sources to create a comprehensive picture of freight movement among states and major metropolitan areas by all modes of transportation. FHWA administers the Freight Analysis Framework (FAF) (Oak Ridge National Laboratory, 2022) to periodically survey goods movement and to use that data to develop long-term forecasts for commodity flows between domestic and international origin-destination pairs (Fullenbaum & Grillo, 2016). In keeping with the 5-year FAF cycle, FAF4 was developed from Commodity Flow Survey (CFS) released in early 2016, with 2012 as the base year data set. CFS acts as the backbone of FAF and are integrated with auxiliary data sources that explain goods movement in agriculture, resource extraction, utility, construction, retail, services, and other sectors. FHWA works with various entities to apply macroeconomic data and other industry insights to forecast the future commodity flows up to the year 2045.

The FAF version 4 (FAF4) forecasts are provided for 132 mutually exclusive regions that fully partition all the states within US. Moreover, exports from and imports to these 132 regions are forecasted with respect to 8 international regions. The flow forecasts are further disaggregated by 7 domestic and 8 international modes of transportation and by 43 domestic and 42 international commodity classes (Fullenbaum & Grillo 2016). The result is a detailed database of forecasted domestic and international freight flows into, within, and out of each CFS-defined region. FAF4 provides estimates for tonnage, value, and ton-miles by regions of origin and destination, commodity type, and mode. Data are available for the base year of 2012, the recent years of 2013–2018, and forecasts from 2020 through 2045 in 5-year intervals.

For this project, data was collected for all major commodities flowing into and out of the state of Indiana, the mode by which it is transported, the weight and monetary value of the transported goods. The data was extracted using the Data Tabulation Tool (DTT) present on the FAF website (Oak Ridge National Laboratory, 2022).

2.1.1 FAF Zones

The CFS region definitions represent the basic geographic unit of analysis for FAF4. The forecasting process focuses on inter-regional flows. FAF4 forecasts are provided for 132 mutually exclusive regions that fully partition all the states within US. Each of these CFS regions are assigned a zone ID and consist of number counties aggregated as a single geographical entity.

Indiana has the following four FAF zones:

1. Chicago-Naperville, IL-IN-WI CFS Area (IN Part) Zone ID: 181,
2. Indianapolis-Carmel-Muncie, IN CFS Area Zone ID: 182,
3. Fort Wayne-Huntington-Auburn, IN CFS Area Zone ID: 183, and
4. Remainder of Indiana Zone ID: 189.

The four FAF zones present in Indiana are highlighted in Figure 2.1 and list of counties in each zone is listed in Table 2.1.

The FAF DTT allows us to extract total flows into, out of and within these zones. Total flows contain the data associated with freight moved between domestic origins and domestic destinations and includes both domestic and foreign shipments. For import shipments, the origin of the flow is zone of entry and for export shipments, the destination of the flow is zone of exit.

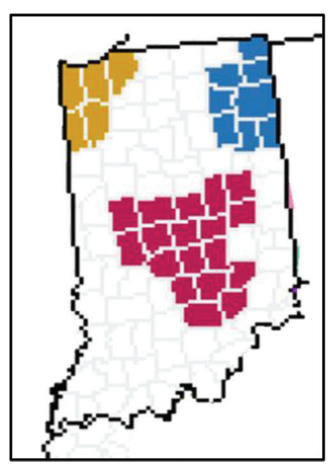

Figure 2.1 The four zones of Indiana.

TABLE 2.1
List of Counties in FAF Zones in Indiana (Oak Ridge National Laboratory, 2022)

FAF Zones in Indiana			
Chicago	**Fort Wayne**	**Indianapolis**	**Rest of Indiana**
Lake	Allen	Marion	Other counties
Newton	Adams	Delaware	
Jasper	Wells	Henry	
Porter	Huntington	Decatur	
LaPorte	Whitley	Madison	
	DeKalb	Hancock	
	Steuben	Shelby	
	Noble	Bartholomew	
		Jackson	
		Jennings	
		Brown	
		Johnson	
		Morgan	
		Montgomery	
		Putnam	
		Boone	
		Hamilton	
		Hendricks	

2.1.2 Standard Classification of Transported Goods (SCTG) CODES

Commodities are classified at the 2-digit level of the Standard Classification of Transported Goods (SCTG) codes, summarized in Figure 2.2. A complete description of these categories and their constituent parts can be found on the Bureau of Transportation Statistics' (BTS) CFS website (Bureau of Transportation Statistics, 2018). All 2-digit SCTG commodity flow between 132 domestic zones and 8 foreign zones is available on FAF.

2.1.3 Indiana Statistics from FAF4

In this section we utilize the data extracted from the FAF Data Tabulation Tool to present a few statistics for the state of Indiana.

Table 2.2 presents the top commodities by weight that flow into the state, out from the state, and within the state of Indiana for the year 2018. Coal and base metals are major commodities that cross the state boundary for inflow and outflow. Cereal grains majorly flow within the state as well as out of it. While within the state, gravel is the most transported commodity.

Table 2.3 shows the forecasted commodity flow for the year 2045. In comparison to the 2018 flow, we observe large increase in both inbound and outbound commodities. There is no large variation in the inbound commodity mix. We observe that outbound SCTG code commodity—other food stuff and non-metallic products have grown with respect to cereal in the year 2045 and there is a decrease in the coal being transported within the state.

Table 2.4 shows the commodity mix for the inbound, outbound, and commodity flow within the state.

Table 2.5 shows the modal mix in the commodity flow for domestic, export, and import flows. We observe that around 5.6% of total commodities that are generated in the state is exported out of the US and similarly only 5% of the total commodities of the total inbound commodity originate from foreign zones.

Trucks are used to transport goods domestically predominantly while rail is the preferred mode of transport for import goods.

2.2 County-Wise Disaggregation

The smallest level of flow available on FAF is zone level commodity flow. To study change in freight volumes over time at a finer level county-level flows need to be derived. This will also help us analyze what counties grew in freight volumes and change in economic activity spatially over time.

In this project major commodities for the state of Indiana are identified and their flow into a county, out of a county and within a county are identified for past years and projected for future years under various scenarios.

2.2.1 Methodology

Initially the major commodities flowing though the state of Indiana are identified. The top commodities contributing towards freight have been generated from FAF DTT in the previous section. It is to be noted that over 95% freight that moves through the state is being transported through trucks and rail. Therefore, majority of our analysis will focus on these modes of transport. The *INDOT Multimodal Freight Plan Update* (Cambridge Systematics, Inc., n.d.) also lists top commodities that are transported by these modes, and they are presented in Figure 2.3 (2018) and Figure 2.4 (2045). The freight plan also lists production industry and attraction industry associated with each of these commodities. Production industry accounts for the industries associated with generation of a particular commodity and in turn affects the outflow of the commodity, while the attraction industry(s) are industries that consume the said commodity and in turn affects its inflow. All freight flows are a function of the inflow generated by the attraction industries and the outflow generated by the production industries.

Next step in our analysis is to disaggregate the zone level flows that we extract from the tabulation tool into county-level flows. Using total flows from the Data Tabulation Tool, we generate total weight of commodity flowing into a zone, out of it, and within it. This is done for all four zones in the state. Then we identify the GDP associated with the production and attraction industry of a commodity for all the counties. Next, the ratio of the industry GDP of a county relative to the aggregate of the industry GDP for all the counties of the zone in which the county is a part of is calculated. This ratio is calculated for both the production and

Code	Commodity Description
01	Animals and Fish (live)
02	Cereal Grains (includes seed)
03	Agricultural Products (excludes Animal Feed, Cereal Grains, and Forage Products)
04	Animal Feed, Eggs, Honey, and Other Products of Animal Origin
05	Meat, Poultry, Fish, Seafood, and Their Preparations
06	Milled Grain Products and Preparations, and Bakery Products
07	Other Prepared Foodstuffs, Fats and Oils
08	Alcoholic Beverages and Denatured Alcohol
09	Tobacco Products
10	Monumental or Building Stone
11	Natural Sands
12	Gravel and Crushed Stone (excludes Dolomite and Slate)
13	Other Non-Metallic Minerals not elsewhere classified
14	Metallic Ores and Concentrates
15	Coal
16	Crude Petroleum
17	Gasoline, Aviation Turbine Fuel, and Ethanol (includes Kerosene, and Fuel Alcohols)
18	Fuel Oils (includes Diesel, Bunker C, and Biodiesel)
19	Other Coal and Petroleum Products, not elsewhere classified
20	Basic Chemicals
21	Pharmaceutical Products
22	Fertilizers
23	Other Chemical Products and Preparations
24	Plastics and Rubber
25	Logs and Other Wood in the Rough
26	Wood Products
27	Pulp, Newsprint, Paper, and Paperboard
28	Paper or Paperboard Articles
29	Printed Products
30	Textiles, Leather, and Articles of Textiles or Leather
31	Non-Metallic Mineral Products
32	Base Metal in Primary or Semi-Finished Forms and in Finished Basic Shapes
33	Articles of Base Metal
34	Machinery
35	Electronic and Other Electrical Equipment and Components, and Office Equipment
36	Motorized and Other Vehicles (includes parts)
37	Transportation Equipment, not elsewhere classified
38	Precision Instruments and Apparatus
39	Furniture, Mattresses and Mattress Supports, Lamps, Lighting Fittings, and Illuminated Signs
40	Miscellaneous Manufactured Products
41	Waste and Scrap (excludes of agriculture or food)
43	Mixed Freight

Source: Center for Transportation Analysis, 2015

Figure 2.2 Two-digit SCTG codes (Center for Transportation Analysis, 2015).

attraction industry and for all the counties. These ratios are multiplied to the original outflow and inflow of the zones to obtain the tonnage of the commodity being transported into the county and out of the county. We assume that all flows within a zone is distributed among the counties of that zone according to GDP of the production industry and is used to calculate the flows within a county. This methodology is used to calculate the county-level flows for all years under consideration by inputting the Industry GDP for the respective years. The analysis is repeated for various modes of transport to get the modal flow for counties. The same is used to forecast future flows by using scenario GDP as the input to the model. The flows then generated will help us identify the special distribution of the commodity freight movement and its change over the years.

2.2.2 Scenario Analysis

In the previous section, the methodology to obtain county-level commodity flows is explained. To forecast future flows, we use future industry GDP as the input. This GDP can vary according to various socio-economic parameters and is scenario dependent. In this section we explain various possible future scenarios and its effect on the GDP and in effect the commodity flows.

TABLE 2.2
Top Commodities by Weight (2018)

Within the Given State (S to S)		Outbound from the Given State (S to all other states)		Inbound to the Given State (all other states to S)	
Commodity (switching)	**lbs_within 543.2**	**Commodity (lbs_out)**	**lbs_out 376.4**	**Commodity (lbs_in)**	**lbs_in 496.9**
Gravel	102.7	Coal-n.e.c.	73.4	Coal-n.e.c.	109.2
Cereal grains	82.8	Base metals	54.0	Coal	51.4
Coal	58.3	Cereal grains	33.7	Crude petroleum	45.2
Gasoline	45.2	Other foodstuffs	28.4	Base metals	34.1
Fuel oils	36.1	Animal feed	19.5	Metallic ores	20.4
Nonmetal mineral products	29.3	Motorized vehicles	19.5	Waste/scrap	18.2
Other agriculture products	26.6	Nonmetal mineral products	18.8	Other foodstuffs	17.9
Base metals	21.4	Gravel	11.4	Cereal grains	15.8
Waste/scrap	18.2	Other agriculture products	11.3	Gasoline	14.4
Natural sands	16.5	Mixed freight	11.1	Other agriculture products	13.8

Note: Unit of measure is billion lbs.
Data from the Bureau of Transportation Statistics, 2021.

TABLE 2.3
Top Commodities by Weight (2045)

Within the Given State (S to S)		Outbound from the Given State (S to all other states)		Inbound to the Given State (all other states to S)	
Commodity (lbs_within)	**lbs_within 666.2**	**Commodity (lbs_out)**	**lbs_out 671.0**	**Commodity (lbs_in)**	**lbs_in 788.4**
Gravel	146.0	Coal-n.e.c.	196.5	Coal-n.e.c.	283.3
Cereal grains	90.9	Base metals	94.8	Base metals	56.0
Nonmetal mineral products	42.5	Other foodstuffs	47.4	Crude petroleum	47.5
Base metals	39.2	Animal feed	40.2	Coal	33.5
Gasoline	37.2	Nonmetal mineral products	38.9	Other foodstuffs	30.2
Coal	35.6	Cereal grains	29.2	Waste/scrap	28.1
Fuel oils	33.7	Motorized vehicles	25.3	Metallic ores	23.3
Other agriculture products	31.6	Gravel	16.3	Cereal grains	23.3
Waste/scrap	30.9	Mixed freight	16.0	Other agriculture products	22.2
Other foodstuffs	26.5	Milled grain products	15.1	Basic chemicals	22.0

Note: Unit of measure is billion lbs.
Data from the Bureau of Transportation Statistics, 2021.

In the late 2000s, teams of researchers, modelers, climate scientists around the world began the process of developing new scenarios to explore how the world might evolve over the rest of the 21st century. These pathways have been named "Shared Socioeconomic Pathways" or SSPs and represent different possible evolutions of the world's economies based on geo-political choices (Hausfather, 2018). Following these SSPs, "Representative Concentration Pathways" (RCPs) were developed by a group of researchers, and they describe different levels of greenhouse gases and other radiative forcing that might occur in the future. Because these SSPs and RCPs have been translated into quantitative estimates of future growth, we used them to build scenarios for GDP growth.

2.2.2.1 Shared Socioeconomic Pathways. The SSPs examine how global societies, population, economics, and political situations might change the face of the world and growth over the next century. These SSPs examine five different scenarios in which the world might progress despite climate policy. They also consider how different levels of climate change mitigation could be attained when the mitigation targets of RCPs are combined with the SSPs.

The five different SSPs are defined as follows.

SSP1: world of sustainability-focused growth and equality.
SSP2: "middle of the road" world where trends broadly follow their historical patterns.
SSP3: fragmented world of "resurgent nationalism."
SSP4: world of ever-increasing inequality.
SSP5: world of rapid and unconstrained growth in economic output and energy use.

TABLE 2.4
Shipments by Commodity (2018)

	Within the Given State (S to S)		Outbound (S to all other states)		Inbound (all other states to S)	
	lbs	lbs_within%	lbs_out	lbs_out%	lbs_in	lbs_in%
Commodity	**543.2**	**100.0%**	**376.4**	**100.0%**	**496.9**	**100.0%**
Alcoholic beverages	2.0	0.4	1.3	0.3	1.7	0.3
Animal feed	10.0	1.8	19.5	5.2	6.5	1.3
Articles-base metal	3.2	0.6	6.2	1.6	5.3	1.1
Base metals	21.4	3.9	54.0	14.3	34.1	6.9
Basic chemicals	2.6	0.5	4.6	1.2	10.7	2.2
Building stone	1.1	0.2	0.8	0.2	0.1	0.0
Cereal grains	82.8	15.2	33.7	9.0	15.8	3.2
Chemical products	1.5	0.3	2.8	0.7	3.8	0.8
Coal	58.3	10.7	7.0	1.9	51.4	10.4
Coal-n.e.c.	8.8	1.6	73.4	19.5	109.2	22.0
Crude petroleum	0.4	0.1	5.6	1.5	45.2	9.1
Electronics	1.8	0.3	1.8	0.5	3.4	0.7
Fertilizers	3.5	0.6	2.7	0.7	8.1	1.6
Fuel oils	36.1	6.6	0.9	0.2	8.4	1.7
Furniture	1.5	0.3	1.1	0.3	1.5	0.3
Gasoline	45.2	8.3	6.1	1.6	14.4	2.9
Gravel	102.7	18.9	11.4	3.0	13.6	2.7
Live animals/fish	3.8	0.7	0.8	0.2	2.3	0.5
Logs	5.5	1.0	0.2	0.1	0.1	0.0
Machinery	1.6	0.3	4.2	1.1	4.7	0.9
Meat/seafood	1.2	0.2	5.4	1.4	2.7	0.5
Metallic ores	0.1	0.0	0.1	0.0	20.4	4.1
Milled grain products	1.7	0.3	8.3	2.2	3.7	0.7
Miscellaneous manufacturing products	5.7	1.0	5.7	1.5	3.7	0.7
Mixed freight	6.2	1.1	11.1	2.9	9.8	2.0
Motorized vehicles	7.2	1.3	19.5	5.2	12.3	2.5
Natural sands	16.5	3.0	0.5	0.1	4.5	0.9
Newsprint/paper	0.8	0.1	3.4	0.9	7.9	1.6
Nonmetal mineral products	29.3	5.4	18.8	5.0	10.2	2.1
Nonmetallic minerals	3.2	0.6	1.1	0.3	4.1	0.8
Other agricultural products	26.6	4.9	11.3	3.0	13.8	2.8
Other foodstuffs	16.1	3.0	28.4	7.5	17.9	3.6
Paper articles	1.5	0.3	1.4	0.4	2.7	0.5
Pharmaceuticals	0.1	0.0	0.3	0.1	1.1	0.2
Plastics/rubber	3.0	0.6	7.5	2.0	10.9	2.2
Precision instruments	0.1	0.0	0.4	0.1	0.6	0.1
Printed products	0.3	0.0	1.1	0.3	1.0	0.2
Textiles/leather	0.4	0.1	0.7	0.2	1.3	0.3
Tobacco products	0.0	0.0	0.0	0.0	0.0	0.0
Transport equipment	0.0	0.0	0.9	0.2	0.2	0.0
Unknown	0.0	0.0	0.1	0.0	0.0	0.0
Waste/scrap	18.2	3.3	4.9	1.3	18.2	3.7
Wood products	11.1	2.0	7.7	2.0	9.8	2.0

Note:
Unit of measure is billion lbs.
Data from the Bureau of Transportation Statistics, 2021.

SSP1 scenario poses low challenges to mitigation and low challenges to adaptation. This future emphasizes on human well-being and global population peaks mid-century. It boasts environmentally friendly technologies and renewable energy (Kriegler, 2020b).

SSP2 scenario poses moderate challenges to mitigation and moderate challenges to adaptation. The population growth stabilizes toward the end of the century. Current social, economic, and technological trends continue in the future for this scenario (Kriegler, 2020b).

SSP3 scenario poses high challenges to mitigation and high challenges to adaptation. This future emphasizes on national issues due to regional conflicts and nationalism. The population growth continues with high growth in developing countries in this scenario.

TABLE 2.5
Shipments by Trade Type and Transportation Mode (2018)

		Within the Given State (S to S)		Outbound from the Given State (S to all other states)		Inbound to the Given State (all other states to S)	
		lbs. within	**lbs. within%**	**lbs. out**	**lbs. out%**	**lbs. in**	**lbs. in%**
Trade Type		**543.2**	**100.0%**	**376.4**	**100.0%**	**496.9**	**100.0%**
Domestic Only	**Domestic Mode**	**542.7**	**99.9%**	**355.2**	**94.4%**	**472.1**	**95.0%**
Domestic Only	Air (include truck-air)	0.0	0.0	0.1	0.0	0.1	0.0
Domestic Only	Multiple modes & mail	2.1	0.4	14.0	3.7	29.0	5.8
Domestic Only	Pipeline	43.2	8.0	68.6	18.2	157.9	31.8
Domestic Only	Rail	31.2	5.7	53.7	14.3	73.1	14.7
Domestic Only	Truck	460.9	84.9	200.3	53.2	191.9	38.6
Domestic Only	Water	5.2	1.0	18.4	4.9	20.1	4.0
Export	**Domestic Mode**	**0.4**	**0.1**	**21.2**	**5.6**	**0.0**	**0.0**
Export	Air (include truck-air)	0.0	0.0	0.0	0.0	0.0	0.0
Export	Multiple modes & mail	0.0	0.0	2.6	0.7	0.0	0.0
Export	Other and unknown	0.4	0.1	0.0	0.0	0.0	0.0
Export	Pipeline	0.0	0.0	4.6	1.2	0.0	0.0
Export	Rail	0.0	0.0	4.7	1.2	0.0	0.0
Export	Truck	0.0	0.0	8.6	2.3	0.0	0.0
Export	Water	0.0	0.0	0.7	0.2	0.0	0.0
Import	**Domestic Mode**	**0.0**	**0.0**	**0.0**	**0.0**	**24.8**	**5.0**
Import	Air (include truck-air)	0.0	0.0	0.0	0.0	0.0	0.0
Import	Multiple modes & mail	0.0	0.0	0.0	0.0	4.4	0.9
Import	Other and unknown	0.0	0.0	0.0	0.0	0.0	0.0
Import	Pipeline	0.0	0.0	0.0	0.0	0.0	0.0
Import	Rail	0.0	0.0	0.0	0.0	13.4	2.7
Import	Truck	0.0	0.0	0.0	0.0	6.7	1.3
Import	Water	0.0	0.0	0.0	0.0	0.2	0.0

Note: Unit of measure is billion lbs.
Data from the Bureau of Transportation Statistics, 2021.

Economic development is slow and fossil fuel dependence is high in this future (Kriegler, 2020b).

SSP4 scenario poses low challenges to mitigation and high challenges to adaptation. This future sees a growing divide between globally-connected, well-educated society and fragmented lower income societies. The population growth stabilizes toward the end of the century. Unrest and conflict become more common in this scenario (Kriegler, 2020b).

SSP 5 scenario poses high challenges to mitigation and low challenges to adaptation. This future emphasizes on economic growth and technological progress and global population peaks mid-century. It boasts global adoption of resource and energy intensive lifestyles with lack of environmental awareness (Kriegler, 2020b).

Figure 2.5 represents how global population and global GDP will change in all five scenarios by the end of this century.

2.2.2.2 Representative concentration pathways. With the release of SSPs, modelers and scientists expanded the range of RCPs which set a target level for radiative forcing levels (in watts per meter squared) or atmospheric greenhouse gas concentrations. Modelers have identified various RCP levels.

In 2100, these forcing levels are limited to 6.0, 4.5, 3.4, 2.6, and 1.9 watts per meter squared. After the adoption of the Paris agreement, RCP2.6 is being considered the most stringent forcing by modelers.

RCP1.9 aims at declining emissions very strongly, keeping radiative forcing levels at 1.9 W/m^2 and focusing on limiting warming below 1.5 degree Celsius. While RCP2.6 encourages declining emissions strongly and targets limiting warming below 2 degrees Celsius by keeping radiative forcing levels at 2.6 W/m^2, in accord with the Paris Agreement. RCP3.4, on the other hand, represents an intermediate pathway between the "very stringent" RCP2.6 and less stringent mitigation efforts associated with RCP4.5. RCP4.5 indicates slowly declining emission trend, aiming at keeping the radiative forcing levels at 4.5 W/m^2 and temperature rise at 2.4 degree Celsius or below. RCP6.0 targets at keeping radiative forcing levels at 6.0 W/m^2, stabilizing emissions and limiting temperature increase to 2.8 degree Celsius or below. RCP8.5 considers the high-end pathway where there is no climate change mitigation. The radiative forcing levels are at 8.5 W/m^2,

Top Truck Commodities in Indiana, 2015

TOP TRUCK COMMODITIES BY TONS			TOP TRUCK COMMODITIES BY VALUE		
Commodity	**Production Industry(s)**	**Attraction Industry(s)**	**Commodity**	**Production Industry(s)**	**Attraction Industry(s)**
Gravel	NAICS 212-Mining (Except Oil And Gas)	Population	**Motorized Vehicles**	NAICS 336 - Transportation Equipment Manufacturing	NAICS 441-Motor Vehicle And Parts Dealers
Cereal Grains	NAICS 11-Agriculture	NAICS 311-Food Manufacturing	**Mixed Freight**	Total Employment	NAICS 42-Wholesale Trade
Base Metals	NAICS 331-Primary Metal Manufacturing	NAICS 333-Machinery Manufacturing & NAICS 336-Transportation Equipment Manufacturing	**Base Metals**	NAICS 331-Primary Metal Manufacturing	NAICS 333-Machinery Manufacturing & NAICS 336-Transportation Equipment Manufacturing
Coal	NAICS 212-Mining (Except Oil & Gas)	NAICS 221-Utilities	**Electronics**	NAICS 334-Computer And Electronic Product Manufacturing & NAICS 335-Electrical Equipment Manufacturing	NAICS 42-Wholesale Trade
Nonmetal Min. Prods.	NAICS 327 Nonmetallic Mineral Product Manufacturing	NAICS 42-Wholesale Trade	**Machinery**	NAICS 333-Machinery Manufacturing	Total Employment
Gasoline	NAICS 324-Petroleum Products Manufacturing	Population	**Plastics/Rubber**	NAICS 326-Plastic & Rubber Products Manufacturing	NAICS 42-Wholesale Trade
Other Foodstuffs	NAICS 311-Food Manufacturing & NAICS 325-Chemical Product Manufacturing	NAICS 311-Food Manufacturing	**Gasoline**	NAICS 324-Petroleum Products Manufacturing	Population
Waste/Scrap	Total Employment	NAICS 562-Waste Management And Remediation Services	**Other Foodstuffs**	NAICS 311-Food Manufacturing & NAICS 325-Chemical Product Manufacturing	NAICS 311-Food Manufacturing
Other Ag Prods.	NAICS 11-Agriculture	NAICS 311-Food Manufacturing	**Pharmaceuticals**	NAICS 325-Chemical Product Manufacturing	NAICS 42-Wholesale Trade
Natural Sands	NAICS 212-Mining (Except Oil & Gas)	Population	**Misc. Mfg. Prods.**	NAICS 33-Durable Manufacturing	NAICS 42-Wholesale Trade

Figure 2.3 Top truck commodities in Indiana (2015) (Cambridge Systematics, Inc., n.d.).

controlling temperature rise at 4.3 degree Celsius and indicating rising emissions (Kriegler, 2020a).

2.2.2.3 Scenario creation. FAF4 gives commodity flow forecast until the year 2045 with an optimistic and pessimistic target associated with various macro-economic changes that may occur. In this project future county wise disaggregated flows are projected for each commodity independently using its related industry GDP as mentioned in Section 2.2.1. It is fair to assume that these industry GDP would vary under each associated SSP scenario and therefore have very different commodity flows giving rise to a range of possible outcomes.

In our model, we have considered the five SSPs and the values for GDP from a public database (IIASA, n.d.) for future prediction of commodity flows in all those scenarios. We have included SSP baseline data which represents how GDP growth will take place if there are no climate policies to mitigate the change. And SSP data combined with RCP2.6 to identify how scenarios will change if the climate change policies are adopted and implemented. In SSP3, models were simply not able to achieve either RCP2.6 or RCP1.9 targets due to regional rivalry and resurgent nationalism limiting the ability of the world to cooperate on reducing emissions over the next few decades. So, RCP 3.4 has been included for SSP3 in place of RCP2.6.

For our model, we needed to predict commodity flow at the county-level in Indiana for future years of 2025, 2035, and 2045. The world-level GDP was converted into county-level GDP. We calculated the ratios using

Top Rail Commodities in Indiana, 2015

TOP RAIL COMMODITIES BY TONS			TOP RAIL COMMODITIES BY VALUE		
Commodity	**Production Industry(s)**	**Attraction Industry(s)**	**Commodity**	**Production Industry(s)**	**Attraction Industry(s)**
Coal	NAICS 212 - Mining (Except Oil And Gas)	NAICS 221- Utilities	**Base metals**	NAICS 332- Fabricated Metal Product Manufacturing	NAICS 333- Machinery Manufacturing & NAICS 336- Transportation Equipment Manufacturing
Base metals	NAICS 332- Fabricated Metal Product Manufacturing	NAICS 333- Machinery Manufacturing & NAICS 336- Transportation Equipment Manufacturing	**Motorized vehicles**	NAICS 336- Transportation Equipment Manufacturing	NAICS 441- Motor Vehicle and Parts Dealers
Cereal grains	NAICS 11- Agriculture	NAICS 311- Food Product Manufacturing	**Machinery**	NAICS 333- Machinery Manufacturing	Total employment
Animal feed	NAICS 11- Agriculture	NAICS 311- Food Product Manufacturing	**Other foodstuffs**	NAICS 311- Food Product Manufacturing & NAICS 325- Chemical Product Manufacturing	NAICS 311- Food Product Manufacturing
Other foodstuffs	NAICS 311- Food Product Manufacturing & NAICS 325- Chemical Product Manufacturing	NAICS 311- Food Product Manufacturing	**Plastics/rubber**	NAICS 326- Plastic & Rubber Products Manufacturing ,	NAICS 42 - Wholesale Trade
Fertilizers	NAICS 325- Chemical Product Manufacturing	NAICS 11- Agriculture	**Coal**	NAICS 212 - Mining (Except Oil And Gas)	NAICS 221 Utilities
Metallic ores	NAICS 212 - Mining (Except Oil And Gas)	NAICS 331- Primary Metal Manufacturing	**Cereal grains**	NAICS 11- Agriculture	NAICS 311- Food Product Manufacturing
Basic chemicals	NAICS 325- Chemical Product Manufacturing	NAICS 42- Wholesale Trade	**Animal feed**	NAICS 11- Agriculture	NAICS 311- Food Product Manufacturing
Other ag prods.	NAICS 11- Agriculture	NAICS 311- Food Product Manufacturing	**Basic chemicals**	NAICS 325- Chemical Product Manufacturing	NAICS 42- Wholesale Trade
Waste/scrap	Total employment	NAICS 562- Waste Management and Remediation Services	**Fertilizers**	NAICS 325- Chemical Product Manufacturing	NAICS 11- Agriculture

Figure 2.4 Top rail commodities in Indiana (2015) (Cambridge Systematics, Inc., n.d.).

world baseline GDP and US baseline GDP to predict US GDP values for SSP and RCP from future world GDP. Next, we scaled down the US GDP values to predict state-level SSP and RCP GDP for Indiana by using linear regression and calculating the growth rate and intercept using the historical US and Indiana GDP values. To scale down these state-level GDP to county GDP, we took the average growth rate for every county using historical data and the same has been done scaling down to industry GDP from county GDP.

Initially, world GDP values were taken for all the five scenarios for SSP baseline and RCP2.6 (RCP3.4 for SSP3) from the IIASC database from 2010 through 2050. We then took an average to get the GDP values at an interval of 5 years as shown in Figure 2.6.

This world-level GDP had to be converted to future industry-level GDP for a county. We did that one step at a time. From the SSP database we also obtained US GDP baseline values. Now, to obtain the US RCP GDP values, we calculated the ratios of world baseline GDP and US baseline GDP and multiplied these values with world baseline GDP (Figure 2.7).

Next, we scaled down the US GDP values to the Indiana state level by regressing past Indiana GDP against US GDP.

Figure 2.8 shows the scaled down values to Indiana state level.

For scaling it down to the county-level, we initially found the weighted average ratio between county GDP and Indiana's GDP for all the counties using BEA

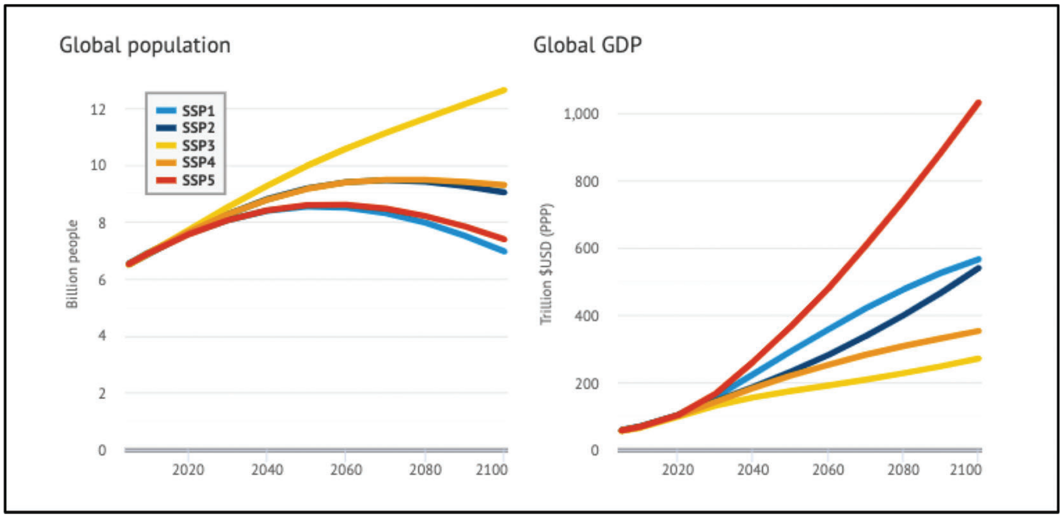

Figure 2.5 Global population (left) in billion USD and global gross domestic product (right) in trillion USD on a purchasing power parity (PPP) basis (Hausfather, 2018).

Scenario	Region	2010	2015	2020	2025	2030	2035	2040	2045	2050
SSP3-34	World	64808.1	81104.5	97400.9	113729.9	130059.0	140208.5	150358.0	158411.5	166465.0
SSP3-Baseline	World	64812.7	81130.4	97448.0	113925.0	130402.0	142489.5	154577.0	164115.5	173654.0
SSP4-26	World	66937.0	83387.6	99838.1	120672.0	141505.8	161957.1	182408.5	200712.3	219016.1
SSP4-Baseline	World	66937.0	83379.8	99822.6	120538.3	141254.1	161839.1	182424.1	200769.0	219113.8
SSP1-26	World	68461.9	85138.6	101815.3	128835.0	155854.8	189525.1	223195.5	257248.5	291301.4
SSP1-Baseline	World	68461.9	85138.6	101815.3	128835.0	155854.8	189525.1	223195.5	257248.5	291301.4
SSP2-26	World	67517.9	84299.7	101081.5	121772.2	142462.8	163463.3	184463.7	206490.7	228517.7
SSP2-Baseline	World	67528.8	84386.7	101244.5	122157.1	143069.7	164512.2	185954.6	208627.4	231300.2
SSP5-26	World	67570.0	84735.0	101900.0	133300.0	164700.0	209600.0	254500.0	303050.0	351600.0
SSP5-Baseline	World	67570.0	84735.0	101900.0	133850.0	165800.0	213000.0	260200.0	312450.0	364700.0

Figure 2.6 SSP of the world GDP/PPP (in billion USD as of 2005) at an interval of 5 years (IIASA, n.d.).

Scenario	Region	2010	2015	2020	2025	2030	2035	2040	2045	2050
SSP1	USA	13087.12	14772.26	17156.08	19536.27	21979.95	24428.26	26777.92	28990.58	31007.59
SSP1-26	USA	13087.12	14772.26	17156.08	19536.27	21979.95	24428.26	26777.92	28990.58	31007.59
SSP2	USA	13087.12	14754.81	17032.56	19086.82	20965.92	22688.69	24320.37	25861.45	27281.87
SSP2-26	USA	13085.01	14739.61	17005.13	19026.67	20876.99	22544.03	24125.38	25596.58	26953.67
SSP3	USA	13087.12	14652.18	16642.45	18224.43	19477.09	20484.66	21325.1	22008.29	22472.58
SSP3-34	USA	13086.19	14647.5	16634.4	18193.22	19425.85	20156.74	20743.06	21243.37	21542.25
SSP4	USA	13087.12	14720.99	16972.43	19249.43	21559.68	23821.42	25898.89	27779.91	29446.67
SSP4-26	USA	13087.12	14722.37	16975.08	19270.77	21598.1	23838.79	25896.67	27772.07	29433.55
SSP5	USA	13087.12	14862.28	17514.18	20524.26	23990.21	27793.54	31738.97	35907.43	40312.78
SSP5-26	USA	13087.12	14862.28	17514.18	20439.92	23831.04	27349.89	31043.69	34827.16	38864.75

Figure 2.7 SSP of the US GDP/PPP (in billion 2005 USD).

Scenario	Region	2010	2015	2020	2025	2030	2035	2040	2045	2050
SSP1	IN	254.5841	278.6965	312.8061	346.8638	381.8298	416.8624	450.4831	482.1437	511.0046
SSP1-26	IN	254.5841	278.6965	312.8061	346.8638	381.8298	416.8624	450.4831	482.1437	511.0046
SSP2	IN	254.5841	278.4468	311.0386	340.4326	367.3204	391.9712	415.3185	437.3695	457.6941
SSP2-26	IN	254.5539	278.2292	310.6462	339.572	366.0478	389.9013	412.5284	433.5796	452.998
SSP3	IN	254.5841	276.9782	305.4566	328.0928	346.0169	360.4341	372.4598	382.2355	388.8788
SSP3-34	IN	254.5708	276.9113	305.3414	327.6463	345.2838	355.7419	364.1314	371.2904	375.5669
SSP4	IN	254.5841	277.9629	310.1783	342.7594	375.8164	408.1791	437.9052	464.8204	488.6698
SSP4-26	IN	254.5841	277.9826	310.2162	343.0647	376.366	408.4276	437.8734	464.7082	488.4821
SSP5	IN	254.5841	279.9846	317.93	361.0006	410.5943	465.0155	521.4699	581.1156	644.1509
SSP5-26	IN	254.5841	279.9846	317.93	359.7939	408.3169	458.6673	511.5212	565.6582	623.4313

Figure 2.8 SSP of the Indiana GDP/PPP (in billion 2005 USD).

database (Bureau of Economic Analysis, n.d.). Then, the product of the scenario GDP for a particular year multiplied by the county ratio provided us with the county GDP for all the scenarios for future years. Further, the county-level GDP values were scaled down to industry-level GDP. For this, we used the BEA data (Bureau of Economic Analysis, n.d.) to find how much each industry was contributing to the total county GDP for all the counties by dividing the total industry county GDP with individual industry GDP. Again, a weighted average ratio of the industry contribution was calculated for all industries and this ratio was multiplied to every scenario's county GDP for the future years to find the future industry GDP value for a given scenario.

Given in Figure 2.9 is a sample where all industry GDPs are calculated for Tippecanoe County for the years 2020 through 2025 for SSP1 scenario.

This scenario-based industry data is used as input to disaggregate the zone level flows into county-level flows. In this exercise we vary the SSP and RCP scenarios to understand how the commodity flow is affected under each condition.

2.2.3 Commodity Flows

Using the methodology presented in previous sections, we generated county wise commodity flows for the years 2013, 2015, and 2018 to understand the change in pattern, if any, in recent years. The analysis is visually represented and published in publicly available interactive dashboard where the user can select the year, commodity, and the mode of transport. This visual representation also allows us to identify cluster regions for a particular commodity. For example, Figure 2.10 shows the distribution of total flow of coal for the year 2013 by truck and in comparison, Figure 2.11 shows the same flow for the year 2018. We can notice that the coal flows have reduced in the Central and Northern Indiana and has clustered towards the southern counties in 2018 when compared to 2013. A similar analysis can be done for major commodities and for both truck and rail mode of transport.

For future flows we use the industry GDP obtained for each SSP scenario to generate freight volume. To get the RCP effect, we identify a parameter closely related to the commodity and we assume the change in the parameter when RCP effect is introduced is carried over to the flow of the commodity as well. For example, in Figure 2.12 we see there is a reduction in the usage of coal in primary energy generation when RCP constraint is put on a scenario. We find the ratio of coal usage in RCP scenario versus the baseline scenario and assume that the freight generation will also be reduced as the usage declines. This ratio is then used to calculate the flow under RCP condition from the baseline scenario. Such parameters are identified for all major commodities and their effects are calculated for the years 2025, 2035, and 2045.

The forecast data generated is hosted as a public interactive dashboard where the user can select the year, scenario, mode, commodity, and type of flow. The Figure 2.13 shows the outflow of coal by truck from all counties for the year 2045 under SSP5 scenario. SSP data for the commodities discussed in the case studies presented in the later section of this project are available on this dashboard for the years 2025, 2035, and 2045.

GeoName	Scenario	Industry Description	NAICS Code	Industry contribution	2020	2025	2030	2035	2040	2045	2050
Tippecanoe	SSP1	All industry total	0	1.000	9154040	1E+07	1.1E+07	1.2E+07	1.3E+07	1.4E+07	1.5E+07
Tippecanoe	SSP1	Private industries	0	0.784	7177956	7959477	8761843	9565734	1E+07	1.1E+07	1.2E+07
Tippecanoe	SSP1	Agriculture, forestry, fishing and huntin	11	0.001	9761.06	10823.8	11914.9	13008.1	14057.2	15045.2	15945.8
Tippecanoe	SSP1	Mining, quarrying, and oil and gas extra	21	0.001	5506.62	6106.17	6721.71	7338.42	7930.28	8487.63	8995.7
Tippecanoe	SSP1	Utilities	22	0.002	19507.5	21631.4	23812	25996.7	28093.4	30067.8	31867.7
Tippecanoe	SSP1	Construction	23	0.033	300730	333473	367089	400769	433092	463530	491277
Tippecanoe	SSP1	Manufacturing	31-33	0.287	2628701	2914908	3208750	3503149	3785685	4051749	4294285
Tippecanoe	SSP1	Durable goods manufacturing	321,327-339	0.229	2097633	2326019	2560496	2795419	3020876	3233187	3426724
Tippecanoe	SSP1	Nondurable goods manufacturing	311-316,322-326	0.058	531068	588889	648253	707730	764810	818562	867560
Tippecanoe	SSP1	Wholesale trade	42	0.031	285547	316637	348556	380535	411226	440128	466474
Tippecanoe	SSP1	Retail trade	44-45	0.053	485209	538037	592275	646616	698766	747877	792644
Tippecanoe	SSP1	Transportation and warehousing	48-49	0.018	167503	185740	204464	223224	241227	258181	273635
Tippecanoe	SSP1	Information	51	0.013	116898	129626	142693	155785	168349	180181	190967
Tippecanoe	SSP1	Finance, insurance, real estate, rental,	52, 53	0.130	1187802	1317127	1449902	1582929	1710595	1830818	1940410
Tippecanoe	SSP1	Finance and insurance	52	0.045	410132	454786	500631	546564	590645	632157	669997
Tippecanoe	SSP1	Real estate and rental and leasing	53	0.085	777670	862341	949270	1036365	1119950	1198661	1270413
Tippecanoe	SSP1	Professional and business services	54, 55, 56	0.062	570412	632517	696279	760161	821470	879204	931833
Tippecanoe	SSP1	Professional, scientific, and technical	54	0.037	334365	370770	408146	445593	481531	515373	546223
Tippecanoe	SSP1	Management of companies and ente	55	0.003	31777.5	35237.4	38789.5	42348.4	45763.9	48980.2	51912.2
Tippecanoe	SSP1	Administrative and support and waste	56	0.022	203031	225137	247832	270570	292392	312942	331675
Tippecanoe	SSP1	Educational services, health care, and	61, 62	0.098	895520	993022	1093125	1193419	1289670	1380310	1462935
Tippecanoe	SSP1	Educational services	61	0.005	44949.1	49843.1	54867.6	59901.7	64732.8	69282.4	73429.6
Tippecanoe	SSP1	Health care and social assistance	62	0.093	850571	943179	1038257	1133517	1224937	1311027	1389505
Tippecanoe	SSP1	Arts, entertainment, recreation, accom	71, 72	0.034	310015	343769	378423	413143	446464	477842	506446
Tippecanoe	SSP1	Arts, entertainment, and recreation	71	0.003	26999.9	29939.6	32957.7	35981.6	38883.6	41616.4	44107.5
Tippecanoe	SSP1	Accommodation and food services	72	0.031	283016	313830	345466	377162	407581	436226	462338

Figure 2.9 SSP1 industry GDP for Tippecanoe County (in thousands, 2005 USD).

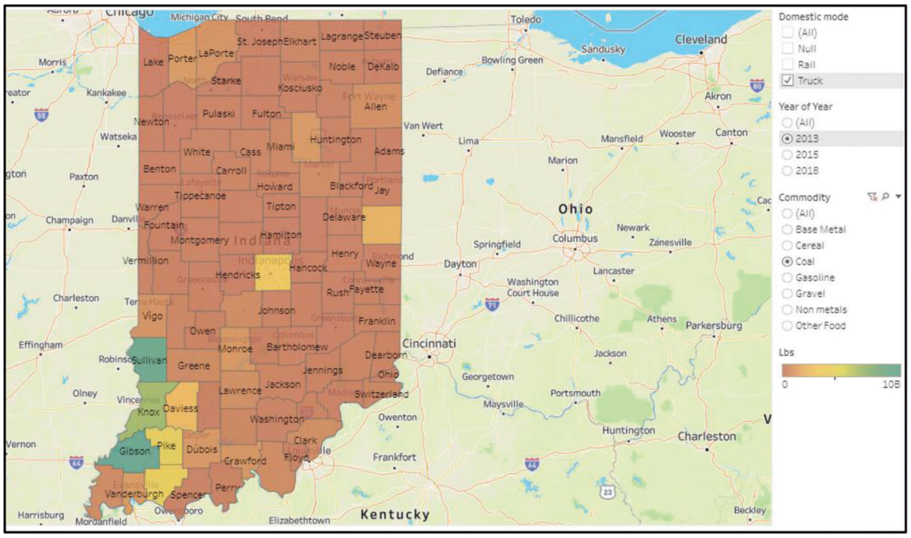

Figure 2.10 Distribution of total flow of coal by truck for 2013.

Figure 2.11 Distribution of total flow of coal by truck for 2018.

Region	Model - Scenario	Scenario	Variable	Unit	2010	2020	2025	2030	2035	2040	2045	2050		2025 Ratio	2035 Ratio	2045 Ratio
World	IMAGE - SSP1-Baseline	SSP1	Primary Energy|Coal	EJ/yr	144.984	158.902	164.734	170.565	175.612	180.658	180.553	180.448				
World	IMAGE - SSP1-26	SSP1-26	Primary Energy|Coal	EJ/yr	144.984	152.229	142.32	132.41	114.719	97.027	81.884	66.741		0.863938	0.653252	0.453518
World	MESSAGE-GLOBIOM - SSP2-Baseline	SSP2	Primary Energy|Coal	EJ/yr	139.734	143.771	154.622	165.472	173.27	181.068	194.121	207.174				
World	MESSAGE-GLOBIOM - SSP2-26	SSP2-26	Primary Energy|Coal	EJ/yr	139.727	135.204	109.06	82.916	64.975	47.034	51.3155	55.597		0.705335	0.374993	0.264348
World	AIM/CGE - SSP3-Baseline	SSP3	Primary Energy|Coal	EJ/yr	134.413	175.485	198.867	222.249	242.983	263.716	285.188	306.659				
World	AIM/CGE - SSP3-34	SSP3-34	Primary Energy|Coal	EJ/yr	133.474	163.26	166.972	170.683	132.436	94.188	95.638	97.088		0.839614	0.545041	0.335351
World	GCAM4 - SSP4-Baseline	SSP4	Primary Energy|Coal	EJ/yr	143.26	197.213	224.092	250.97	264.539	278.107	282.943	287.778				
World	GCAM4 - SSP4-26	SSP4-26	Primary Energy|Coal	EJ/yr	143.26	186.149	152.178	118.206	107.407	96.607	91.9095	87.212		0.679086	0.406015	0.324835
World	REMIND-MAGPIE - SSP5-Baseline	SSP5	Primary Energy|Coal	EJ/yr	135.4	136.9	150.35	163.8	198.7	233.6	293.5	353.4				
World	REMIND-MAGPIE - SSP5-26	SSP5-26	Primary Energy|Coal	EJ/yr	135.4	118.4	89.44	60.48	40.05	19.62	12.736	5.852		0.594879	0.20156	0.043394

Figure 2.12 Coal usage as the primary energy source for the baseline and RCP scenarios (IIASA, 2018).

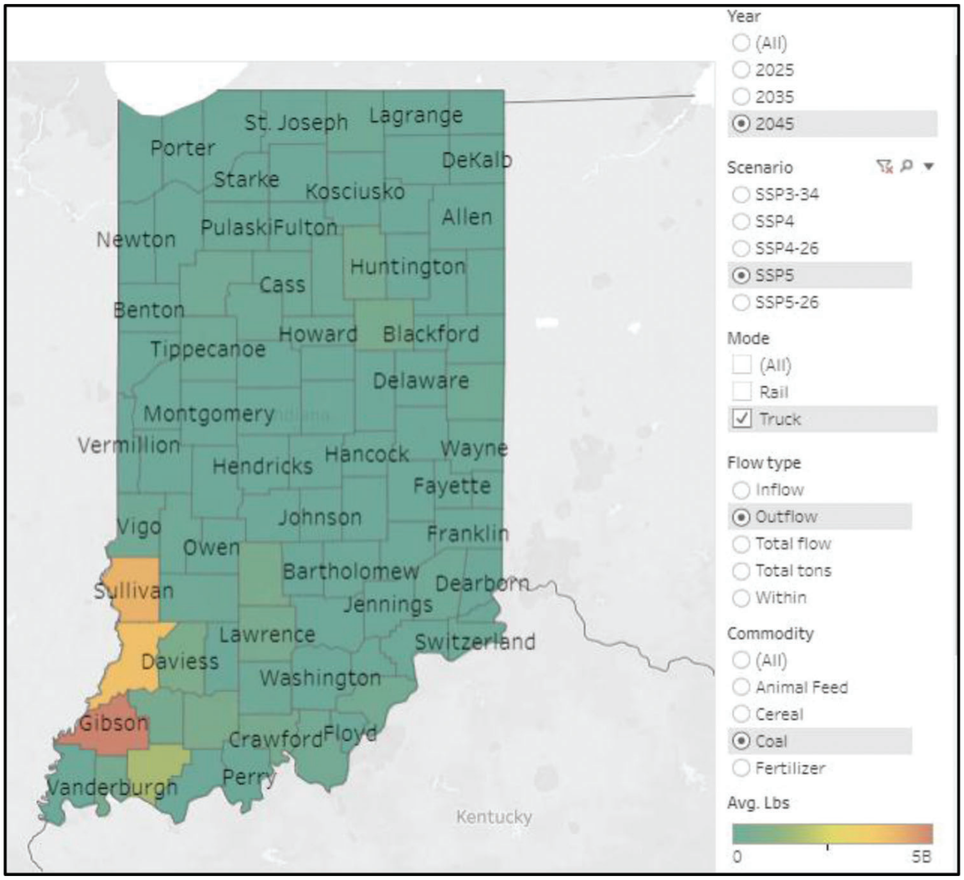

Figure 2.13 Outflow of coal by truck from all counties under the SSP5 scenario for the year 2045.

3. LITERATURE REVIEW AND BENCHMARKING STUDY

3.1 Benchmarking

The state freight plan of Indiana was benchmarked against the state freight plans of Ohio, Michigan, and Minnesota to understand the opportunities of improvement in the area of Indiana's industry-level competitiveness and its evolution in the next 20 years. During the course of benchmarking, an emphasis was placed on the Fixing America's Surface Transportation (FAST) Act goals (Cambridge Systematics, Inc., 2018), the projects taken by the states to meet the FAST Act goals, and the influence on the freight system. Therefore, the commodity data and the data comprising the projects proposed by each state in their state freight plan were analyzed.

FAST Act Goals

In order to measure the performance of the freight network, goals were set under FAST Act, to help the states identify specific projects within their freight system and allocate funding for the same.

The FAST Act sets the following national freight goals:

- improve contribution to economic efficiency
- reduce congestion,
- increase safety,
- improve the state of good repair,
- use technology for maintenance and measurement of performance, and
- reduce environmental effects.

3.1.1 Indiana

Based on the national FAST Act goals, Indiana and the rest of the states have set goals for their respective freight networks. Indiana has identified the following set of goals to improve the state freight system, and the following goals were defined in the *Indiana Multimodal Freight Plan Update 2018* (Cambridge Systematics, Inc., 2018):

1. *Economic Impact:* improve jobs within the state by encouraging strong and diverse economy.
2. *Capacity to Meet Demand:* improve the freight network to reduce congestion, repairs, and emission.
3. *Multimodal Integration and Synergy*
4. *Access to National and International Markets:* support better connectivity between Indiana's water ports and highway and rail modes.
5. *Quality of Life:* identify opportunities to improve and maintain Indiana's transportation infrastructure, supporting the safe movement of freight through the state.

During the course of benchmarking, we have compared these goals to identify the nature of the projects undertaken by each state to achieve these objectives as well as understanding the focus and prioritization of the various goals.

3.1.1.1 Indiana goals. Figure 3.1 represents the analysis of Indiana's project investment focus based on the freight goals. This data is obtained from the *Indiana Multimodal Freight Plan Update 2018* (Cambridge Systematics, Inc., 2018) and the projects were proposed in the year 2016. The data for this analysis was sourced from the state freight plan and categorized based on the project description. There is a heavy emphasis towards the reduction of congestion across the roads of Indiana. This will promote greater freight movement and improve the speed of the deliveries and thus increase the efficiency. Indiana has significant import, export, and freight movement within the state, therefore, for projects oriented toward reduction in congestion would significantly support efficient freight movement. Based on the data recorded in the state freight plan of 2018, a total funding of USD 95.4 million has been dedicated toward the reduction of congestion. Funding for this has been sourced through federal, state and NHFP resources. Federal funding has been the highest contributor with over USD 53 million, followed by the state with a funding of over USD 39 million, and ultimately followed by the NHFP source with USD 2 million.

The second focus is improving the state of good repair, which entails improving the conditions of the roads for faster movement of the freight across the roads of Indiana. The total investment dedicated towards this goal is approximately USD 77 million. The funding to achieve this freight goal is sourced through federal, state, and NHFP resources. The federal funding is once again the highest contributor with over USD 35 million followed by the state funding of over USD 24 million and then NHFP funding with over USD 17 million. The NHFP funding dedicated to the projects oriented towards the improvement of the state good repair is much greater than the projects oriented towards reducing congestion.

The third focus has been increasing the safety to ensure safe movement of freight across the roads in Indiana. The projects pursued are in the PHFS such as the I-69 and I-65 including preventive maintenance objectives. It is interesting to note the significant difference in the amount dedicated toward the freight goal of increasing safety. The total investment in this case is over USD 14.6 million, with federal, state, and NHFP funding. The greatest contributor to projects in this goal is federal funding with over USD 7.3 million dedicated towards the increasing safety, followed by NHFP funding of USD 5 million and then followed by the state funding of over USD 1.5 million. The NHFP funding in this case is still greater than the case of reducing congestion, in spite of the huge difference in the funds dedicated towards the freight goal of reducing congestion in relation to increasing safety.

The projects that were outside of the defined FAST Act goals are classified as miscellaneous projects. An example of the same is "small structure pipe lining on I-69." This is the category of least focus based on the information from the state freight plan with a total funding of over USD 10 million dedicated towards the projects in this category. The funding is sourced from the federal, state, and NHFP resources. The highest contributor for this category is the federal funding with over USD 7.7 million, followed by the state funding with over USD 1.8 million in contribution and ultimately NHFP with USD 561,578 in contribution.

3.1.1.2 Projects within Indiana. We conducted an in-depth analysis to understand the nature of the projects proposed within Indiana. Figure 3.2 represents these projects. Most projects were focused on maintenance and improving the conditions of the bridges across Indiana. The most popular roads in terms of these projects were I-65, I-69, and I-70. A total of over USD

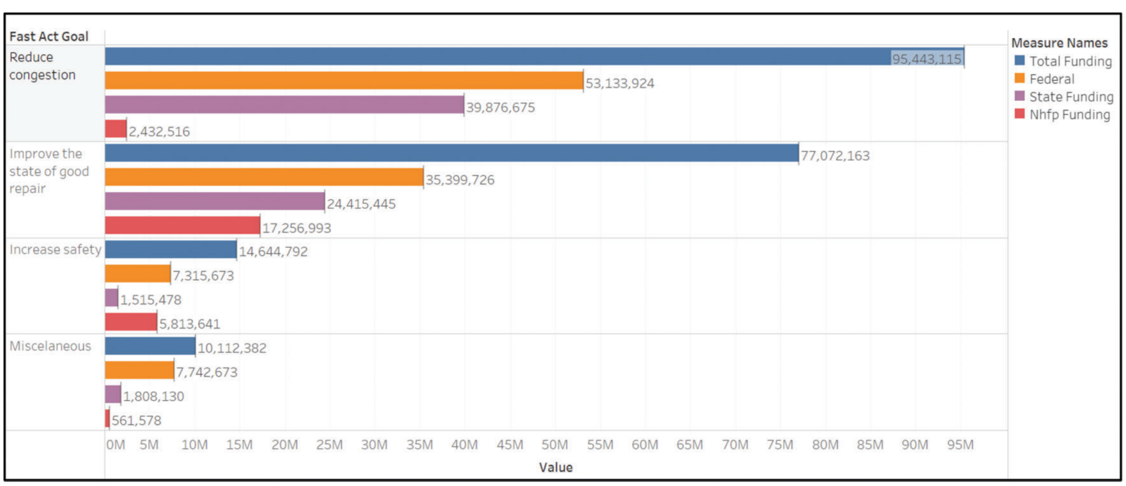

Figure 3.1 Indiana's focus on FAST Act goals.

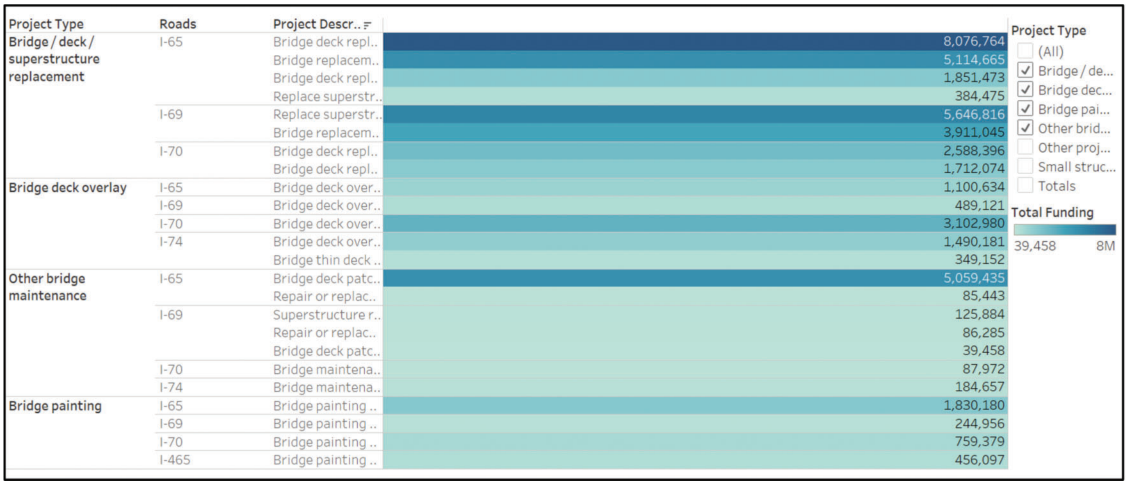

Figure 3.2 Projects within Indiana.

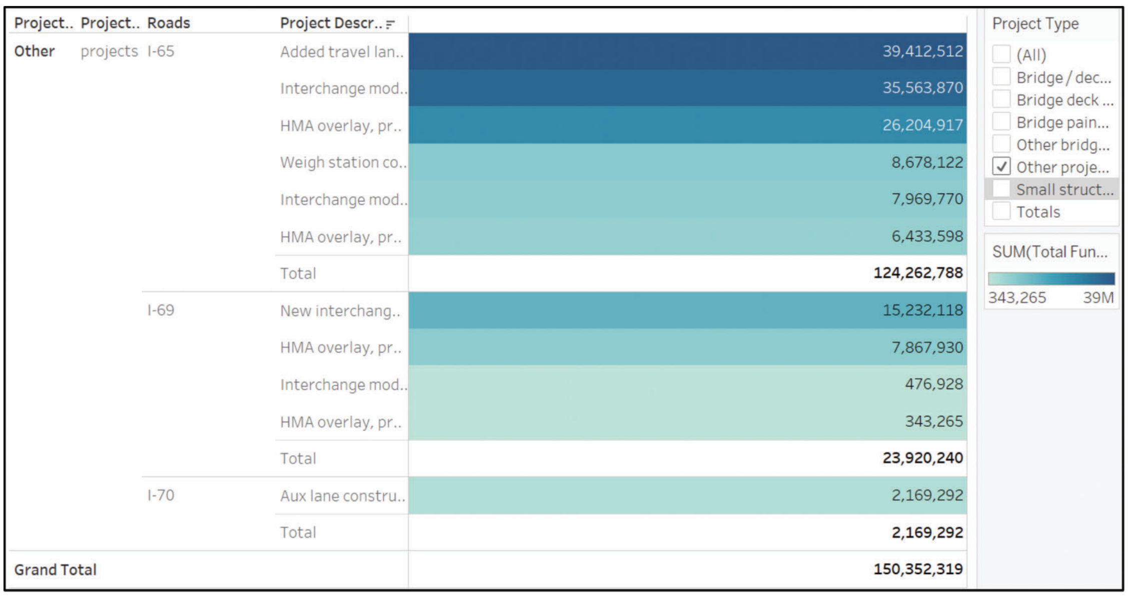

Figure 3.3 Other projects within Indiana.

44.7 million was dedicated to the projects in pertaining to the bridges.

Figure 3.3 represents the projects that are classified as other projects, which include improvement projects on I-65, I-69, and I-70, mostly focusing on the reducing congestion and improving the state of good repair goals. The investment into these projects were significantly greater of over USD 150.3 million.

Figure 3.4 represents the projects pertaining to the small structure pipe lining across Indiana. The projects are focused on I-65, I-69, and I-70 roads. A total of over USD 2.1 million in investment is dedicated to the projects focused on small structure pipe lining.

3.1.1.3 Movement of top commodities. Movement of top commodities (Cambridge Systematics, Inc., 2018) by truck in Indiana is represented in Table 3.1. Table 3.1 represents top commodities by weight whereas Table 3.2 represents top commodities by value.

3.1.2 Michigan

3.1.2.1 Michigan goals. Michigan developed its long-range transportation plan (MDOT, 2018), which is also oriented to achieve the FAST Act goals.

The following goals, established in the 2030 MITP (MI Transportation Plan), were reaffirmed in the 2035 and 2040 MITP.

1. *System Improvement:* Modernize and enhance the transportation system to improve mobility and accessibility.
2. *Efficient and Effective Operations:* Improve the efficiency and effectiveness of the transportation system and

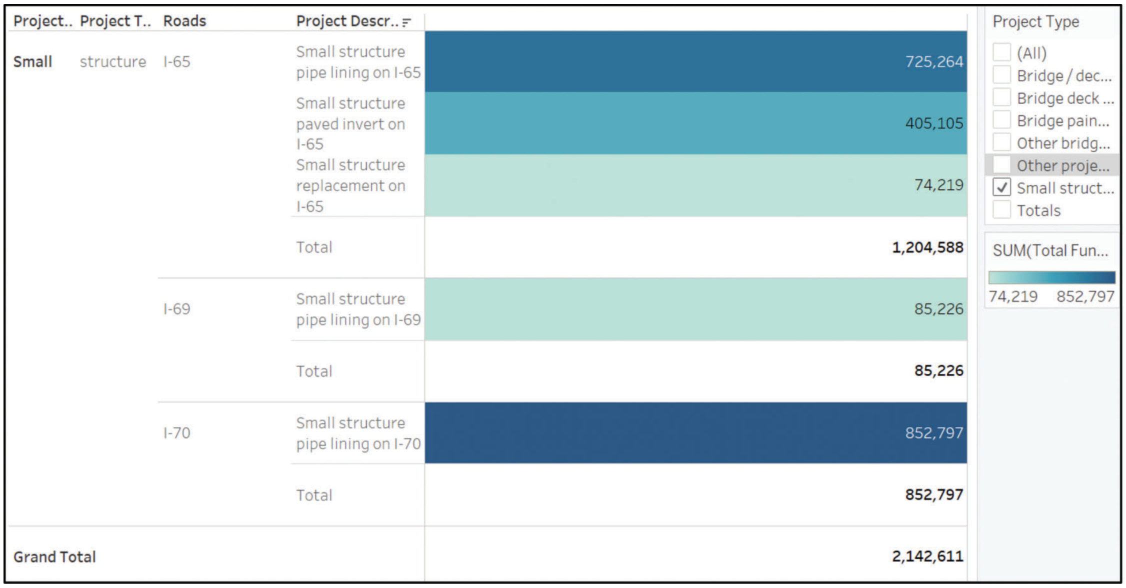

Figure 3.4 Small structure pipe lining projects.

TABLE 3.1
Movement of Top Commodities by Weight (Indiana)

Top Commodity	Weight (thousand tons)
All others	123,508.20
Gravel	39,958.53
Base metals	39,958.53
Cereal grains	32,693.35
Nonmetal mineral products	25,428.16
Other foods stuff	21,795.56
Gasoline	18,162.97
Coal	18,162.97
Waste/scrap	14,530.38
Other agriculture products	14,530.38
Motorized vehicles	14,530.38

TABLE 3.2
Movement of Top Commodities by Value (Indiana)

Top Commodity	Value (million USD)
All others	112,519.98
Motorized vehicles	63,761.32
Mixed freight	37,506.66
Base metals	33,755.99
Machinery	26,254.66
Other foods stuff	15,002.66
Gasoline	11,252.00
Pharmaceuticals	11,252.00

transportation services and expand MDOT's coordination and collaboration with partners.

3. *Safety and Security:* Continue to improve transportation safety and ensure the security of the transportation system.
4. *Stewardship:* Preserve transportation system investments, protect the environment, and utilize public resources in a responsible manner.

Table 3.3 represents the relationship between the Michigan Transportation Plan and the FAST Act goals.

The *Michigan Freight Plan* was analyzed to understand the focus of the state in terms of freight goals and the same was used to benchmark against Indiana. The *Michigan Freight Plan* has information for multiple years including 2016, 2018, 2019, 2020, 2021, and 2022. The freight goals of Indiana were considered as the benchmark to categorize projects pursued by Michigan. The projects were categorized into the same set of goals as Indiana based on the description given to the projects and analysis was done to understand Michigan's focus in terms of the state's freight goals.

3.1.2.2 Michigan projects. Figure 3.5 represents the analysis for Michigan's investment plan for the year 2016. Based on the projects mentioned in the state freight plan for the year 2016, the focus in terms of the freight goals was improving the state of good repair. The total investment focused towards achieving this in the year 2016 was over USD 149.9 million, with contributions from federal, state and NHFP funding. The highest contributor in the year 2016 was the federal funding with over USD 134.9 million in contribution, followed by USD 30 million by the NHFP funding, and followed by USD 14.99 million by state funding.

Figure 3.6 represents the analysis of the focus of Michigan's freight plans for the year 2018. In the year 2018, the projects are more diversified in focus, as compared to the projects in the year 2016. The focus in the year has extended to reducing congestion and incorporation of technology for maintenance and measurement of performance, along with improving the state of good repair. There is a significant difference in terms of the value of investment dedicated towards improving the state of good repair in the year 2018. A major contributor to this, is the modernization project on I-75. Based on the analysis, the highest priority

TABLE 3.3
Relationship between the Michigan's Transportation Plan and the FAST Act Goals

2040 MITP Goals / National Freight Goals	Efficient and Effective Operations	System Improvements	Safety and Security	Stewardship	Modal Choice	Freight Adequacy
Enhance economic efficiency, productivity, and competitiveness	•	•	•	•	•	•
Reduce congestion and bottlenecks	•	•	•		•	•
Improve safety, security, and resiliency	•	•	•	•	•	•
Improve state of good repair	•	•	•	•	•	•
Use advanced technology to improve the safety, efficiency, productivity, and reliability of the network	•	–	•	•	•	•
Reduce adverse environmental and community impacts	•	•	•	•	•	•
Improve the short- and long-distance movement of goods	•	•	•	•	–	•

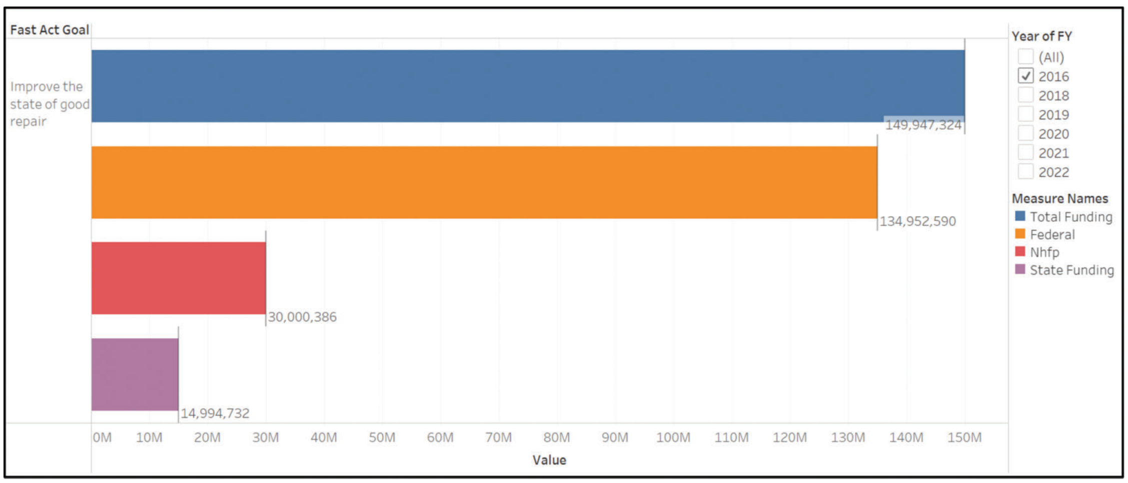

Figure 3.5 Analysis of Michigan's investment plan for the year 2016.

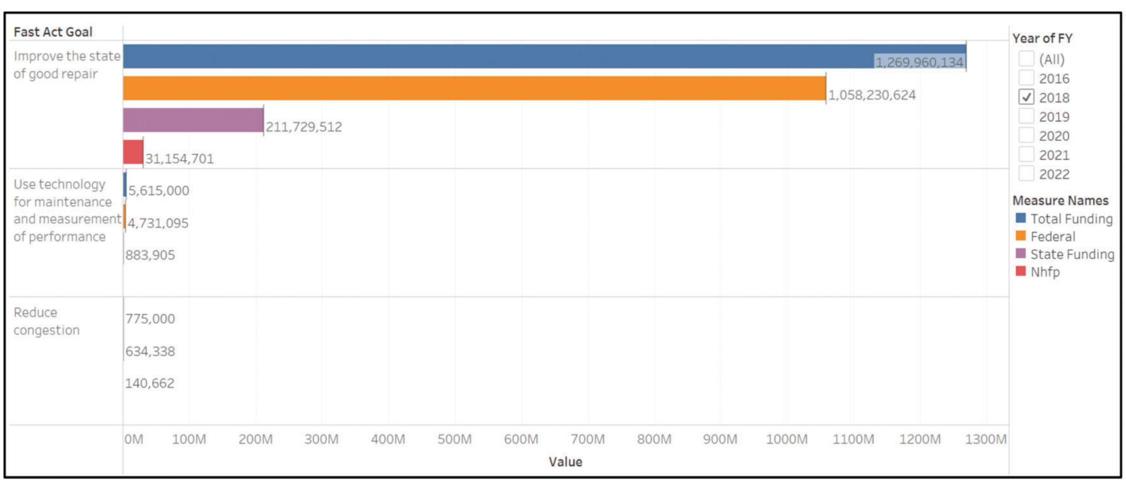

Figure 3.6 Analysis of Michigan's investment plan for 2018.

is given to the goal of improving the state of good repair, with over USD 1.26 billion in investment. The sources of funding are federal, state, and NHFP funding, with federal funding contributing the highest amount of over USD 1.05 billion, followed by the state funding of over USD 211.7 million and then by the NHFP funding of over USD 31.1 million. The goal of using technology for maintenance and measurement of performance is next in priority. A total of over USD 5.6 million is dedicated towards projects oriented towards this goal. The sources of funding are federal, and state funding. The highest amount of funding is provided by the federal funding with over USD 4.7 million in contribution, followed by the state funding of over USD 883,905. The projects focused on reduction in congestion is of third priority in the year 2018. A total of USD 775,000 was dedicated towards projects with the focus of reducing congestion alone. The sources of funding here are federal and state, with USD 634,338 contributed by the federal funding and USD 140,662 contributed by the state funding.

Figure 3.7 represents the project focus in terms of achieving the freight goals by Michigan during the year 2019. The focus continues to remain improvement of the state of good repair, using technologies for maintenance and measurement of performance, and increasing safety. The highest investment is focused towards improving the state of good repair with over USD 326 million in investment. The sources of funding are federal, state, and NHFP with over USD 280 million, USD 45 million and USD 35 million, respectively. The next highest focus in terms of the freight goal is increasing safety with over USD 10 million in investment. The source of funding for this goal is federal and state funding, with USD 8.18 million and USD 1.8 million, respectively. The third focus in terms of the freight goal is using technology for maintenance and measurement of performance with over USD 7.3 million in investment. The sources of funding are again state and federal. The highest funding is contributed by federal source, with a funding of over USD 6 million, followed by state funding of over USD 1.2 million.

Figure 3.8 represents the analysis for the year 2020. Improvement of state of good repair is the only significant focus in terms of freight goals during the year 2020 with a total funding of over USD 227 million.

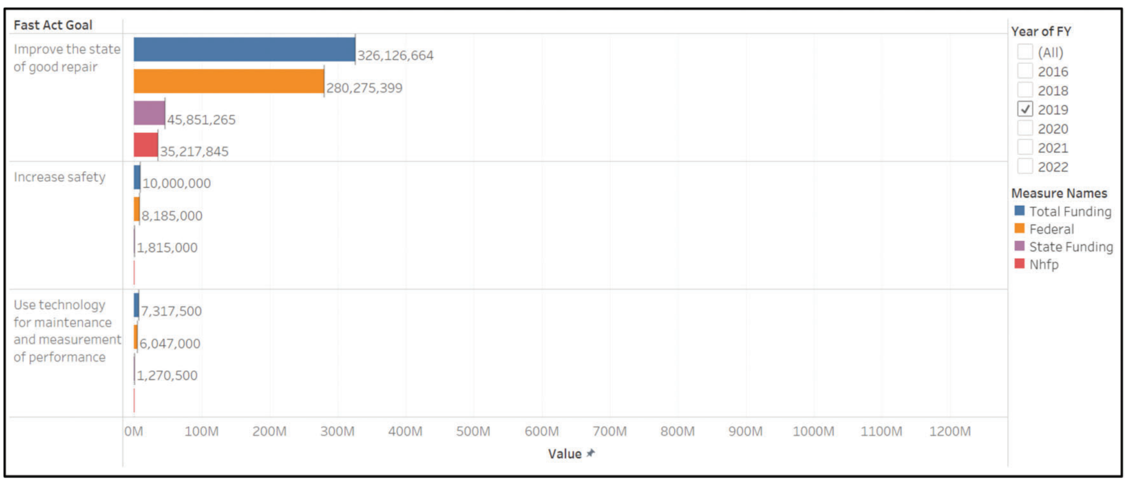

Figure 3.7 Analysis of Michigan's investment plan for 2019.

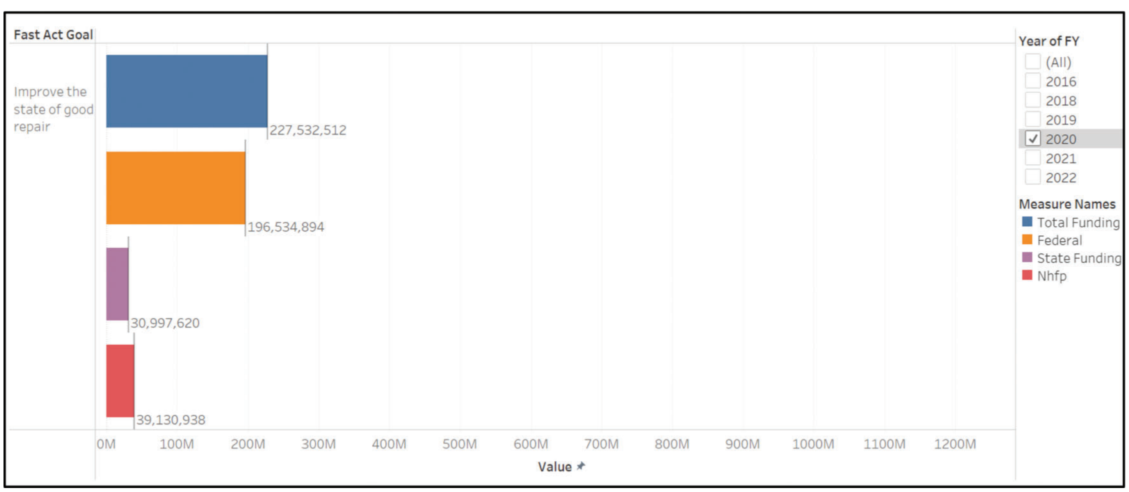

Figure 3.8 Analysis of Michigan's investment plan for 2020.

The sources of funding are federal, state, and NHFP funding with over USD 196 million, USD 30 million and USD 39 million, respectively.

Figure 3.9 represents the most important freight goals for the year 2021 in Michigan. The freight goal of the highest priority is improving the state of good repair with a total funding of USD 577 million dedicated towards this freight goal. The sources of funding have been federal and state funding, with over USD 513 million contributed by the federal funding and USD 63 million dedicated by the state funding. The next focused freight goal is using technology for maintenance and measurement of performance. The total funding dedicated towards this goal is over USD 1 million, with USD 826,943 dedicated by the federal source and USD 183,373 dedicated by state funding.

Figure 3.10 represents the focus of the freight goal in the year 2022 in Michigan. Improvement of the state of good repair is the only significant focus during this year with a funding of over USD 347.9 million. The sources of the funding are federal and state funding with over USD 310.9 million and USD 36.9 million, respectively.

3.1.2.3 Movement of top commodities. Movement of top commodities (MDOT, 2018) by truck in Michigan is represented in Table 3.4 by weight whereas Table 3.5 represents top commodities by value. Metallic ores, coal, and petroleum or coal products are the common commodities in top five commodities by weight and by value.

3.1.3 Minnesota

3.1.3.1 Minnesota goals. In Minnesota, the *Moving Ahead for Progress in the 21st Century Act* (MAP-21) formulated the methodology to meet the National Freight Goals. The following were the objectives as mentioned in the *Minnesota Statewide Freight System and Investment Plan* of 2018.

1. Improve the contribution of the freight transportation system to economic efficiency, productivity, and competitiveness.
2. Reduce congestion on the freight transportation system.
3. Improve the safety, security, and resilience of the freight transportation system.

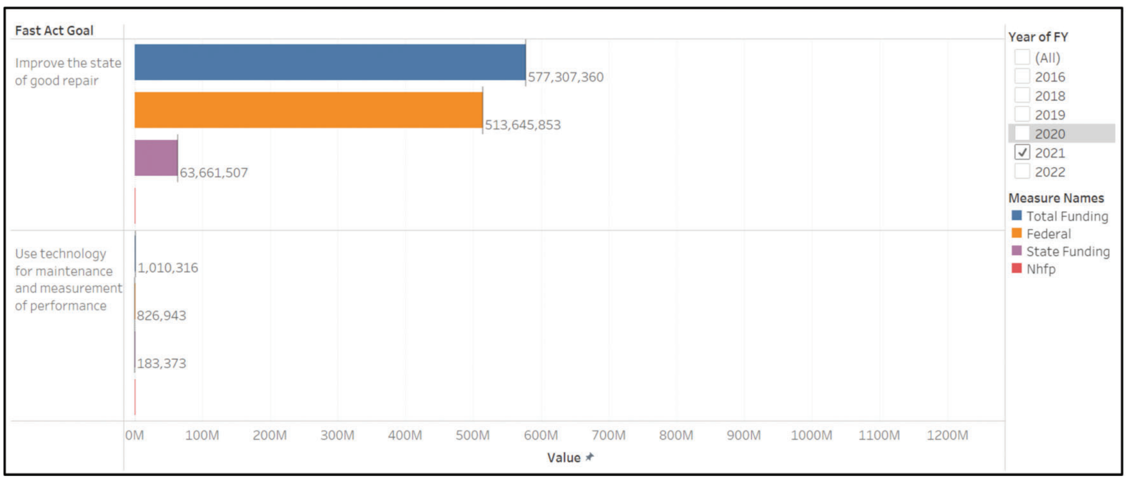

Figure 3.9 Analysis of Michigan's investment plan for the year 2021.

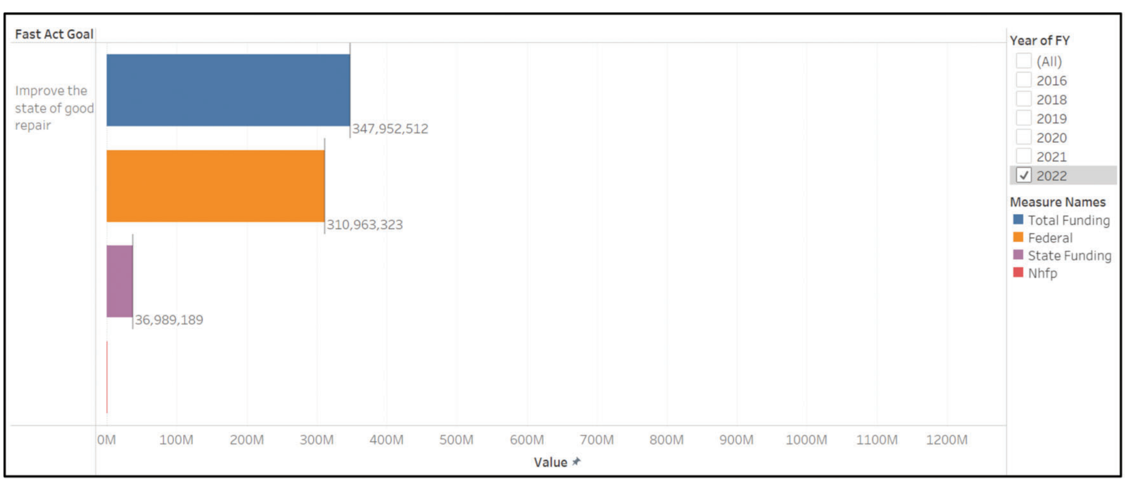

Figure 3.10 Analysis of Michigan's investment plan for the year 2022.

TABLE 3.4
Movement of Top Commodities by Weight (Michigan)

Top Commodity	Weight (million tons)
Nonmetallic ores	21.95
Metallic ores	15.63
Coal	15.56
Petroleum or coal products	5.48
Clay, cement, glass, or stone products	3.85

TABLE 3.5
Movement of Top Commodities by Value (Michigan)

Top Commodity	Value (million USD)
Petroleum or coal products	5,691.01
Metallic ores	1,477.31
Crude petroleum and natural gas	663.23
Chemical products	626.87
Coal	588.06

4. Improve the state of good repair of the freight transportation system.
5. Use advanced technology, performance management, innovation, competition, and accountability in operating and preserving the freight transportation system.
6. Reduce adverse environmental and community impacts of the freight transportation system.

3.1.3.2 Minnesota projects. Minnesota's project focus is based on the state freight plan.

The *Minnesota Statewide Freight System and Investment Plan* (MnDOT, 2018) was analyzed to understand the focus of the state in terms of freight goals and the same was used to benchmark against Indiana. The state freight plan of Minnesota has information for multiple years including 2016, 2017, 2018, 2019, 2020, 2021, and 2022. The freight goals of Indiana were considered as the benchmark to categorize projects pursued by Minnesota. The projects were categorized into the same set of goals as Indiana based on the description given to the projects and analysis was done to understand Minnesota's focus in terms of the state's freight goals.

Figure 3.11 represents the analysis for the year 2016 for Minnesota. The only significant focus in terms of the freight goal, in terms of investment is improving the state of good repair with over USD 17.7 million in dedicated funding towards I-35 unbounded overlay. The details of the individual sources of funding for this project is not provided in the *Minnesota State Freight Plan.*

Figure 3.12 represents the analysis of freight goals of Minnesota for the year 2017. The analysis shows a diversified focus in terms of the freight goals with reducing congestion in the highest priority with over USD 5.4 million in dedicated investment. Improving the state of good repair is the second in priority with over USD 3.3 million in dedicated funding. Improving safety is the third focus in priority with USD 1.5 million in dedicated funds.

Figure 3.13 represents the analysis for the year 2018. The freight focus has changed to economic impact being the highest priority with over USD 39 million dedicated funding. The second in priority is Improving the state of good repair with over USD 3.6 million dedicated funding. Reducing congestion is the next in priority with over USD 200,000 in dedicated funds and then, USD 200,000 is dedicated towards miscellaneous projects.

Figure 3.14 represents the analysis for the years 2019, 2020, and 2021. The focus in terms of the freight goal during this year in Minnesota is economic impact, with

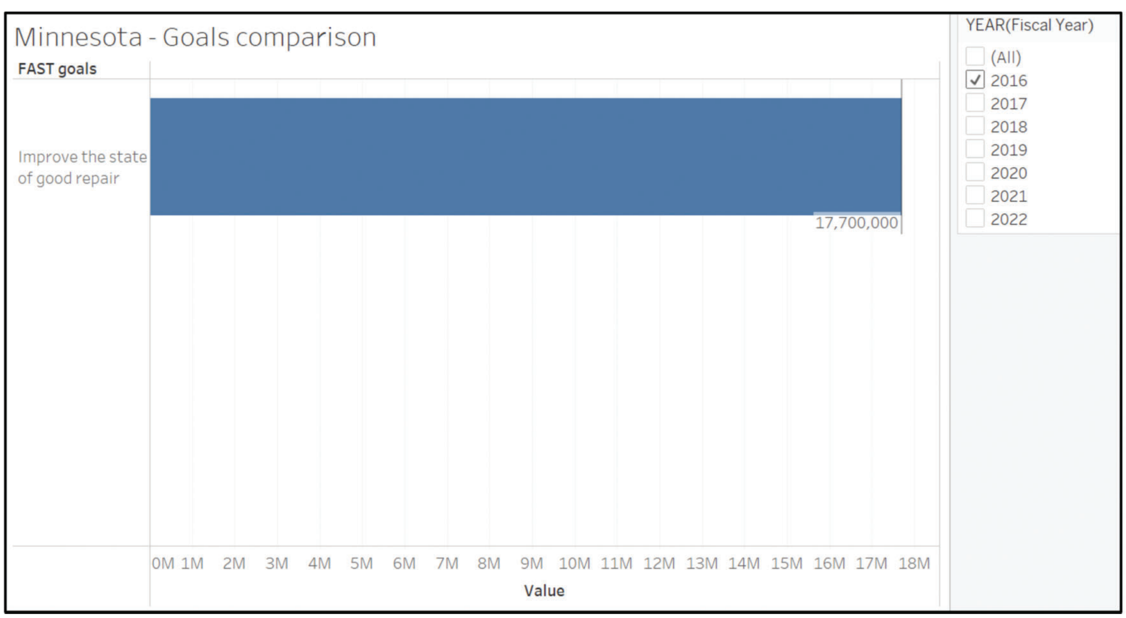

Figure 3.11 Analysis of Minnesota's investment plan for 2016.

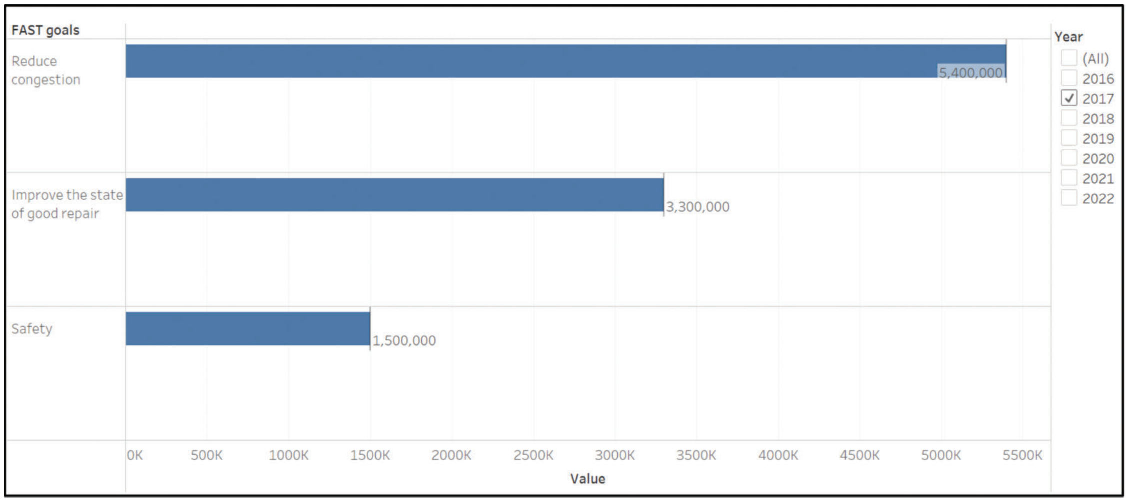

Figure 3.12 Analysis of Minnesota's investment plan for 2017.

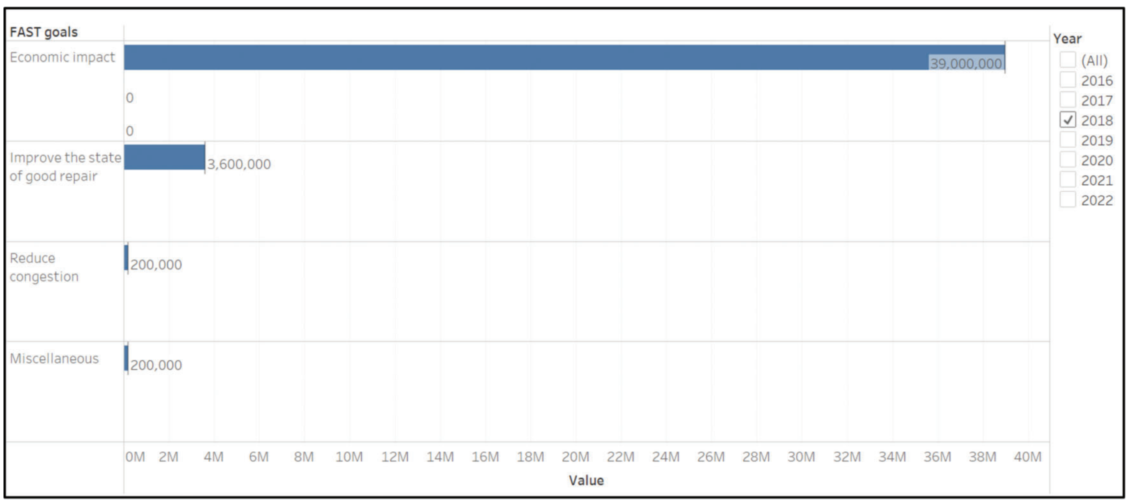

Figure 3.13 Analysis of Minnesota's investment plan for 2018.

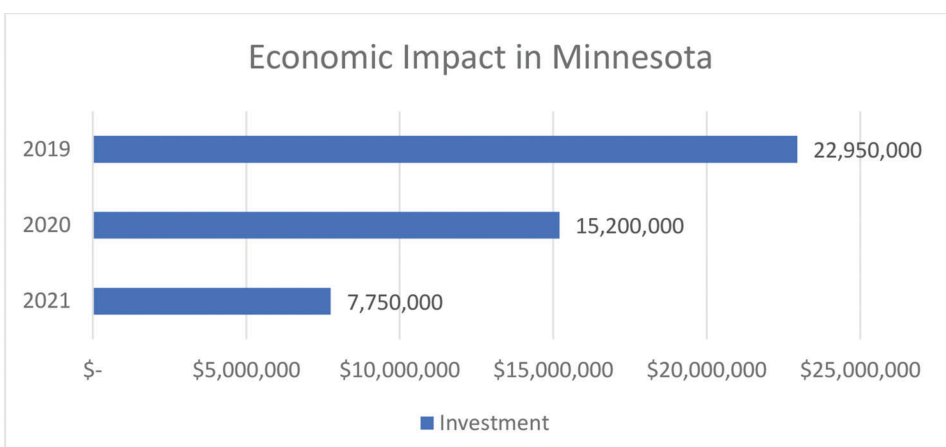

Figure 3.14 Analysis of Minnesota's investment plan for 2019, 2020, and 2021.

a total funding of USD 250,000. The sources of funding are state and NHFP funding. NHFP funding is the major contributor with USD 200,000 investment and USD 50,000 investment from state funding.

Figure 3.15 represents the analysis for the year 2022 with a focus on the economic impact as the major freight goal. The total funding dedicated to this freight goal is USD 22.9 million. The sources of the funding are state and NHFP. The major contributor is NHFP funding with over USD 15.2 million and state funding with over USD 7.7 million.

3.1.3.3 Movement of top commodities. Forecast of movement of top commodities (MnDOT, 2018), in weight (tons), by truck in Minnesota by 2040 is represented in Table 3.6. These commodities constitute a total of about 121,564,450 tons moving across the state. It is evident that cereal grain is the top commodity with a huge margin.

3.1.4 Ohio

3.1.4.1 Ohio goals. The *Transport Ohio Statewide Freight Plan* (ODOT, 2019) was considered for benchmarking, and the following performance measures are mentioned to meet the national freight goals.

- *Economic Development:* Develop and operate a state transportation system that supports a competitive and thriving economy, attracts new businesses and provides predictable freight movements.
- *Mobility and Efficiency:* Reduce congestion and increase travel reliability.
- *Safety:* Continue to improve transportation system safety.
- *Preservation:* Promote cost-effective preservation of multimodal assets.
- *Accessibility and Connectivity:* Increase customer access to Ohio's multimodal transportation system and improve linkages between modes (Note: This goal includes expanding the use of technology to improve user access to real time system condition information.)
- *Accountability:* Finalize ODOT's performance management goals once the FHWA releases final guidance.
- *Economic Development:* Develop and operate a state transportation system that supports a competitive and thriving economy, attracts new businesses and provides predictable freight movements.
- *Stewardship:* Advance financial, environmental, and social objectives for transportation investments.

3.1.4.2 Ohio projects. We used the state freight goals of Indiana as the benchmark to categorize the various projects pursued by Ohio. Figure 3.16 represents the analysis of Ohio's investment to achieve the state's freight goals. The major focus is on two goals: improving the state of good repair and reducing congestion. A total of USD 521.5 million has been focused towards improving the state of good repair and USD 23.1 million towards reducing congestion. Most of the funds have been focused on I-70, followed by I-75.

TABLE 3.6
Movement of Top Commodities by Weight (Minnesota)

Commodity	Weight (tons)
Cereal grains	159,337,502
Animal feed	56,369,940
Other agricultural products	53,667,516
Gravel	44,214,491
Nonmetal mineral products	43,748,163
Waste/scrap	28,309,040
Other foodstuffs	26,844,150
Milled grain products	18,761,563
Live animals/fish	14,596,918
Coal-n.e.c.	14,361,904
Mixed freight	13,835,631
Gasoline	13,174,338
Machinery	10,999,433
Natural sands	10,898,664
Wood products	10,563,900

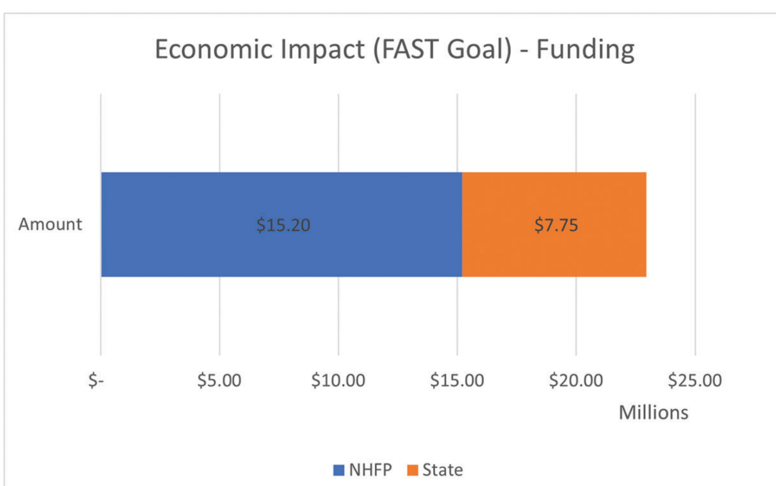

Figure 3.15 Analysis of Minnesota's investment plan for 2022.

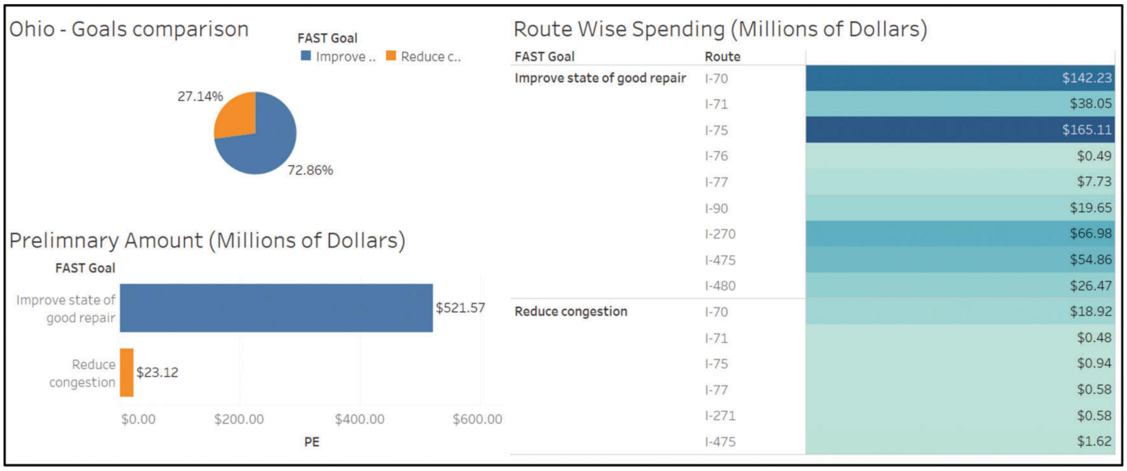

Figure 3.16 Analysis of Ohio's investment plan.

TABLE 3.7
Movement of Top Commodities by Weight (Ohio)

Commodity	Weight (thousand tons)
Base metals	78,102.60
Gravel	76,157.80
Nonmetal mineral products	60,689.80
Other foodstuffs	60,449.40
Waste/scrap	59,450.40
Cereal grains	53,329.00
Motorized vehicles	36,622.80
Natural sands	35,034.80
Plastics/rubber	34,122.40
Mixed freight	30,034.40

TABLE 3.8
Movement of Top Commodities by Value (Ohio)

Commodity	Value (million USD)
Motorized vehicles	215,941.10
Machinery	168,953.30
Electronics	130,210.30
Base metals	110,376.10
Plastics/rubber	98,217.00
Mixed freight	92,440.00
Textiles/leather	92,049.80
Pharmaceuticals	78,840.10
Chemical products	76,983.50
Other foodstuffs	74,049.70

3.1.4.3 Movement of top commodities. Movement of top commodities (ODOT, 2019) by truck in Ohio is represented in Table 3.7 by weight whereas Table 3.8 represents top commodities by value. Base metals, motorized vehicles, plastics/rubber, and mixed freight are the top commodities by weight as well as value.

3.2 Summary

The performance of the freight system within Indiana is measured by the ability of the state's freight systems to meet the FAST Act goals. The *Indiana Multimodal Freight Plan Update 2018* has been used to conduct the analysis. Based on the goals set by the FAST Act, the states developed some state-specific goals, and these were compared during the course of benchmarking. The investment plan pursued within Indiana, suggests a major focus on reducing congestion and improving the state of good repair. Michigan has a very similar plan; however, the investment amount in Michigan is much higher majorly influenced by the I-75 modernization project. Minnesota, however, has a significant focus on the Economic impact goal, followed by the goals of reducing congestion and improving the state of good repair. A similar trend is observed in Ohio as well.

In summary investment categories have remained consistent across neighboring states that were analyzed. The analysis further suggests that there is an opportunity to diversify and focus certain projects on safety and economic impact. The benchmarking analysis showed that the focus of the plans was on specific projects and their relationship to broad FAST Act goals, rather than specific industries. A specific goal of this project is to investigate specific links between critically important and significant Indiana industries and various transportation networks that could yield transportation projects to directly improve the competitiveness of the respective industries.

3.3 Minnesota Industry-Based Study

Manufacturers and other freight shippers are unique and important customers for the Minnesota Department of Transportation (MnDOT). The objectives of the study are the following:

- meet with manufacturers and industries to understand their perspectives and priorities,
- systematically collect and analyze customer information,
- build relationships, and
- support statewide continuous improvement and develop recommendations.

District 3 is one of Greater Minnesota's fastest-growing regions, accounting for about 13% of the state's population, second only to the Twin Cities Metro area. As shown in Figure 3.17, District 3 is located in the central part of Minnesota, covering 10,209 square miles (12.8% of the state's total area). Manufacturing is also well-represented in District 3.

Interviews were conducted with the business people one on one. A total of 465 businesses were contacted and 126 interviews were conducted. The 126 interviews conducted were guided by questionnaires that allowed for semi-structured interviews, meaning interviewers followed the guides but participants could pursue other relevant topics as they arose. The 126 interviews consisted of 104 manufacturer interviews and 22 carrier interviews, as mentioned in Figure 3.18.

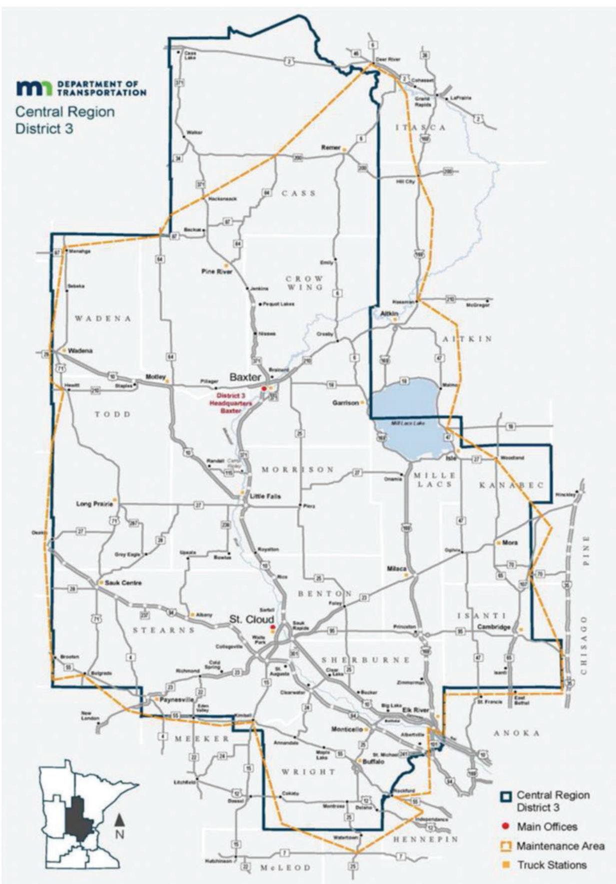

Figure 3.17 Minnesota District 3 county map.

Industry	Business Interviewed
Manufacturer	104
Carrier	22
Total	**126**

Figure 3.18 Number of businesses interviewed by industry.

3.3.1 Industry Cluster

Listed in order, the region's strongest traded clusters represented are the following.

1. Trailers, motor homes, and appliances
2. Construction products and services
3. Wood products
4. Livestock processing
5. Recreational and small electric goods
6. Printing services
7. Furniture
8. Metalworking technology
9. Production technology and heavy machinery
10. Vulcanized and fired materials
11. Agricultural inputs and services
12. Food processing and manufacturing
13. Plastics
14. Downstream metal products
15. Downstream chemical products

Clusters can be grouped into *traded* and *local* clusters. A local cluster is composed of industries that primarily sell within a region and are present in most (if not all) geographic areas. A traded cluster is composed of industries concentrated in a geographic region that sell to customers in other regions and nations. Figure 3.19 provides the distribution of local and traded cluster businesses that were interviewed in the 126 interviews.

3.3.2 Employees

During the 126 business interviews, data on employment was gathered. More than 10,300 people are employed by the 126 companies. Figure 3.20 depicts the distribution of enterprises by employee count. Only four of the firms surveyed had more than 500 employees, with more than two-thirds having less than 100. The average number of employees was 90, with the majority of companies employing between 20 and 49 people.

3.3.3 Modes of Transportation

All (104) firms indicated trucks are used to obtain supplies or ship products, with fewer than half (43 companies/41%) saying they utilize at least one other form of transportation (rail, air, or water). Figure 3.21 depicts the number of manufacturers who stated that they utilize each form of transportation. Of the 104 manufacturers, 90% indicated trucks are the most important form of transportation for their business.

3.3.4 Customer Markets

Many of the firms surveyed for this research produce and transport items not just in their hometowns, but also across the country and throughout the world. The geographic spread of the District 3 companies that were questioned is seen in Figure 3.22.

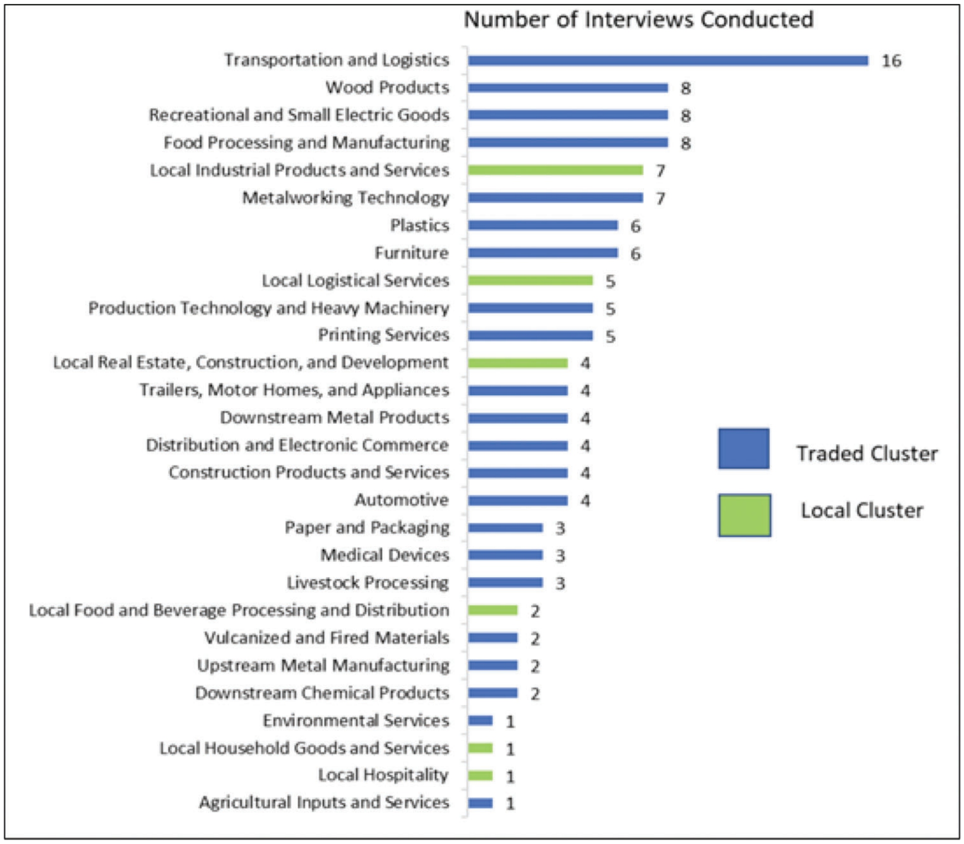

Figure 3.19 Traded and local clusters represented in District 3 interviews.

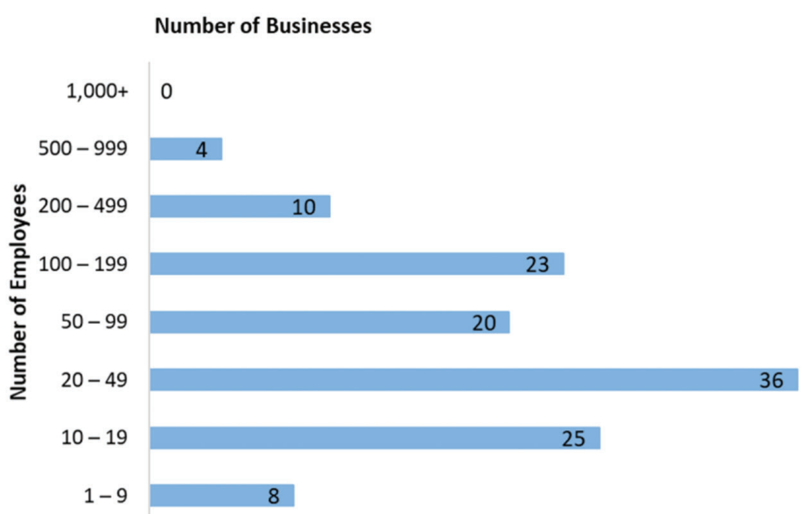

Figure 3.20 Number of business employees interviewed.

3.3.5 Summary

- Businesses said *construction* projects create congestion and contribute to traffic incidents, which causes shipping delays and makes moving products less efficient.
- Businesses said *congestion* affects their daily operations because it delays shipping and increases costs (e.g., labor, fuel, overtime).
- Businesses generally reported liking highway features that improve *safety* and increase efficiency, such as intersection warnings (e.g., *Prepare to Stop When Flashing* advanced warning signs).
- Businesses said *policies* around oversize and overweight restrictions in Minnesota affect business operations and shipping costs.
- Businesses said *rough pavement* can cause shifting freight, wear and tear on trucks and equipment, and driver

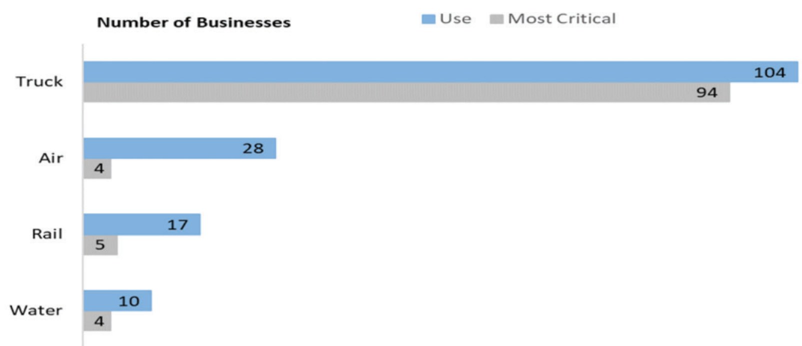

Figure 3.21 Modes of transportation that are used and are most critical to manufacturers.

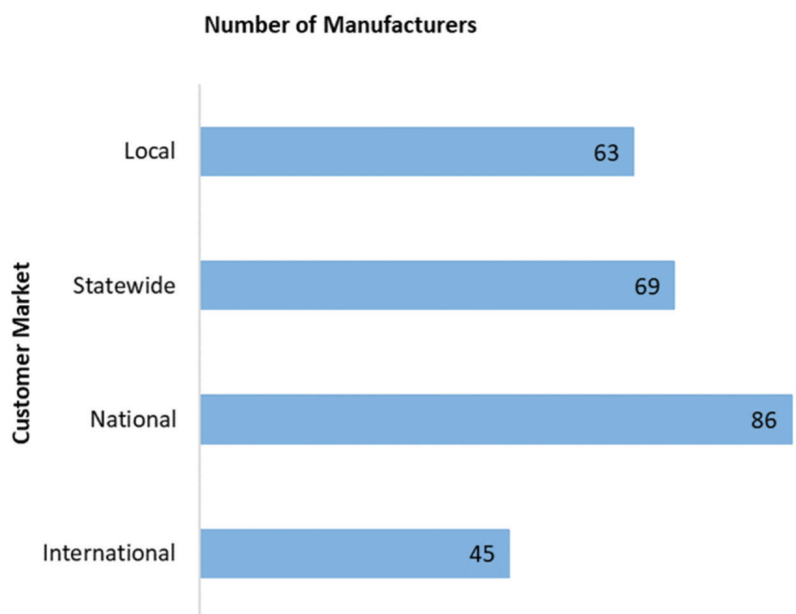

Figure 3.22 Customer market for manufacturers.

fatigue or injury. Businesses also commonly said shifts in freight can cause damage to product, which can be costly to fix or replace.

- MnDOT has observed greater concern about *truck parking* with the advent of e-logs and hours of service regulations and has worked concertedly on this issue, since 2016, with seven neighboring states.

4. INDUSTRY SURVEY AND ANALYSIS

4.1 Objectives

This phase of the project consisted of developing and conducting a survey of companies in Indiana with the primary goal of understanding the status and issues of freight mobility across the state.

Specific survey objectives include the following:

- investigation of the nature of the company and the commodities they manage,
- investigation of the company's reliance on road and other modes of transportation,
- collecting information about the location of suppliers and consumers, and
- identify the challenges encountered by the companies.

The results of this survey will be used to make recommendations to INDOT concerning specific projects.

An online survey consisting of twenty questions was created on Qualtrics. The complete survey is shown in the appendix section of this report. The survey questions were designed to identify the industry the respondent belongs to, the types of commodities that they manage, their logistic needs (amount of inbound and outbound freight), and the location of their suppliers and customers. Based on the response for these questions, these participants were asked for suggestions on road projects that the state transportation should focus on that could potentially benefit their company's competitive position. Furthermore, the respondents were asked to rank the issues they face based on how crucial each problem was to their business. They were also given an option to specify any additional issue not listed previously that had an impact on the freight movement. The link to the survey was shared with a targeted audience of approximately 400 companies in Indiana. These companies mainly belonged to manufacturing, transportation, retail/wholesale trade, logistics, and agricultural industry where high freight movement is observed.

The Oregon Department of Transportation survey methods (Lawson & Strathman, 2002) and Indiana furniture supply chain projects (Iyer et al., 2006) were analyzed and used as a basis of this project's survey. The details from the survey portion of these projects are summarized as in the next section.

4.1.1 Oregon Department of Transportation Survey Method

The objective of this study was to create a survey methodology that could be used to obtain information from members of the freight community about their opinions of infrastructure issues. To achieve this aim, the project took a four-pronged strategy detailed as follows:

1. researching past freight survey initiatives and survey instruments,
2. interacting with freight industry members for advice on the best survey technique,
3. methodically analyzing a variety of survey procedures, and
4. showing a potential survey instrument and deployment of methodology.

In-person interviews, computer-assisted telephone interviews, mail-out/mail-back surveys, and combinations of these deployment techniques are the 4 types of survey procedures that were used to obtain information from survey respondents. Among these, it was found that the in-person interviews had the highest response rate. However, this method was more costly and time consuming than the others. On the other hand, mail-out/mail-back approach was the least expensive but also had typically lower response rates than other methods.

For paper surveys, response rates varied from 8% to 24%, while for phone surveys, response rates ranged from 24% to 43% (with considerable ambiguity about calculating methodologies). As a result, response rates had been minimal for the most part.

4.1.2 Indiana Furniture Supply Chain Survey

This project's goal was to establish a method for understanding how INDOT decisions influence the state's economic growth potential by focusing on one industry: Indiana's furniture industry. The wood furniture sector is characterized by large, low-volume production, a wide range of products, and either high or low personalization. Logs of wood, machining and assembly, and paint and finishing are among the supply chain challenges for this industry.

The purpose of the survey in this project was to gain a broad understanding of the industry, its supply chain structure, and its major locations. This phase identified Dubois County as one of the industry's most significant sites, while also having the worst access to major state highways, making it an ideal place to analyze the impact of INDOT initiatives on the sector.

Twenty Indiana wood products firms participated in a brief survey to examine general supply chain concerns. A lengthy survey of ten Dubois County wood products firms was also conducted to examine more particular supply chain concerns.

4.2 Survey Results and Analysis

Analysis of the response to the survey is shown in the rest of the chapter. The graphs and pie charts highlight the most relevant findings of the survey.

1. How would you characterize your company?

Figure 4.1 shows that a majority of the respondents (65%) are from the manufacturing industry. The next largest categories are transportation and others, where food manufacturing and surveying were represented. Agricultural, construction, and retail/wholesale industries were also represented.

2. What is the frequency of inbound/outbound trucks per day at your site?

Figure 4.2 shows that most companies (81%) require between 1–15 trucks per day for inbound and outbound shipments while the remainder (19%) use 15–30 and 30–45 trucks per day.

3. Where are the primary suppliers/customers of your products located?

Figure 4.3(a) shows that most suppliers (57%) are located out of state. While a significant number of suppliers (28%) are international, few (15%) are located in state. Similarly, Figure 4.3(b) most customers (66%) are located out of state, and 20% are located in the state, with the remaining (14%) being international customers. Long-distance transportation and excellent interstate transportation networks are especially crucial for all businesses, given the high number of out-of-state suppliers and customers.

4. Of these five types of road projects, which one should the State Transportation Authority focus on in your county that will benefit your company? Choose multiple, if necessary. Rank them in order of importance, with one being the highest.

The respondents were offered multiple options to pick from, and the majority of them chose more than one. The results (Figure 4.4) imply that the state transportation authority should focus on enhancing road access, maintaining existing roads, and creating extra lanes to decrease traffic congestion. Table 4.1 shows

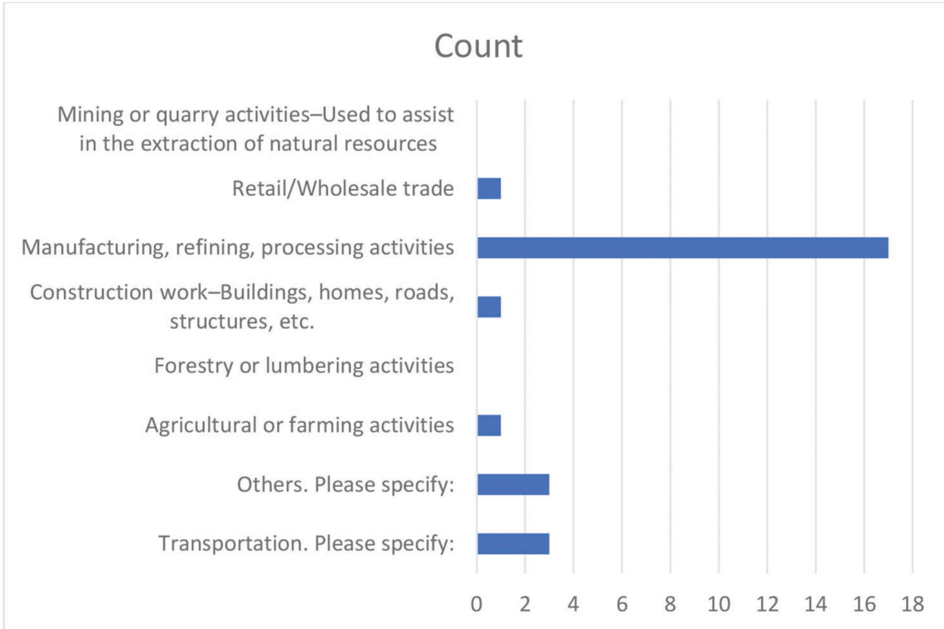

Figure 4.1 Industry category.

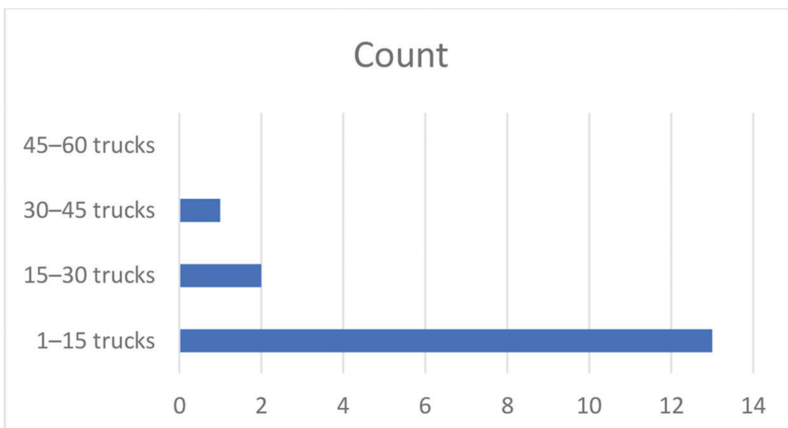

Figure 4.2 Frequency of trucks.

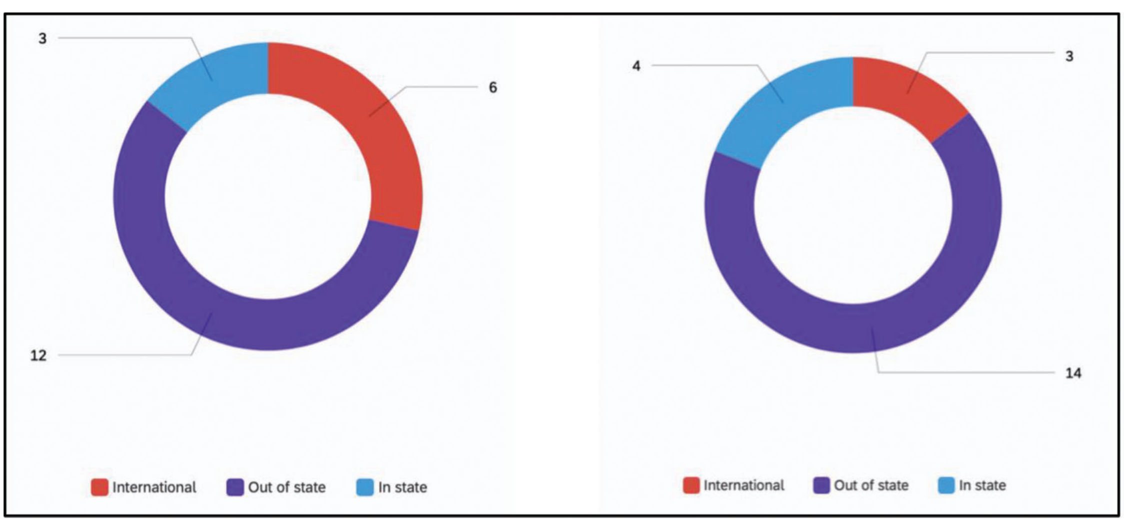

Figure 4.3 Location of (a) primary suppliers and (b) primary customers.

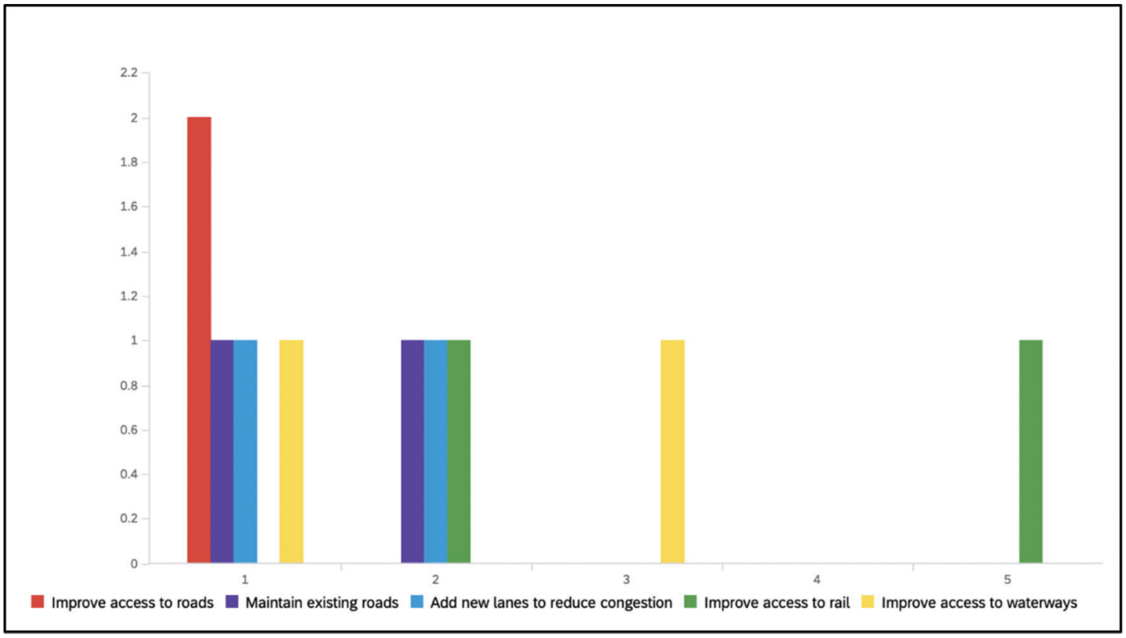

Figure 4.4 INDOT project focus.

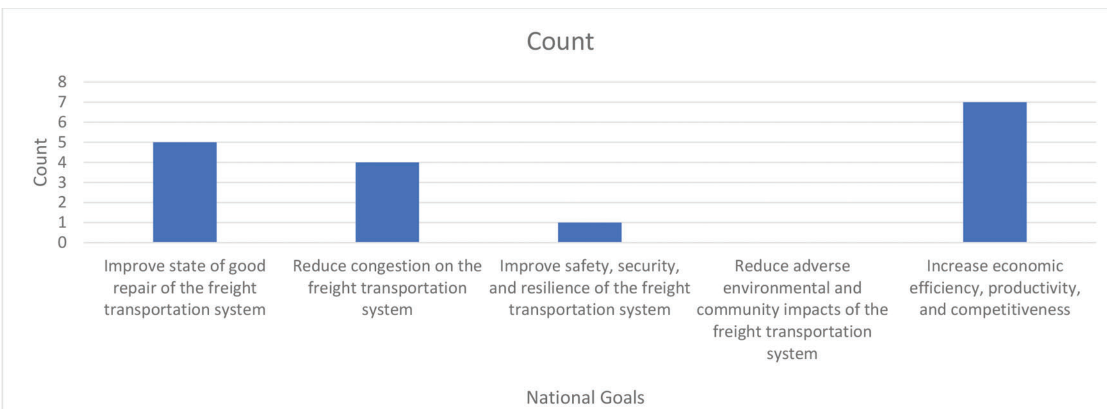

Figure 4.5 National freight goals focus.

TABLE 4.1
Average Score of Each Project

Type of Project	Average Score
Improve access to roads	1
Maintain existing roads	1.5
Add new lanes to reduce congestion	1.5
Improve access to waterways	2
Improve access to rails	3.5

the average score for each project, with the lowest score representing the highest priority.

5. Which one of these national freight goals will be the most beneficial to your company?

Figure 4.5 shows that each of the five options was selected across all categories, except for one option; reduce adverse environmental impacts of freight transportation system. An interpretation of these results is that many of these factors are linked. For example, an improvement in the existing road conditions and reducing congestion would automatically increase the economic efficiency and competitiveness.

4.3 Summary of Findings

The survey found that freight logistics play a significant role in the supply chains of the businesses studied. On an average, about 1–15 trucks are being used each day by majority of the companies for inbound and outbound shipments. A majority of the respondents were from the manufacturing firms, and this explains why there is always a need for trucks. Most of these industries' primary suppliers and consumers are situated outside Indiana, with just a small percentage of them being in-state and worldwide. As a result, long-distance transportation and excellent interstate links are essential.

The responses suggest that the state transportation authority should focus more on improving access to roads, primarily the major thoroughfares; maintaining the existing roads; and on adding new lanes to reduce congestion. Companies do not employ rail or water transportation very often. This could be primarily due to the fact that Indiana is situated in the center of the country, offering a 1-day access by truck to a majority of its customers and suppliers. However, a small number of respondents stated that these forms of transportation need to be improved.

A major finding from the respondents indicated that they were more inclined towards being economically competitive, which should be expected. Thus, the state transportation authority must focus more on improving the quality of existing roads and on building new roads that would reduce congestion to enhance the competitive position of the companies.

5. CASE-STUDY BASED OPTIMIZATION MODEL

This section presents the development of a scenario-based optimization model to minimize overall cost due to ramp congestion in the transportation infrastructure across all commodities needed in a particular supply chain. A component of the overall cost is the associated cost of capacity increase to facilitate smooth flow of freight vehicles either by constructing a new ramp lane or by diverting the flow to another ramp which leads to the same industry cluster as the congested ramp. The model, described later in the chapter is a Mixed Integer Programming model (MIP). The model was developed in an Excel-framework and integrated with an open-source solver called opensolver (https://opensolver.org/).

Various tasks and concepts developed as part of this project are now demonstrated through the use of three case studies. The case studies describe three important industry clusters essential to the continued growth and development of Indiana's economy. Two of the case studies, *Indiana Furniture Supply Chain Study* and *Honda Plant Project*, came from previous projects, while the third one, based on the recreational vehicle (RV) industry cluster in Elkhart County, Indiana, was developed specifically for this project. Extensive modeling using the optimization model was performed to demonstrate how INDOT can link long-term strategic investment projects to support development and expansion of critical industry clusters.

For the report, we have demonstrated the RV Industry case study in detail with the optimization model and the results. The other case studies are mentioned in the appendix.

5.1 Case Study: RV Industry

This case study was developed specifically for this project to synthesize findings from the previous studies and to demonstrate specific use of the economic model to suggest INDOT projects that could impact the continued growth and success of an important Indiana industry cluster.

5.1.1 Overview

The recreational vehicle (RV) industry is a 50 billion dollar per year market, with manufacturing largely centered in Elkhart County, Indiana. Despite the Covid pandemic, the RV industry set a record with approximately 507,000 units shipped in 2020. It is estimated that 80% of the recreational vehicles sold in the United States are manufactured in Northern Indiana, with 3 out of every 5 RVs made in Elkhart County, Indiana. The RV industry continues to thrive in 2021, with approximately 52,000 units shipped in April 2021. Figure 5.1 shows the number of units shipped monthly in 2020 and 2019.

The RV industry in Elkhart County and northwest Indiana continues to demonstrate explosive growth. Shipments of 49,241 units in May 2021 set an all-time record and extended the streak of consecutive month shipment records to seven. Accompanied by this growth in units is a growth in capital projects for the area that is estimated to be at approximately $300 million dollars. This expansion will further tax the transportation infrastructure. In addition to the increase in traffic for the supply chain inbound and outbound logistics, the import of workers from outside the immediate area puts additional strain on the roads. It is estimated that 35,000 RV workers commute from over 45 minutes away every day (Semmler, 2021).

There are over 100 manufacturers of RVs in the United States. The largest producers of RVs include Forest River, Oliver, Thor Industries, Coachmen Industries, Newmar, Jayco, Airstream, and Winnebago Industries. A majority of these top manufacturers are headquartered in Elkhart County, and all have significant manufacturing facilities in Northern Indiana. RVs are typically sold through a network of dealerships, of which there are over 7,000 in the United States.

RV manufacturers are scattered throughout Elkhart County, Indiana. The major RV manufacturers are shown in Figure 5.2.

There are *six classes of RVs* with a broad classification of being a self-contained unit or a towable unit.

Self-contained units are classified as follows.

Class A: Motorhomes are either gas or diesel powered. They are built on a specialty chassis and are between 30 and 40 feet long. Typically custom manufactured, they contain kitchens, master bedrooms and baths, high end electronics and designer furniture.

Class B: Motorhomes are built on a commercial van platform.

Class C: Motorhomes are built on a standard truck chassis and are between 20 to 25 feet long. They contain

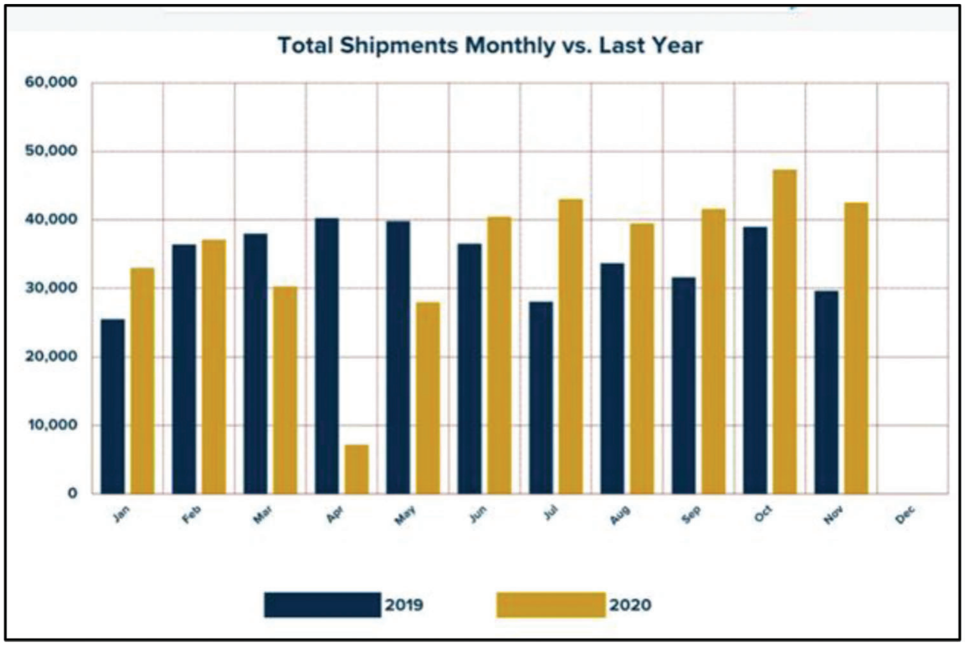

Figure 5.1 Monthly RV shipments.

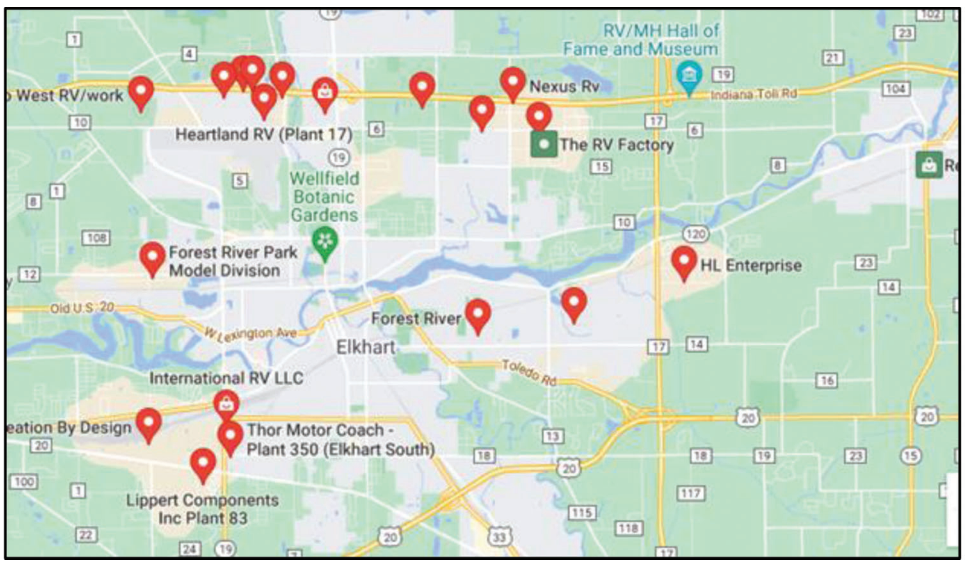

Figure 5.2 Major RV manufacturers in Elkhart County.

many of the luxury items in Class A motorhomes but lack much of the customization features.

Towable units are classified as follows.

5th wheel: Units are designed to be pulled by pickup trucks with a 5th wheel mechanism in the bed of the pickup.

Travel Trailer: Units are pulled using a standard bumper hitch and generally weigh between 4,000 and 10,000 pounds.

Campers, Tiny Trailers, and Pop-up: Units are pulled with a standard bumper hitch and are usually below 4,000 pounds.

Self-contained units represent about 11% of the units produced and are generally priced above $100,000. Towable units represent approximately 89% of the units produced, with 5th wheels representing 21%, travel trailers 20%, and the remainder being campers, tiny trailers, and pop-ups.

Based on 2020 sales numbers, the approximate distribution of the sale of RVs by classification are shown in Table 5.1.

TABLE 5.1
RV Shipments by Classification

Type	% of Total Shipments
Class A	3.3
Class B	1.3
Class C	6.1
5th Wheel	18.7
Travel Trailer	70.5

Elkhart County is located in North Central Indiana. It has an area of 468 square miles and a population of 206,341. Elkhart County is known as the *RV Capital of the World* and is home to the RV Museum. A total of 80% of Elkhart County's workforce is composed of manufacturing.

The supply chain for RVs is highly dependent on the classification. Class A units are custom manufactured. Class B and C units are built upon truck and van bodies which are supplied by major auto manufacturers such as Ford, Mercedes Benz, and Chrysler. The other units are typically fabricated from scratch using a number of suppliers generally located in Northern Indiana. Employment in the Elkhart-based RV industry is shown in Table 5.2.

Thor Industries and Forest River are multi-billion-dollar corporations and are two of the largest RV manufacturers in the world. Lippert Components, Patrick Industries, and Masterbrand are large RV component suppliers. Utilimaster is a large frame manufacturer. The size of these industries demonstrates the closeness of the supply chain to the end-item manufacturers.

Major characteristics of RV manufacturing include the following.

- Most start with similar frames/chassis.
- Many trailer manufacturers use frames built by the same third-party supplier, and axles and suspension from one of three different manufacturers.
- Gas powered motorhomes are usually built on a Ford chassis.
- Most diesel motorhomes are built on freightliner chassis. Some are on Spartan, and some (less commonly) are custom to a brand (like Tiffin's Powerglide).
- RVs are made from a combination of steel frames, aluminum or wood wall framing with fiberglass or aluminum exteriors, and fiberglass or TPO roofing.
- Most RV manufacturers use the same appliances and components made by third-party suppliers. For example, water heaters, furnaces, air conditioners, awnings, steps, furniture, etc.
- Many use offsite companies to make their cabinet doors.
- Insulation and underbelly materials are often the same products, from the same third-party suppliers.
- Many of the construction techniques and order of the production steps are very similar.
- Most RVs are built with very hands-on, manual build processes with little automation, compared to the auto industry.
- Nearly all RVs are built in low technology, unassuming, simple metal buildings.

TABLE 5.2
RV Employment in Elkhart County

Company	# Employees
Thor Industries	13,622
Forest River	10,000
Lippert Components	5,500
Patrick Industries	2,900
Utilimaster	849
Fairmont Homes/Gulfstream	705
Masterbrand Cabinets	700

- Full body paint (for available RVs) adds a couple of weeks of production time. Also adding many thousands of dollars to the cost. Many manufacturers outsource the paint process to companies that specialize in paint.

The core competency for RV manufacturing lies in the wall/roof construction. The process for making walls and roofs straight, strong, weather and road worthy is dependent on fiberglass and frame building expertise.

While in some cases it is outsourced, frame building is generally done by the manufacturer.

In the Class A, B, and C RV types, cabinet building is done by the manufacturer.

In most RVs, engines, axles, wheels, braking, suspension systems, appliances (stove, refrigerator, microwave, television, dishwasher), furniture (seats, beds, tables), batteries, pumps, furnaces, air conditioners, sinks, toilets, windows, doors, switches, and outlets are all purchased from suppliers.

Major raw materials used in RV manufacturing include wood, steel, aluminum, insulation, wire, and fiberglass.

The process for making RVs is similar for all classes. Table 5.3 shows the basic steps and materials/components necessary for the production of RVs.

For the most part, Class A, B, and C vehicles are highly customized and are generally built to order.

Towable units are generally standardized and are built to stock with numerous interior/exterior/finish options available. These units are generally built on assembly lines with varying daily production rates based on demand projections. Inventory levels inside the manufacturing facilities are kept low with frequent restocking. This is accomplished by the locality of the extended supply chain.

5.1.2 Justification

Nearly all of the raw materials and components for RV manufacturing are delivered to the assembly and production facilities by trucks. Standard semi-trucks with flatbed trailers or standard box trailers handle most of the raw materials. Delivery-type vans are also used. For the Class C RVs, the truck cab and chassis are typically driven from the manufacturer individually or in a towable configuration of at most three vehicles.

TABLE 5.3
Bill of Material for RV Manufacturing

Process Step	Class A	Class B, C	Towable	Materials
Chassis	Fabricated	Purchased	Fabricated	Steel (channels, bars), aluminum channels
Floor	Fabricated	–	–	OSB, plywood, vinyl, tile, waterproof membrane
Sidewalls/slidewall construction	Fabricated	Fabricated	Fabricated	High density foam, luan veneer, fiberglass
Cabinet construction/installation	Fabricated	–	Fabricated	Wood, hardwoods, hardware, stain
Plumbing installation	Purchased	Purchased	Purchased	Toilets, sinks, PEX tubing, fittings, faucets, water tanks, waste tanks
Electric wiring/harness	–	–	–	Wire, outlets, breakers
Ductwork installation	–	–	–	Flexible tubing
Furnace installation	Purchased	Purchased	Purchased	Furnace, gas lines
Attach sidewalls				
Install furniture	Fabricated	–	Purchased	Chairs, tables, couch, bed
Install appliances	Purchased	Purchased	Purchased	Stove, refrigerator, microwave, television
Install roof	–	–	–	Wood, fiberglass, EPDM membrane
Windshield	Purchased	Purchased	Purchased	Glass
Paint/graphics	–	–	–	Vinyl

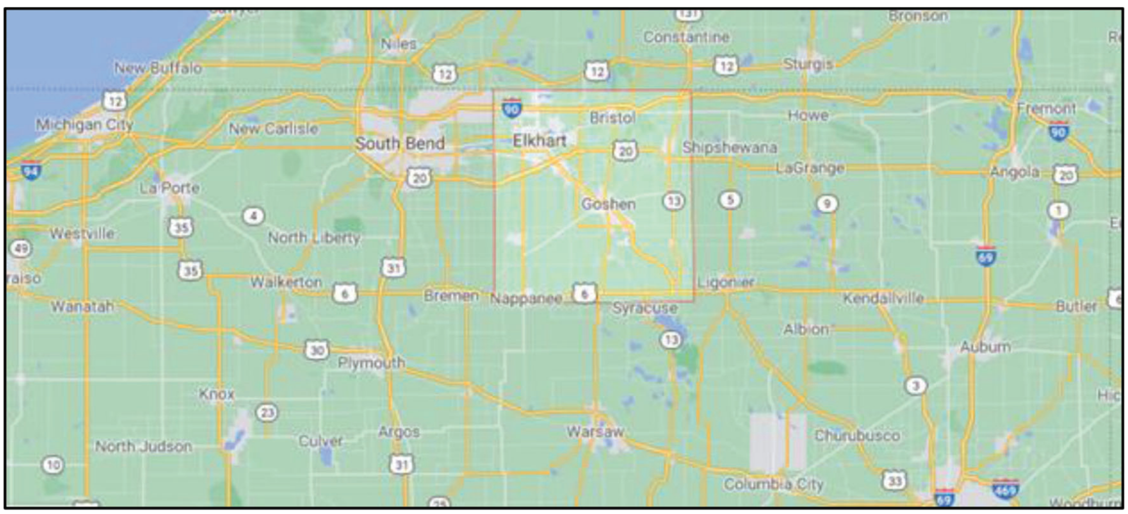

Figure 5.3 Major highways around Elkhart County.

Class B RV vans are individually driven or delivered in a standard semi auto carrier.

Class A RVs are typically driven from the factory individually to a dealer or customer with a towable vehicle for the return trip. Class C RVs are driven from the factory individually with a towable vehicle or on flatbed trailers with typically two units per trailer. Class B RVs are typically delivered with a semi auto carrier holding six to ten RVs.

As shown in Figure 5.3, Elkhart County is located in Northern Indiana and has close access to major East-West highway corridors. This is advantageous to the RV industry since a majority of the logistics, both inbound and outbound are truck-based.

US Highways 20 and 6 extend through the county. The Indiana Toll Road (90) also extends through the county and provides access to I-94 approximately 40 miles to the west. Highways 20 and 6 also provide access to north/south routes through connections to US-31 at the west and I-69 to the east. Connection to I-65 can also be reached from the Indiana Toll Road or I-94, US 20, US 6, or US 30. For the optimization model, we have considered ramps on US Highway 20 and US Highway 80 as these two major highways lead to other highways.

Figure 5.4 shows a Pareto distribution of shipments by state. The largest 17 states are shown.

The chart in Figure 5.5 shows the distribution of shipments in the United States. This can be used to estimate the amount of traffic on various routes out of Elkhart County based on their final destinations. The regions are identified using Elkhart County as the center of a rectangle. States are put into the following various regions based on major highways.

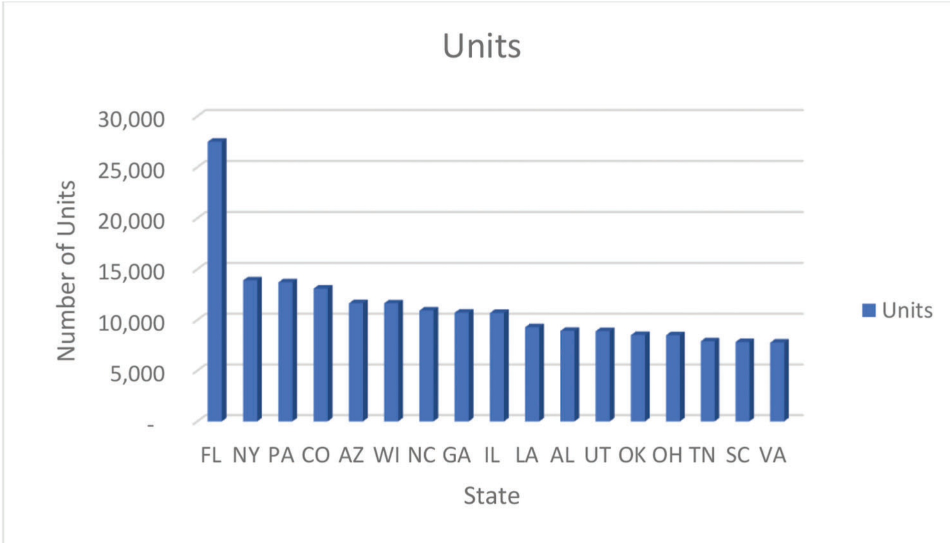

Figure 5.4 Outbound RV shipment from Indiana.

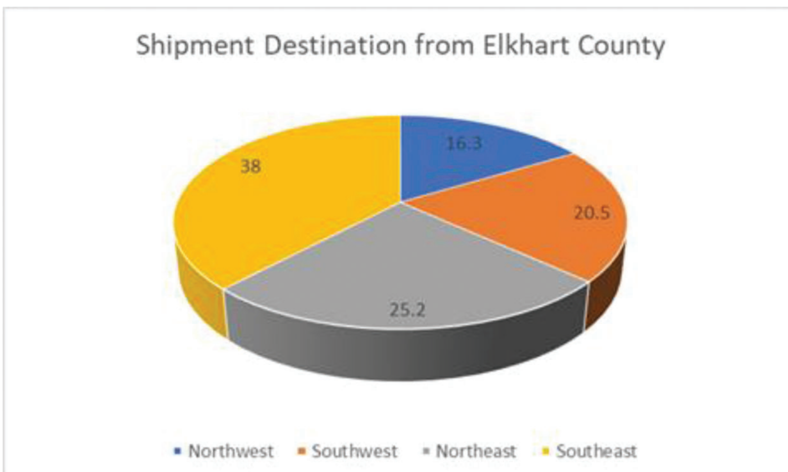

Figure 5.5 Region-wise shipment distribution.

- Northwest: States on or above I-80 and west of I-65/ US 31.
- Southwest: States south of I-20 and west of I-65/US 31.
- Northeast: States east of I-69 and on or above I-80.
- Southeast: States east of I-69 and south of I-20.

In summary, the RV industry is a perfect example of an industry cluster. A majority of the manufacturers are located in a small radius, and the supply chain can deliver necessary components to this target area using a common set of transportation infrastructure. This provides a compact view to apply an optimization model, in which a series of targeted infrastructure improvements can benefit an entire industry cluster.

5.2 Optimization Model

We developed a mathematical model to optimize capacity addition while maintaining the desired expected congestion level.

5.2.1 Model Description

In this model, capacity is added to ramps ahead of scenario realizations and before the two periods of freight, while industry flow on ramps is optimized to manage travel costs and congestion costs as well as the upfront capacity addition costs.

The description of the variables used in the model include the following.

i = County identifier.

j = Ramp into county identifier. Ramp $j = 1, 2, \ldots R(i)$ for county i.

k = Scenario identifier. Scenario $k = 1, 2, \ldots K$.

t = Time period identifier. Time $t = 1, 2, \ldots T$.

m = Commodity identifier.

$q(k)$ = Probability of occurrence of each scenario k.

$F(i,m,k,t)$ = Commodity m headed to the RV industry cluster (i.e., inflow of a commodity) in county i in period t for scenario k.

$F'(i, k, t)$ = Outflow of RV vehicles from the Elkhart county in county i in period t for scenario k.

$X(i,j,m,k,t)$ = Flow of commodity m through ramp/highway j in county i headed to RV industry cluster for scenario k at time period t. Note: $\Sigma(j)\ X(i,j,m,k,t) = F(i,m,k,t)$.

$X'(i, j, k, t)$ = Flow of RV vehicles through ramp/highway j in county i Note: $\Sigma(j)\ X'(i,j,k,t) = F'(i,k,t)$.

$CD(i,j,m)$ = Cost associated with the distance traveled from the ramp i to the industry cluster by commodity m (in county i).

$CD'(i,j)$ = Cost associated with the distance traveled from the ramp i out of the industry cluster by RV outbound/outflow (in county i).

f' = fraction of commodity flow (fraction of commodity usage in RV manufacturing).

$C_0(i,j)$ = Base capacity of each ramp j in county i.

$CN(i,j)$ = Capacity that can be added to each ramp j in county i. Additional capacity available for t periods and all scenarios.

$P(i,j)$ = Cost associated with increasing capacity of each ramp j in county i by $CN(i,j)$.

$Y(i,j)$ = A zero one variable if set to 1, increases capacity by $CN(i,j)$.

$EX(i,j,k,t)$ = Flow in excess of the capacity on ramp j in county i under scenario k in period t. This is a measure of congestion i.e., larger this value, larger the congestion.

UD = Disutility associated with congestion. We add it just to get flows to try to remain within capacity.

$CX(i,j)$ = Target congestion for ramp j in county i.

$AXE(i,j,k,t)$ = Observed downside i.e., congestion beyond the level $CX(i,j)$ in period t.

$ECONG$ = Expected congestion beyond the threshold values $CX(i,j)$ across all scenarios, exits etc.

The optimization model formulation is shown below.

$$Min\,\Sigma_{(i,j)} Y(i,j) * P(i,j) + \Sigma_{(i,j,m,k,t)} CD(i,j,m) * X(i,j,m,k,t) + \Sigma UD * EX(i,j,k,t) + \Sigma_{(i,j,k,t)} CD'(i,j) * X'(i,j,k,t) \quad \text{(Equation 5.1)}$$

$$\Sigma_{(j)} X(i,j,m,k,t) = F(i,m,k,t) \qquad \sum_{(j)} X'(i,j,k,t) = F'(i,k,t) \quad \text{(Equation 5.2)}$$

$$EX(i,j,m,k,t) \geq X(i,j,m,k,t) - f' * (C_0(i,j) + Y(i,j)\ CN(i,j))\ \forall j,k,t,m$$
$$AXE(i,j,m,k,t) \geq EX(i,j,m,k,t) - CX(i,j)\ \forall\, i,j,k,t \quad \text{(Equation 5.3)}$$

$$\Sigma_{(i,j,k,t)} q(k)\, AXE(i,j,m,k,t) \leq ECONG\ for\ all\ m \quad \text{(Equation 5.4)}$$

$$Y = 0\ or\ Y = 1 \quad \text{(Equation 5.5)}$$

$$X \geq 0 \quad \text{(Equation 5.6)}$$

$$EX \geq 0 \quad \text{(Equation 5.7)}$$

$$AXE \geq 0 \qquad X' \geq 0 \quad \text{(Equation 5.8)}$$

Additional constraints were added to differentiate the flow on inbound and outbound ramps.

5.2.2 Model Input

Scenario Probabilities: The user is given a choice to decide what scenario to plan for. Each scenario has an associated probability of it happening. Therefore, a decision can be made by taking multiple scenarios into account. In our analysis five different SSP scenarios are considered. They have largely different GDP predictions and industry growth resulting in different freight growth under each condition. We set the values of each of the five scenarios equal to 0.2.

Ramp Selection: Not all ramps within a county add to congestion. Often these can be attributed to a select few that have high freight numbers travelling through it. If multiple ramps are available at an exit, we select the ramps that have the most trucks passing through it. At all other exits at least one ramp is selected for analysis so that we can study if these routes can act as an alternate route to reach industry clusters of a county. The state roads that have large freight numbers contributing to its congestion are also considered.

Freight Demand: The aggregated freight demand of the county for a future year is calculated. In our model the truck volumes are predicted for five different SSP scenarios and three different future years, 2030, 2040, and 2050. We assume that the source of entire freight demand is generated from the cluster and the contribution of other industries are not considered. The individual demand of the cluster is considered to be in proportion of their relative GDP values. The total freight demand is divided among the cluster in proportion of their GDP for each selected scenario and period.

Ramp Capacity: For each of the identified ramps, capacity is calculated in terms of truck numbers. The base capacity can increase if a ramp construction happens at that location.

Construction Costs: Construction cost refers to adding capacity to an exit either by adding lanes to existing ramps or building new ramps. The cost associated with this construction can vary according to the location and type of project. For our modelling we have considered an average construction cost of $1,500,000 at a ramp location that can increase the ramp capacity by 200 trucks. This value can be changed by the user if actual costs of increasing capacity at a location is already known.

Modifiable Parameters: For our analysis, we changed the values of UD, cost per unit of freight congestion, between 10 and 500 to see the trade-offs. Increasing UD increases the delay cost forcing the system to find a route devoid of congestion. The ECONG parameter, a measure of flow over acceptable congestion, was also varied to see if a construction was forced. The CX parameter, measure of flow over capacity was kept at 20. The planner can change all these parameters to meet their requirements.

For the optimization model, the scenario parameters were defined. Each scenario was allocated equal probability. Figure 5.6 presents the model parameters and the results.

5.3 RV Industry Model

We now present the details of an optimization model developed to analyze potential freight growth across multiple commodities used in the RV industry and preemptively add capacity to alleviate congestion. In order to represent the uncertainty in commodity growth, we use scenarios i.e., significant industry shifts as a mechanism to represent potential freight growth. We considered 8 ramps off of highway 20 and 7 ramps off of highway 80 that lead directly to the RV industry cluster. In our analysis we assume that most freight take Interstate 80 rather than the state roads or county roads. Therefore, all exits on an interstate that led into the county are considered.

Given these ramps and local roads, the associated driving distance (miles) is represented in Figure 5.7.

We assume that the distance travelled from a specific ramp to the industry cluster is constant, thus the distance remains same for all the commodities.

For each ramp, we assume that the ramps have a base capacity in units of trucks per hour, and a cost to add capacity and associated capacity expansion are represented in Figure 5.8 and Figure 5.9.

The RV industry represents a significant part of the Elkhart County GDP, an approximate fraction of 0.44 is multiplied to the base capacities listed Figure 5.8. Figure 5.9 contains the adjusted ramp capacities.

The ramp expansion costs may differ based on the ramp location and layout, as can the capacity that can be added. The cost represents the capital investment that must be planned by INDOT in advance of the realized freight by scenario. Given the lead time to get budgetary (legislative) approval and manage the construction, this capacity is not available unless planned well in advance. Figure 5.10 provides the distinction whether a ramp is an inbound or an outbound ramp.

Consider the growth in commodities across five economic scenarios and three time periods for inbound and outbound as shown in Figure 5.11.

We assume that industry will rationally choose optimal routes to minimize their costs, and that freight will be distributed across different ramps. This choice of additional driving distance to reduce congestion is captured by optimizing the flow across ramps while monitoring the excess freight beyond capacity, defined as congestion. We introduce three terms to describe congestion. The first term is the cost per unit of freight

Probability	1	2	3	4	5
q(k)	0.2	0.2	0.2	0.2	0.2

Figure 5.6 Weight probabilities across scenarios.

Distance Matrix															
Inbound															
Ramp#	20 - 092B	20 - 092C	20 - 092D	20 - 092F	20 - 096A	20 - 096D	20 - 099A	20 - 099D	80 - 090D	80 - 092C	80 - 092D	80 - 096C	80 - 101C	80 - 107D	80 - 108C
Wood	6.2	5.5	6.7	20.8	9.4	2.6	4.5	5	6.5	12.6	4.4	15.4	14.5	17.8	44.3
Steel	6.2	5.5	6.7	20.8	9.4	2.6	4.5	5	6.5	12.6	4.4	15.4	14.5	17.8	44.3
Aluminum	6.2	5.5	6.7	20.8	9.4	2.6	4.5	5	6.5	12.6	4.4	15.4	14.5	17.8	44.3
Insulation	6.2	5.5	6.7	20.8	9.4	2.6	4.5	5	6.5	12.6	4.4	15.4	14.5	17.8	44.3
Wire	6.2	5.5	6.7	20.8	9.4	2.6	4.5	5	6.5	12.6	4.4	15.4	14.5	17.8	44.3
Fiber glass	6.2	5.5	6.7	20.8	9.4	2.6	4.5	5	6.5	12.6	4.4	15.4	14.5	17.8	44.3
Outbound															
Ramp #	20 - 092B	20 - 092C	20 - 092D	20 - 092F	20 - 096A	20 - 096D	20 - 099A	20 - 099D	80 - 090D	80 - 092C	80 - 092D	80 - 096C	80 - 101C	80 - 107D	80 - 108C
RV	6.2	5.5	6.7	20.8	9.4	2.6	4.5	5	6.5	12.6	4.4	15.4	14.5	17.8	44.3

Figure 5.7 Distance matrix for RV industry.

Ramp Base Capacity	152	152	153	152	153	152	204	200	681	194	379	379	379	309	698

Figure 5.8 Ramp base capacity table.

Adjusted Ramp Base Capa	66.88	66.88	67.32	66.88	67.32	66.88	89.76	88	299.64	85.36	166.76	166.76	166.76	135.96	307.12
Ramp Cost	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000
Ramp Add Capacity	88	88	88	88	88	88	88	88	88	88	88	88	88	88	88

Figure 5.9 Ramp adjusted base capacity table.

Outbound	Inbound	Outbound	Outbound/Inbound	Outbound	Outbound/Inbound	Outbound	Outbound/Inbound	Outbound	Outbound/Inbound	Outbound	Outbound/Inbound	Outbound/Inbound	Inbound	Inbound
20 - 092B	20 - 092C	20 - 092D	20 - 092F	20 - 096A	20 - 096D	20 - 099A	20 - 099D	80 - 090D	80 - 092C	80 - 092D	80 - 096C	80 - 101C	80 - 107D	80 - 108C

Figure 5.10 Description of ramps—inbound/outbound.

Freight Requirements								
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
1	**2025**	**2035**	**2045**		**1**	**2025**	**2035**	**2045**
Wood	254	305	353		RV	793.5519	953.6941	1103.044
Steel	265	318	368					
Aluminum	265	318	368					
Insulation	254	305	353					
Wire	265	318	368					
Fiber glass	254	305	353					
	1555							
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
2	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Wood	249	287	320		RV	778.8388	896.7482	1000.61
Steel	260	299	334					
Aluminum	260	299	334					
Insulation	249	287	320					
Wire	260	299	334					
Fiber glass	249	287	320					
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
3	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Wood	240	264	280		RV	750.6079	824.598	874.475
Steel	250	275	291					
Aluminum	250	275	291					
Insulation	240	264	280					
Wire	250	275	291					
Fiber glass	240	264	280					
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
4	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Wood	251	299	340		RV	784.1619	933.8285	1063.412
Steel	261	311	354					
Aluminum	261	311	354					
Insulation	251	299	340					
Wire	261	311	354					
Fiber glass	251	299	340					
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
5	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Wood	264	340	425		RV	825.8941	1063.858	1329.471
Steel	275	355	443					
Aluminum	275	355	443					
Insulation	264	340	425					
Wire	275	355	443					
Fiber glass	264	340	425					

Figure 5.11 Freight requirements for RV industry.

that exceeds capacity, reflecting a lateness penalty. The sample values for this example were a cost per unit of freight congestion depicted by UD which was set at 10 and then varied to generate tradeoffs. The second is an acceptable delay that does not create a competitiveness impact called CX. For this example, we set CX to be 20, then vary it to generate tradeoffs. The third is a planned expected amount of congestion, beyond the acceptable level CX that the planner considers when adding capacity called ECONG. We initially set ECONG at 50, then vary it to generate tradeoffs.

5.3.1 Results

In this section we present results and analysis obtained for the Elkhart County RV industry cluster using the Mixed Integer Programming model. The output of the model allows the planner to decide in advance where additional capacity needs to be added while considering various scenario possibilities. In our analysis only counties that showed a considerable number of its ramps that go out of capacity in the near future are selected.

	UD	ECONG	Transportation Const	Delay Cost	Construction Cost	Objective function
1	10	0	58773.35265	0	7500000	7558773.353
2	10	20	81713.74202	3800	0	85893.74202
3	10	50	68798.16071	9303.1024	0	79031.57331
4	10	100	55045.39258	18303.102	0	75178.80523
5	10	500	38497.2823	31472.139	0	73116.63558
6	50	0	58773.35265	0	7500000	7558773.353
7	50	20	89629.59927	3748.5925	0	93453.16364
8	50	50	89629.59927	3748.5925	0	93453.16364
9	50	100	89629.59927	3748.5925	0	93453.16364
10	50	500	89629.59927	3748.5925	0	93453.16364
11	100	0	58773.35265	0	7500000	7558773.353
12	100	20	89629.59927	7497.185	0	97201.75616
13	100	50	89629.59927	7497.185	0	97201.75616
14	100	100	89629.59927	7497.185	0	97201.75616
15	100	500	89629.59927	7497.185	0	97201.75616
16	500	0	58773.35265	0	7500000	7558773.353
17	500	20	89629.59927	37485.925	0	127190.4963
18	500	50	89629.59927	37485.925	0	127190.4963
19	500	100	89629.59927	37485.925	0	127190.4963
20	500	500	89629.59927	37485.925	0	127190.4963

Figure 5.12 Results table for RV industry.

UD	ECONG	20 - 092B	20 - 092C	20 - 092D	20 - 092F	20 - 096A	20 - 096D	20 - 099A	20 - 099D	80 - 090D	80 - 092C	80 - 092D	80 - 096C	80 - 101C	80 - 107D	80 - 108C
10	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
500	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0

Figure 5.13 Capacity addition for RV industry.

A distance matrix is plotted against the industry cluster that were within a range of 20 km with any of the ramps. This is the measure of transportation cost of taking a ramp to reach an industry location. Construction cost of $1.5 million was considered at each of these locations that can increase the truck capacity by 200 units per hour.

Next the freight volume division for the industry cluster was predicted for five scenarios and three time periods. The relative GDP size of each industry was used to find the percentage of freight distributed to the cluster.

The Mixed Integer Programming model was run 20 times with varying UD and ECONG parameters. The costs associated with transportation, delays and construction are tabulated in Figure 5.12.

We observe that construction costs decrease as ECONG increases as it relaxes the criteria for congestion and hence does not force new construction. Delay costs increase as for the higher values of ECONG as it penalizes the flow beyond capacity. As expected for higher values of UD, the penalty for going over the capacity limit is higher.

Figure 5.13 displays the location of new ramp construction for various ECONG values. The new constructions are seen near Exit 096 of Highway 20 as it is close to the industry cluster and can expect continued and possibly increased heavy truck volume. Expanding this exit also means that the trucks can now take the shortest route to the center of the industry cluster without having to face the delay due to congestion.

To summarize, we have developed the economic optimization model that represents the transportation infrastructure network surrounding the RV industry cluster and the freight flow using it. By looking at various scenarios concerning economic and traffic growth, we can use congestion costs to identify investments in the access to the transportation infrastructure that can support growth and economic benefit to the cluster.

6. IMPLEMENTATION PLAN

The results of this study indicate that systematic, model-based capacity planning analysis can be used effectively in planning transportation infrastructure improvements that are linked to specific industry clusters.

It is observed, based on the results from the model, that there are many counties where a significant delay cost is observed. This delay cost is due to the disutility (UD) that is associated with congestion. The higher the congestion, higher is the penalty for delay (disutility). This penalty results in delay cost. This disutility/delay cost can be observed significantly in Bartholomew County, Gibson County, Vigo County, and Marion County. Depending on the industry requirements, the disutility cost can be varied to serve its needs. If the industry requires quick deliveries or short lead times, it is in the states interest to keep the penalty high. High penalties result in high delay costs which would make the state take actions to reduce the congestion.

From the study, it can be observed that the model recommends construction at multiple ramp locations across the counties that are considered for the study. Ramp construction is recommended due to ECONG values. We can vary the value of ECONG, expected congestion, which drives the requirement for construction of the ramps. ECONG limits the amount of flow in excess of capacity at ramps. The smaller the value of ECONG, the lower the congestion tolerated and thus greater the capacity expansion.

Thus, it is important to note the benefits of being proactive in adding capacity to the ramps in counties and thereby avoiding any congestion related disadvantages to the industries and the state. By being proactive, the state can increase industry competitiveness and attract more businesses to the state.

These recommendations are based on the model assumptions, freight input data, and the adjustable parameters. In terms of implementation, we recommend that INDOT review the results of this study with appropriate personnel from each county to examine model assumptions, input data, and forecast information and if necessary, adjust model parameters. In addition, we suggest that INDOT examine traffic flows relative to automotive and e-commerce industries in respective counties, both inbound and outbound, in light of the industry backlog and future sales projections. Finally, we recommend that INDOT consider conducting a more detailed study of the commodity flows of the automotive and e-commerce industries in the respective counties.

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APPENDICES

Appendix A. Additional Case Studies

Appendix B. Supplemental Material

APPENDIX A. ADDITIONAL CASE STUDIES

A.1 Case Study: Indiana Furniture Supply Chain Study

A.1.1 Overview

According to the Indiana Furniture Supply Chain study (Iyer et al., 2006), the furniture industry in Indiana has a significant economic footprint, with annual sales of approximately $9 billion per year and employing over 45,000 people. The top five counties involved in the Indiana wood processing industry are Dubois, Elkhart, Bartholomew, Marian, and Lagrange. Average annual sales in these counties total nearly $7 billion, representing approximately 78% of the state's total for wood products. Therefore, in the context of multi-modal freight logistics, a case study of the wood products industry provides useful insight. Details of the project pertinent to the approach suggested by this project are presented below.

A.1.2 Justification

A.1.2.1 Supply Chain Structure

The furniture supply chain majorly consists of logging, sawmill, hardwood veneer, softwood veneer, home furniture, office furniture and other furniture. The mode of transportation used within Indiana for furniture is primarily roads, therefore, an efficient freight network can impact the financial success and growth of the industry.

Table A.1 describes the direction of the end products at each stage of the furniture supply chain within Indiana.

Table A.1 Flow and Bill of Material of Furniture Products

Process Step	Direction	Materials
Logging	Outbound	Wood
Sawmill	Inbound/Outbound	Wood
Hardwood Veneer	Inbound/Outbound	Wood
Softwood Veneer	Inbound/Outbound	Wood
Home Furniture	Outbound	Wood
Office Furniture	Outbound	Wood
Other Furniture	Outbound	Wood

A.1.2.2 Inbound Logistics

While the wood and forestry industry significantly generate raw materials for the wood products industry within Indiana, the inbound logistics of these raw materials is significant. The following data has been sourced from the Freight Analysis Framework and it indicates that significant amounts of the categories of wood materials that inbound to Indiana come from other states within the United States. The data shows that among the imported materials wood products is the highest, followed by logs and finished furniture is the least. This indicates that there is a significant manufacturing activity as well as that Indiana serves as a major pathway for these products that are being transported to the neighboring states.

Table A.2 Inbound Logistics for the Furniture Supply Chain (Indiana)

Product	Thousand Tons in 2017	Million Dollars in 2017
Logs	4,405.8398	129.1568
Wood prods.	9,266.3838	7,225.6455
Furniture	1,428.8189	7,395.2015
Total	*15,101.0425*	*14,750.0038*

A.1.2.3 Outbound Logistics

There is a significant production of wood products within Indiana, which serve as the raw material for various categories of furniture. Similar to the inbound logistics, the outbound logistics also has wood products as the most significant material followed by logs and finished furniture. However, in terms of revenue, the furniture products are the most significant contributor. This insight reinforces the insight from inbound logistics, suggesting that Indiana serves as a pathway for furniture freight for wood products being transported to other states, while Indiana also generates revenue through manufacturing finished products.

Table A.3 Outbound Logistics for the Furniture Supply Chain (Indiana)

Product	Thousand Tons in 2017	Million Dollars in 2017
Logs	4,325.9588	88.1832
Wood prods.	6,189.5812	6,422.996
Furniture	1,654.0659	9,345.062
Total	*1,2169.6059*	*15,856.2412*

A.1.2.4 Major Wood Product Counties

The five major stakeholder counties in terms of the wood product industry are Dubois, Elkhart, Bartholomew, Marian, and Lagrange. It is advantageous for the state to note that the five counties are located in a way to support the inbound and outbound logistics in the north central and the south regions. With access to waterways, Indiana has the opportunity to support wood product freight logistics through multiple modes. While Indiana's forests produce high quality wood that is shipped and used for local manufacturing, the freight network that supports the logistics of the furniture supply chain across the United States also supports the economy of Indiana. Therefore, it is important to maintain the quality of the freight network and make further improvements to support growth of this integral industry within the state. The following figures show the major transportation infrastructure in the five counties.

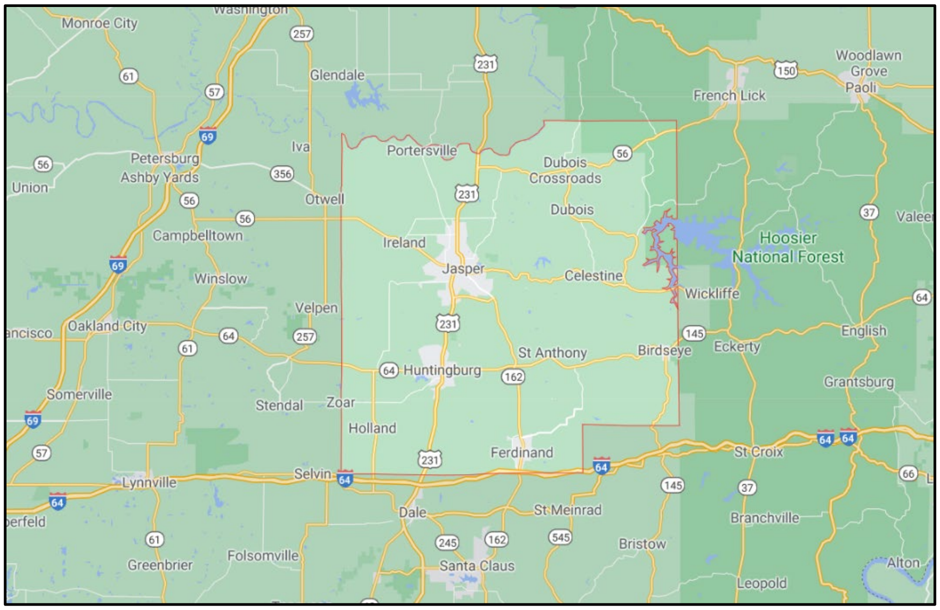

Figure A.1 Highways around Dubois County.

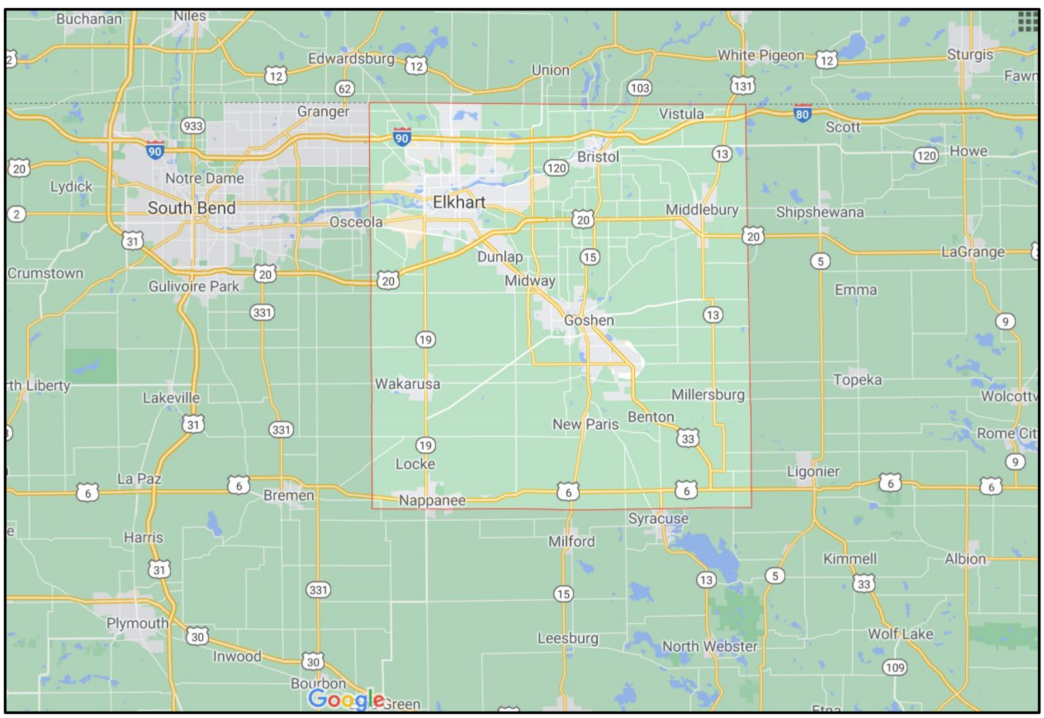

Figure A.2 Highways around Elkhart County.

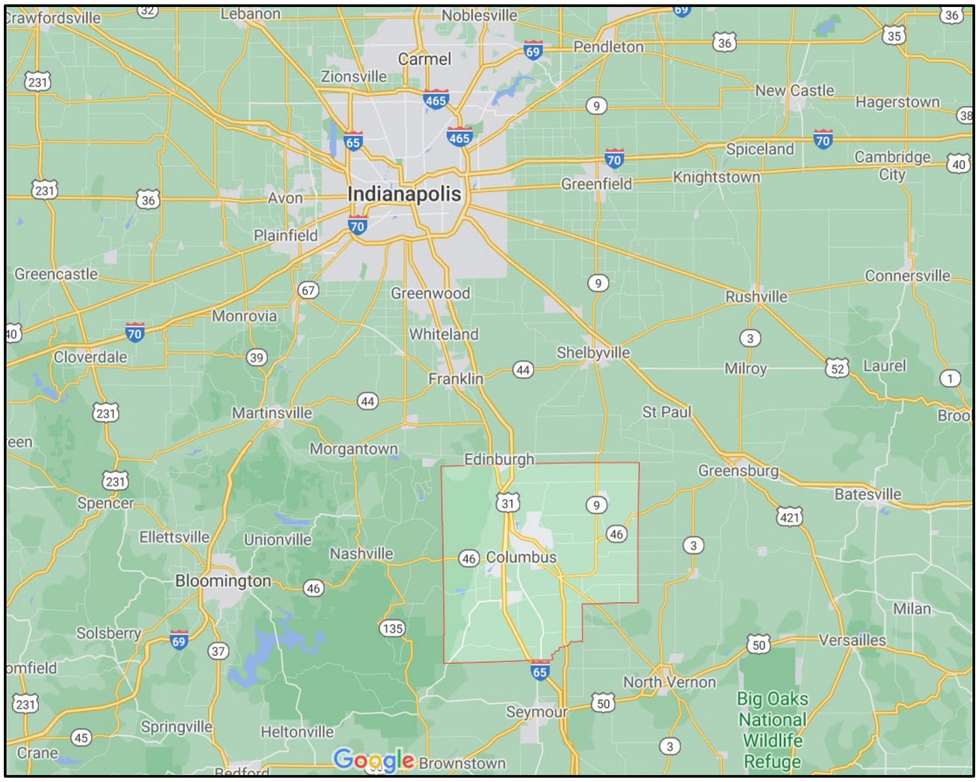

Figure A.3 Highways around Bartholomew County.

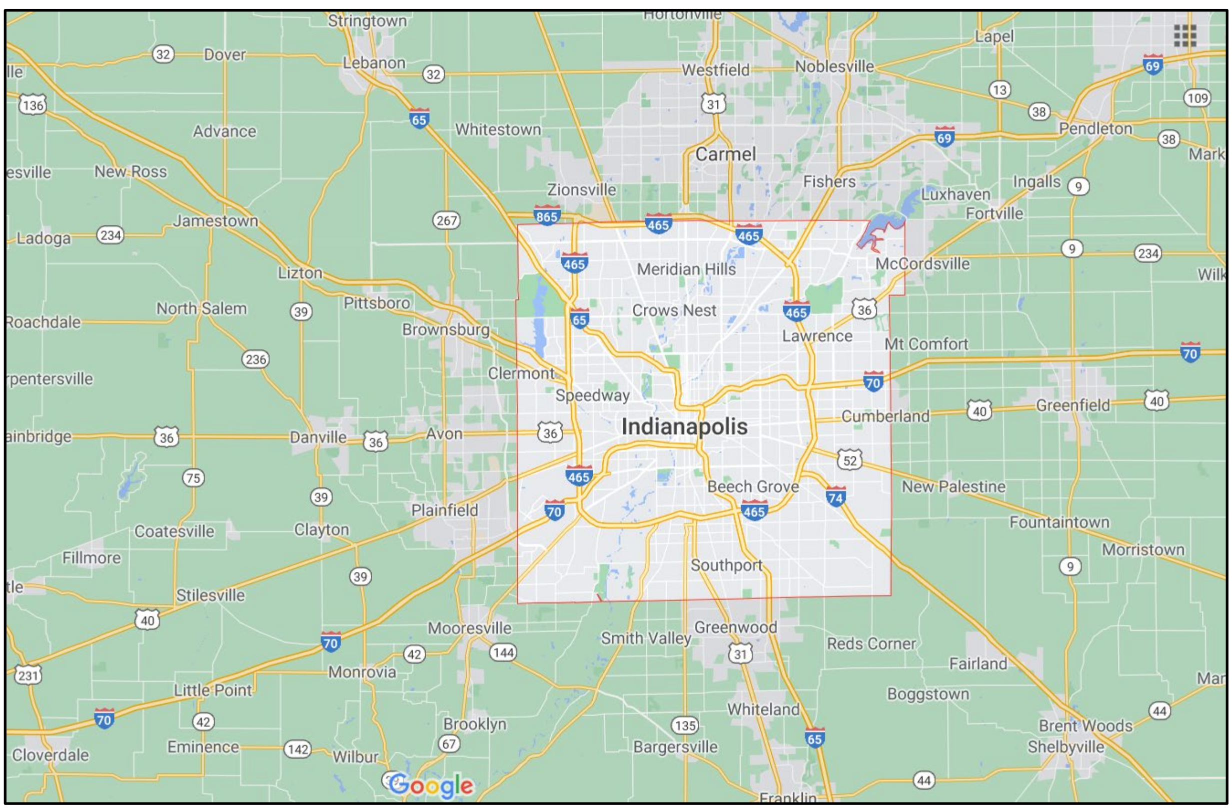

Figure A.4 Highways around Marian County.

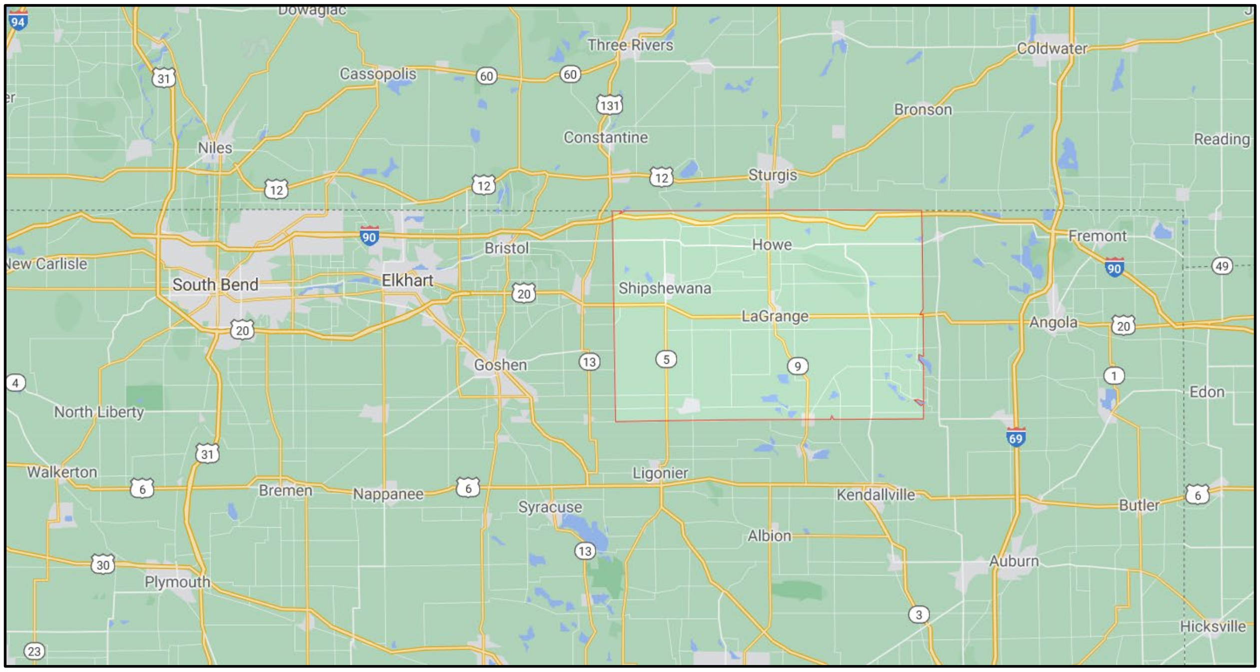

Figure A.5 Highways around Lagrange County.

A.1.2.5 Key Findings

The key finding from this study noted that an industry-level supply chain perspective was lacking despite wood processing being such a large industry in the state. Use of the optimization model indicated that generous cost savings could be generated by using a supply chain viewpoint, along with key investments in the affected infrastructure by INDOT. This insight led to the focus on identifying industry clusters, such as the Recreational Vehicle industry used in this project.

A.1.2.6 Furniture Supply Chain

The inbound and outbound logistics of the furniture supply chain located in Dubois County is listed below. The following data shows the increase in freight requirements for inbound and outbound across three different periods.

Freight Requirements								
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
1	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Wood	254	305	353		Furniture	793.5519	953.6941	1103.044
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
2	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Wood	249	287	320		Furniture	778.8388	896.7482	1000.61
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
3	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Wood	240	264	280		Furniture	750.6079	824.598	874.475
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
4	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Wood	251	299	340		Furniture	784.1619	933.8285	1063.412
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
5	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Wood	264	340	425		Furniture	825.8941	1063.858	1329.471

Figure A.6 Freight requirements for furniture supply chain in Dubois County.

Results

For the optimization model we have considered four major ramps in Dubois County: 063A, 063B, 063C, and 063D. Distance from these ramps to the center of the county is listed in the table below. All the ramps described lie within 30 miles of industry center. Figure A.7 details the distinction between inbound and outbound ramps.

Distance Matrix				
Inbound				
Ramp#	063A	063B	063C	063D
Wood	25.7	14	24.1	13.8
Outbound				
Ramp #	063A	063B	063C	063D
Furniture	25.7	14	24.1	13.8

Figure A.7 Distance matrix for Dubois County.

	Inbound	Outbound	Inbound	Outbound
	063A	063B	063C	063D

Figure A.8 Description of ramps–inbound/outbound.

	UD	ECONG	Transportation Const	Delay Cost	Construction Cost	Objective function
1	10	0	60140.68626	0	9000000	9060140.686
2	10	20	60566.93857	95.241394	7500000	7560671.704
3	10	50	60579.92775	367.84555	6000000	6060984.558
4	10	100	60579.92775	367.84555	6000000	6060984.558
5	10	500	60681.87604	10253.758	1500000	1571961.009
6	50	0	60140.68626	0	9000000	9060140.686
7	50	20	60566.93857	476.20697	7500000	7561052.67
8	50	50	60579.92775	1839.2278	6000000	6062455.94
9	50	100	60579.92775	1839.2278	6000000	6062455.94
10	50	500	60681.87604	51268.788	1500000	1612976.04
11	100	0	60140.68626	0	9000000	9060140.686
12	100	20	60566.93857	952.41394	7500000	7561528.877
13	100	50	60579.92775	3678.4555	6000000	6064295.168
14	100	100	60579.92775	3678.4555	6000000	6064295.168
15	100	500	60681.87604	102537.58	1500000	1664244.828
16	500	0	60140.68626	0	9000000	9060140.686
17	500	20	60566.93857	4762.0697	7500000	7565338.532
18	500	50	60579.92775	18392.278	6000000	6079008.99
19	500	100	60579.92775	18392.278	6000000	6079008.99
20	500	500	60681.87604	512687.88	1500000	2074395.132

Figure A.9 Result table.

The construction costs decrease as ECONG increases as it relaxes the criteria for congestion and hence does not force new construction. Delay costs increase as for the higher values of ECONG as it penalizes the flow beyond capacity.

	UD	ECONG	063A	063B	063C	063D
1	10	0	0	0	1	5
2	10	20	0	0	0	5
3	10	50	0	0	0	4
4	10	100	0	0	0	4
5	10	500	0	0	0	1
6	50	0	0	0	1	5
7	50	20	0	0	0	5
8	50	50	0	0	0	4
9	50	100	0	0	0	4
10	50	500	0	0	0	1
11	100	0	0	0	1	5
12	100	20	0	0	0	5
13	100	50	0	0	0	4
14	100	100	0	0	0	4
15	100	500	0	0	0	1
16	500	0	0	0	1	5
17	500	20	0	0	0	5
18	500	50	0	0	0	4
19	500	100	0	0	0	4
20	500	500	0	0	0	1

Figure A.10 Ramp capacity addition table.

The mathematical model suggests adding capacity to the outbound ramp 063D across all scenarios and 200 truck equivalents to the ramp 063C when no congestion is tolerated.

A.2 Case Study: Honda Plant Project

A.2.1 Overview

The team reviewed the *Understanding the Impact of INDOT Projects on Automotive Industry Cluster Logistics Costs: A Case Study of the Honda Plant* (Iyer et al., 2011). This study focused on understanding the impact of INDOT projects on the Honda, Greensburg plant's supply chain. Details of the project pertinent to the approach suggested by this project are presented below. The entire report is referenced in the appendix.

The goal of the study was the following.

1. Identify approaches for INDOT to be an active partner in facilitating supply chain effectiveness.
2. Maximize the economic impact of INDOT projects on the Honda affiliated Automotive Cluster in South Central Indiana.
3. Create a framework for INDOT to utilize in the future when prospective economic partners are in discussions with the state.

Location of the Plant

The Honda Greensburg Plant is in the Decatur County. This county is located in south eastern Indiana and has close access to major East-West and North-South highway corridors. Greensburg is located adjacent to Interstate 74, halfway between Indianapolis and Cincinnati.

Figure A.11 Location of Honda Greensburg Plant.

US Highways 421, 3, and 46 extend through the county. Interstate Highway 74 also extends through the county and provides access to Indianapolis and Cincinnati.

U.S. Highway 421 links Greensburg with Indianapolis to the north and Lexington, Kentucky, to the south. State Road 3 connects Greensburg with Muncie and Fort Wayne to the north and the Indiana suburbs of Louisville, Kentucky, to the south. State Road 46 links the community with Columbus, Bloomington, and Terre Haute to the west and Batesville to the east.

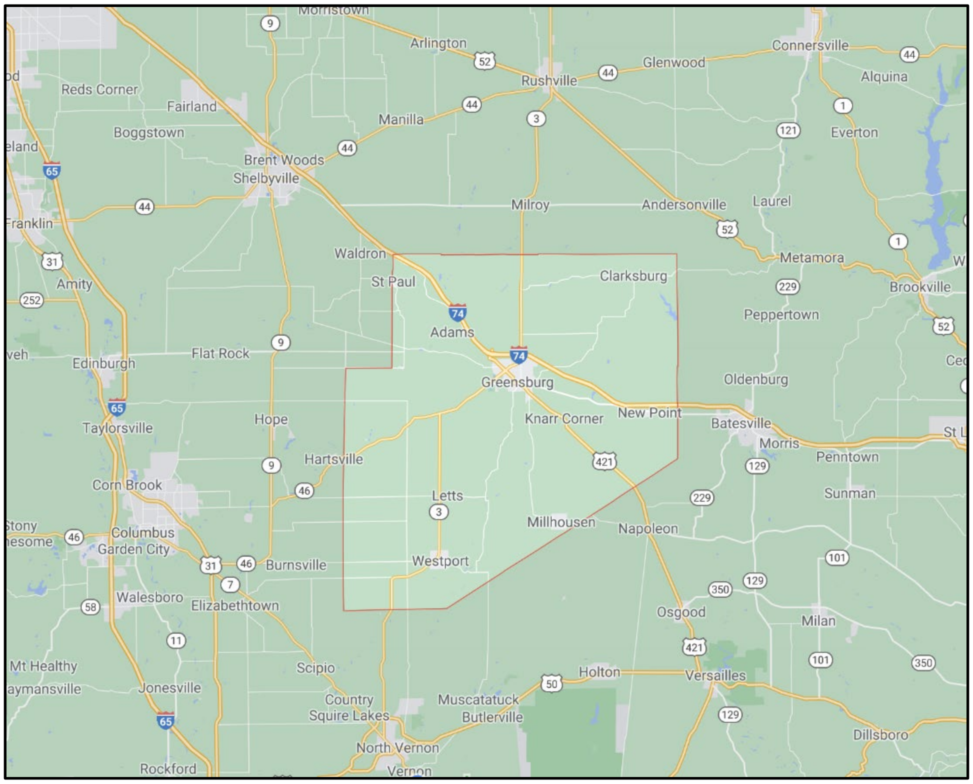

Figure A.12 Highways around Decatur County.

A.2.2 Justification

Supply Chain Structure

Final Assembly is the process that takes place at the Greensburg factory. Other parts and components for the automobiles are sourced from other Honda plants as well as from third-party supplies in Indiana and Ohio.

Table A.4 shows the total estimated distance of Honda's each Ohio plant from Greensburg:

Table A.4 Honda Plants and Their Description

Location	Distance from Greensburg	Operations	Employees
Russells Point, OH	166.69	Manufactures Transmission	1,200
East Liberty, OH	163.33	Painting, Welding etc.	2,800
Anna, OH	148.00	Manufactures Engines	2,800
Marysville, OH	164.24	Sub-Assembly	4,200

The key supply chain steps include the following.

- Honda Tier 1 plants in Anna, OH and Russell's Point, OH will supply engines and transmissions to Greensburg.
- TS Tech in Rushville will provide seats—sequence supplier.

- Plastics and stamping done in house at Greensburg.
- Other Tier 1's (locations unknown) will supply Greensburg (e.g., axles).
- Indiana Tier 2 suppliers for engines and transmissions will supply Anna and Russell's Point.

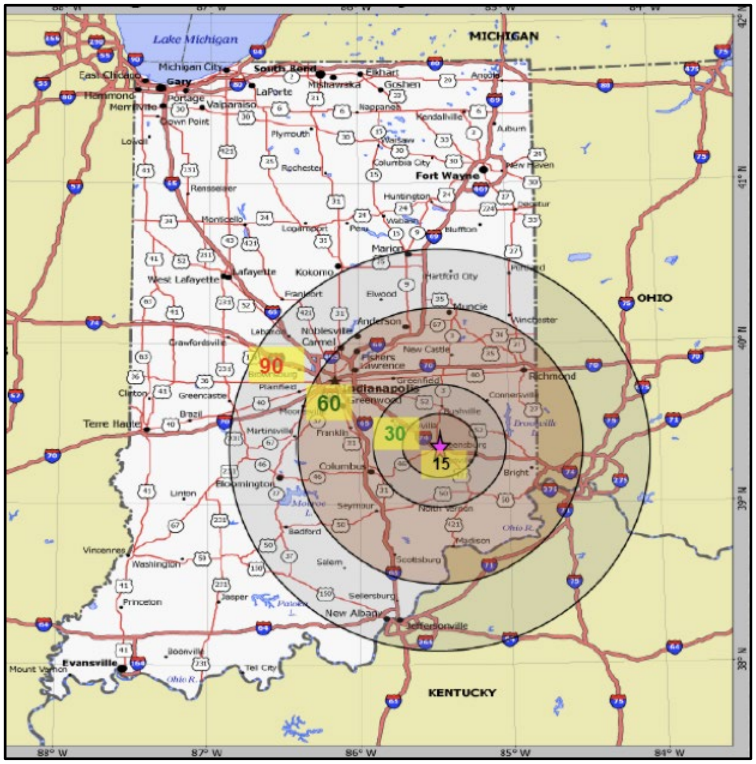

Figure A.13 Economic Development Radius (EDR) around the Greensburg plant.

Figure A.13 shows the Economic Development Radius (EDR) around the plant. The tier 1, tier 2, and tier 3 companies are located in the EDR, where the tier 1 companies are the closest to the plant. Most of the parts and components flow into the Greensburg Plant from the Economic Development Radius. Hence, it is critical for the state to keep the freight network in good shape to support the growth and financial success of the Honda assembly plant, and the economic interests of the state.

The key finding from the project indicated that INDOT projects can play a significant role in the growth and prosperity of key industries within the state when integral planning of INDOT projects with respect to industry clusters is done. Often times, highway projects can play key roles in improving competitive advantages aspects pertinent to specific industries.

A.2.2.1 Honda Plant

We have built an optimization model to analyze the congestion in the ramps locates near the Honda manufacturing plant in Decatur County. The ramps used along with distance (miles) from the plant is as follows.

Ramp#	1320	1320	1320	1340	123B	123F	132A	132B	132C	132D	132G	132G	134A	134B	134C	134D	134F	134G	134H	143A	143B	143C	143D
Plastic	2.4	2.4	2.4	4.2	0008	18.1	1.3	1.4	1.7	2.8	1.5	1.5	3	3.9	21.3	4.1	3.3	3.7	3.9	12.1	12.3	24.3	12.4
Engine	2.4	2.4	2.4	4.2	0008	18.1	1.3	1.4	1.7	2.8	1.5	1.5	3	3.9	21.3	4.1	3.3	3.7	3.9	12.1	12.3	24.3	12.4
Transmission	2.4	2.4	2.4	4.2	0008	18.1	1.3	1.4	1.7	2.8	1.5	1.5	3	3.9	21.3	4.1	3.3	3.7	3.9	12.1	12.3	24.3	12.4
Sheet Metal	2.4	2.4	2.4	4.2	0008	18.1	1.3	1.4	1.7	2.8	1.5	1.5	3	3.9	21.3	4.1	3.3	3.7	3.9	12.1	12.3	24.3	12.4
Fabric	2.4	2.4	2.4	4.2	0008	18.1	1.3	1.4	1.7	2.8	1.5	1.5	3	3.9	21.3	4.1	3.3	3.7	3.9	12.1	12.3	24.3	12.4
Outbound																							
Ramp #	1320	1320	1320	1340	123B	123F	132A	132B	132C	132D	132G	132G	134A	134B	134C	134D	134F	134G	134H	143A	143B	143C	143D
Assembled Car	2.4	2.4	2.4	4.2	0008	18.1	1.3	1.4	1.7	2.8	1.5	1.5	3	3.9	21.3	4.1	3.3	3.7	3.9	12.1	12.3	24.3	12.4

Figure A.14 Distance matrix for Honda Plant.

	1320	1320	1320	1340	123B	123F	132A	132B	132C	132D	132G	132G	134A	134B	134C	134D	134F	134G	134H	143A	143B	143C	143D
Adjusted Ramp Base Capacity	284.0532	284.0532	284.0532	422.604	0607	407.3195	221.7554	103.4483	355.0332	275.4438	219.6814	219.4559	238.1471	220.3689	404.5161	269.5946	305.4902	253.0238	243.3539	462.5094	517.746	572.085	540.8759
Ramp Cost	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000
Ramp Add Capacity	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200

	1320	1320	1320	1340	123B	123F	132A	132B	132C	132D	132G	132G	134A	134B	134C	134D	134F	134G	134H	143A	143B	143C	143D
Adjusted Ramp Base Capacity	284.0532	284.0532	284.0532	422.604	0607	407.3195	221.7554	103.4483	355.0332	275.4438	219.6814	219.4559	238.1471	220.3689	404.5161	269.5946	305.4902	253.0238	243.3539	462.5094	517.746	572.085	540.8759

Figure A.15 Ramp capacity table.

The ramp expansion costs may differ based on the ramp location and layout, as can the capacity that can be added. The ramp base capacities are calculated from truck factor and the standard capacity values available in the HCMS database. The following expression is used:

$$Standard\ Capacity * \frac{Truck\ Factor}{(1 + Truck\ Factor)}$$

The commodity flow data compiled across five scenarios and three periods as mentioned in the Section 2.2.2 is used. All the data in the below table is in truck equivalents.

Freight Requirements								
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
1	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Plastic	1504	1580	1695		Assembled Car	4017.73	4193.743	4539.838
Engine	16939	18546	20468					
Transmission	13374	16136	20280					
Sheet Metal	13374	16136	20280					
Fabric	511	417	378					
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
2	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Plastic	1504	1624	1779		Assembled Car	4017.73	4262.243	4654.828
Engine	16939	18868	21036					
Transmission	13374	16348	20717					
Sheet Metal	13374	16348	20717					
Fabric	511	425	391					
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
3	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Plastic	1504	1675	1892		Assembled Car	4017.73	4340.754	4810.872
Engine	16939	19237	21806					
Transmission	13374	16592	21309					
Sheet Metal	13374	16592	21309					
Fabric	511	435	407					
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
4	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Plastic	1504	1589	1721		Assembled Car	4017.73	4208.118	4574.918
Engine	16939	18614	20641					
Transmission	13374	16180	20413					
Sheet Metal	13374	16180	20413					
Fabric	511	419	382					
Inbound					Outbound			
Scenarios	Time				Scenarios	Time		
5	**2025**	**2035**	**2045**		1	**2025**	**2035**	**2045**
Plastic	1504	1512	1556		Assembled Car	4017.73	4088.898	4348.268
Engine	16939	18054	19522					
Transmission	13374	15811	19553					
Sheet Metal	13374	15811	19553					
Fabric	511	404	358					

Figure A.16 Freight requirements table for Honda Manufacturing Plant.

A.2.2.2 Results

The optimization model described in the preceding section is used with the above data as input and the following results are obtained. We observe that as the ECONG values increases i.e., tolerance for the congestion, construction costs associated with ramps decreases. At the same time delay costs are increased. Industry's tolerance to delay determines the ECONG values to be considered.

	UD	ECONG	Transportation Const	Delay Cost	Construction Cost	Objective function
1	10	0	280369.2858	0	781500000	781780369.3
2	10	20	280676.489	200	778500000	778780896.5
3	10	50	281440.0717	767.49918	772500000	772782284.3
4	10	100	284945.26	2857.7156	762000000	762288088.7
5	10	500	297326.4293	19630.216	723000000	723318919.7
6	50	0	280369.2858	0	781500000	781780369.3
7	50	20	280827.9157	667.92445	778500000	778781509.2
8	50	50	281989.9468	2267.9244	772500000	772784303.2
9	50	100	287522.6704	7819.0066	762000000	762295498.1
10	50	500	307191.7887	73518.153	723000000	723382180.3
11	100	0	280369.2858	0	781500000	781780369.3
12	100	20	280827.9157	1335.8489	778500000	778782177.1
13	100	50	281989.9468	4535.8488	772500000	772786571.2
14	100	100	287522.6704	15638.013	762000000	762303317.1
15	100	500	307191.7887	147036.31	723000000	723455698.5
16	500	0	280369.2858	0	781500000	781780369.3
17	500	20	280827.9157	6679.2445	778500000	778787520.5
18	500	50	281989.9468	22679.244	772500000	772804714.5
19	500	100	287522.6704	78190.066	762000000	762365869.1
20	500	500	307191.7887	735181.53	723000000	724043843.7

Figure A.17 Results table for Honda Manufacturing Plant.

	UD	ECONG	1320	1320	1320	1340	123B	123F	132A	132B	132C	132D	132G	132G	134A	134B	134C	134D	134F	134G	134H	143A	143B	143C	143D
1	10	0	0	0	0	0	0	0	3	0	0	0	0	518	0	0	0	0	0	0	0	0	0	0	0
2	10	20	0	0	0	0	0	0	3	0	0	0	0	516	0	0	0	0	0	0	0	0	0	0	0
3	10	50	0	0	0	0	0	0	3	0	0	0	0	512	0	0	0	0	0	0	0	0	0	0	0
4	10	100	0	0	0	0	0	0	2	0	0	0	0	506	0	0	0	0	0	0	0	0	0	0	0
5	10	500	0	0	0	0	0	0	0	0	0	0	0	482	0	0	0	0	0	0	0	0	0	0	0
6	50	0	0	0	0	0	0	0	3	0	0	0	0	518	0	0	0	0	0	0	0	0	0	0	0
7	50	20	0	0	0	0	0	0	3	0	0	0	0	516	0	0	0	0	0	0	0	0	0	0	0
8	50	50	0	0	0	0	0	0	3	0	0	0	0	512	0	0	0	0	0	0	0	0	0	0	0
9	50	100	0	0	0	0	0	0	2	0	0	0	0	506	0	0	0	0	0	0	0	0	0	0	0
10	50	500	0	0	0	0	0	0	0	0	0	0	0	482	0	0	0	0	0	0	0	0	0	0	0
11	100	0	0	0	0	0	0	0	3	0	0	0	0	518	0	0	0	0	0	0	0	0	0	0	0
12	100	20	0	0	0	0	0	0	3	0	0	0	0	516	0	0	0	0	0	0	0	0	0	0	0
13	100	50	0	0	0	0	0	0	3	0	0	0	0	512	0	0	0	0	0	0	0	0	0	0	0
14	100	100	0	0	0	0	0	0	2	0	0	0	0	506	0	0	0	0	0	0	0	0	0	0	0
15	100	500	0	0	0	0	0	0	0	0	0	0	0	482	0	0	0	0	0	0	0	0	0	0	0
16	500	0	0	0	0	0	0	0	3	0	0	0	0	518	0	0	0	0	0	0	0	0	0	0	0
17	500	20	0	0	0	0	0	0	3	0	0	0	0	516	0	0	0	0	0	0	0	0	0	0	0
18	500	50	0	0	0	0	0	0	3	0	0	0	0	512	0	0	0	0	0	0	0	0	0	0	0
19	500	100	0	0	0	0	0	0	2	0	0	0	0	506	0	0	0	0	0	0	0	0	0	0	0
20	500	500	0	0	0	0	0	0	0	0	0	0	0	482	0	0	0	0	0	0	0	0	0	0	0

Figure A.18 Ramp Capacity addition table for Honda Plant.

The model recommends adding significant capacity to the ramp 132G, since it is the inbound ramp present closest to the Honda manufacturing plant and outbound flow is managed by multiple other outbound ramps.

A.2.3 Automotive Manufacturing Cluster–Allen County

The automotive industry is one of the major industries in Allen County. General Motors (GM) Assembly Plant is one of the major companies located in Fort Wayne in addition to Faurecia Fort Wayne, Dana Incorporated, Multimatic Inc., ElringKlinger Manufacturing Indiana Inc. among other automotive manufacturing companies in Allen County. According to the US BEA, the county employed more than 30,500 employees in the manufacturing industry in 2019 with a $78,879 average earning per job. The manufacturing industry in Allen County is expected to contribute as high as \$7.94 billion dollars (in terms of 2005 USD) in 2050 SSP 5 scenario and as low as \$4.79 billion dollars (in terms of 2005 USD) in 2050 SSP 3 scenario.

Engine (SCTG: 34–Machinery), Transmission (SCTG: 34–Machinery), Plastic (SCTG: 24–Plastic & Rubber), Fabric (SCTG: 30–Textiles, Leather, and Articles of Textiles or Leather), Sheet Metal (SCTG: 32–Base Metal in Primary or Semi-Finished Forms and in Finished Basic Shapes) are the inbound commodities considered for the automotive industry in Allen County. Assembled Car (SCTG: 36–Motorized and Other Vehicles) is the outbound commodity considered for the automotive industry.

Figure A.19 shows the Allen County map and Figure A.20 shows the exit ramps considered for the optimization model.

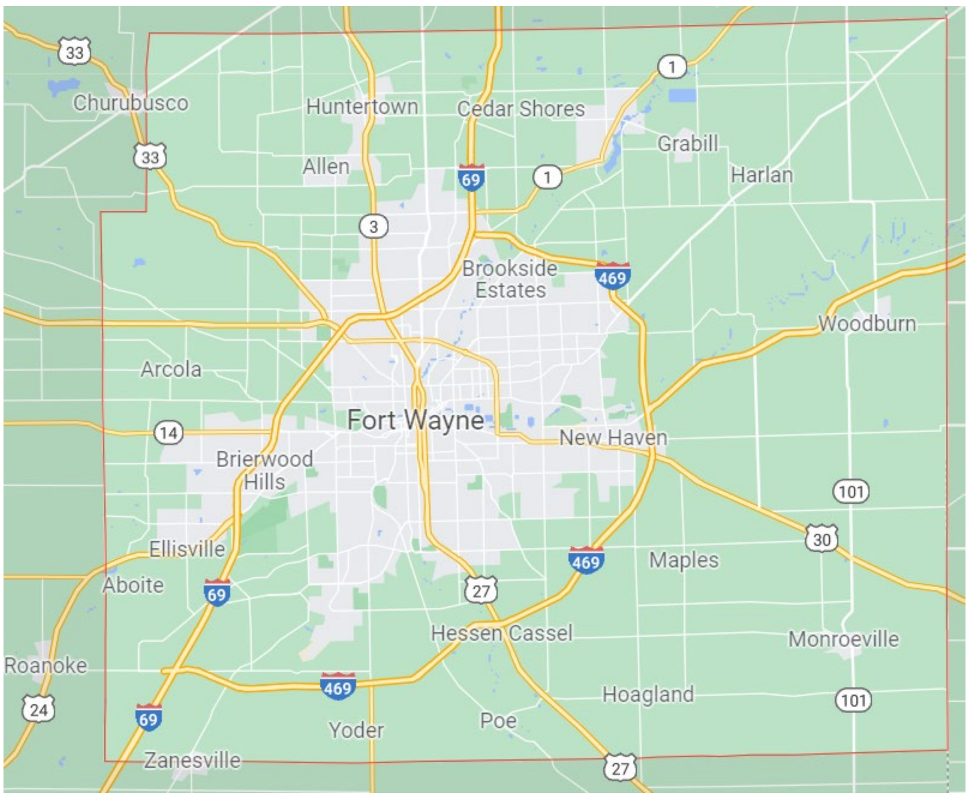

Figure A.19 Allen County map.

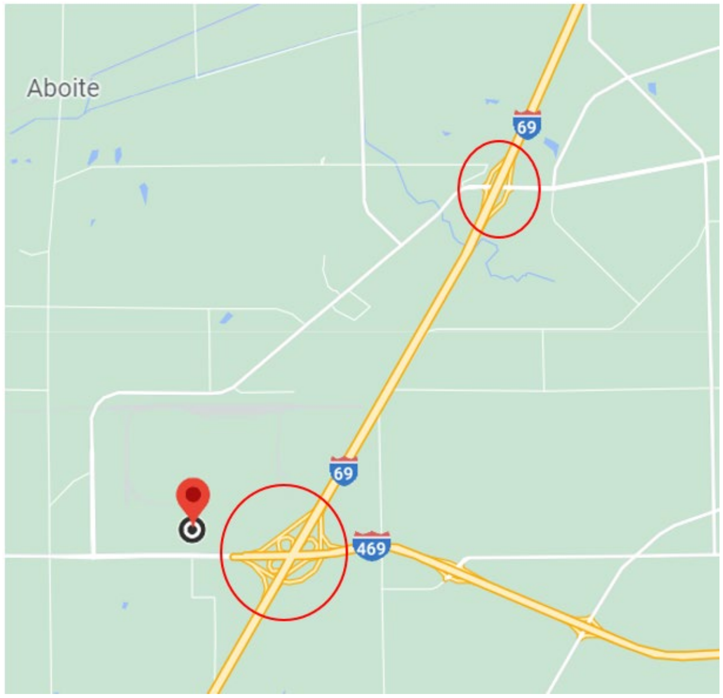

Figure A.20 Ramps close to the cluster.

For the optimization model we have considered thirteen major ramps in Allen County: 69-296A, 69-296B, 69-296F, 69-296H, 69-299A, 69-299B, 69-299C, 69-299D, 469-001A, 469-001B, 469-001C, 469-001D, 469-002A, 469-002B, 469-002C, and 469-002D. Distance from these ramps to the center of the county is listed in Figure A.21. All the ramps described lie within 30 miles of the industry center. Figure A.22 details the distinction between inbound and outbound ramps.

Distance Matrix																	
Inbound																	
Ramp#	69 - 296A	69 - 296B	69 - 296F	69 - 296G	69 - 296H	69 - 299A	69 - 299B	69 - 299C	69 - 299D	469 - 001A	469 - 001B	469 - 001C	469 - 001D	469 - 002A	469 - 002B	469 - 002C	469 - 002D
Plastic	4.8	4.5	1	5	4.8	3.4	4	3.4	3.2	1.8	2.2	2	1.6	2.7	2.9	2.9	2.5
Engine	4.8	4.5	1	5	4.8	3.4	4	3.4	3.2	1.8	2.2	2	1.6	2.7	2.9	2.9	2.5
Transmission	4.8	4.5	1	5	4.8	3.4	4	3.4	3.2	1.8	2.2	2	1.6	2.7	2.9	2.9	2.5
Sheet Metal	4.8	4.5	1	5	4.8	3.4	4	3.4	3.2	1.8	2.2	2	1.6	2.7	2.9	2.9	2.5
Fabric	4.8	4.5	1	5	4.8	3.4	4	3.4	3.2	1.8	2.2	2	1.6	2.7	2.9	2.9	2.5
Outbound																	
Ramp #	69 - 296A	69 - 296B	69 - 296F	69 - 296G	69 - 296H	69 - 299A	69 - 299B	69 - 299C	69 - 299D	469 - 001A	469 - 001B	469 - 001C	469 - 001D	469 - 002A	469 - 002B	469 - 002C	469 - 002D
Motorized Vehicle	4.8	4.5	1	5	4.8	3.4	4	3.4	3.2	1.8	2.2	2	1.6	2.7	2.9	2.9	2.5

Figure A.21 Distance matrix for Allen County ramps

Inbound	Outbound	Inbound	Inbound	Inbound	Inbound	Outbound	Inbound	Inbound	Outbound	Outbound	Inbound	Inbound	Outbound	Outbound	Inbound	Inbound
69 - 296A	69 - 296B	69 - 296F	69 - 296G	69 - 296H	69 - 299A	69 - 299B	69 - 299C	69 - 299D	469 - 001A	469 - 001B	469 - 001C	469 - 001D	469 - 002A	469 - 002B	469 - 002C	469 - 002D

Figure A.22 Inbound/outbound ramp classification.

Figure A.23 represents different costs associated with different values of UD and ECONG. The transportation cost is the cost of moving freight across the ramps. Delay cost is the cost due to congestion. Construction cost is the cost of constructing new ramp at an exit due increased congestion. As ECONG increases, the construction cost decreases and as UD increases, the delay cost increases. Figure A.24 provides results as to which exit ramps need additional construction.

The model suggests higher number of ramps to be constructed with low ECONG value. A maximum of 25 new ramps are suggested to be constructed. The model suggests a maximum of 1250 truck equivalent capacity to be added to the ramps across the county.

#	UD	ECONG	Transportation Cost	Delay Cost	Construction Cost	Objective function
1	1000000	0	$ 16,928.37	$ -	$ 37,500,000.00	$ 37,516,928.37
2	1000000	100	$ 16,928.37	$ -	$ 37,500,000.00	$ 37,516,928.37
3	1000000	500	$ 16,928.37	$ -	$ 37,500,000.00	$ 37,516,928.37
4	5000000	0	$ 16,928.37	$ -	$ 37,500,000.00	$ 37,516,928.37
5	5000000	100	$ 16,928.37	$ -	$ 37,500,000.00	$ 37,516,928.37
6	5000000	500	$ 16,928.37	$ -	$ 37,500,000.00	$ 37,516,928.37

Figure A.23 Costs associated with different UD and ECONG.

#	UD	ECONG	69 - 296A	69 - 296B	69 - 296F	69 - 296G	69 - 296H	69 - 299A	69 - 299B	69 - 299C	69 - 299D	469 - 001A	469 - 001B	469 - 001C	469 - 001D	469 - 002A	469 - 002B	469 - 002C	469 - 002D
1	1000000	0	2	0	2	2	2	2	0	2	2	2	2	2	2	2	1	0	0
2	1000000	100	2	0	2	2	2	2	0	2	2	2	2	2	2	2	1	0	0
3	1000000	500	2	0	2	2	2	2	0	2	2	2	2	2	2	2	1	0	0
4	5000000	0	2	0	2	2	2	2	0	2	2	2	2	2	2	2	1	0	0
5	5000000	100	2	0	2	2	2	2	0	2	2	2	2	2	2	2	1	0	0
6	5000000	500	2	0	2	2	2	2	0	2	2	2	2	2	2	2	1	0	0

Figure A.24 New ramp addition.

A.2.4 Automotive Manufacturing Cluster–Bartholomew County

Bartholomew County has a major automotive industry cluster in Indiana. Carver Toyota of Columbus, Ford of Columbus, Faurecia Gladstone Plant, Cummins Inc., and Columbus Collision are some of the major automotive companies in Columbus, Bartholomew County. Cummins alone employees more than 8,000 employees at the Columbus location. According to the US BEA, the county employed more than 20,000 employees in the manufacturing industry in 2019 with a $97,180 average earning per job. The manufacturing industry in Bartholomew County is expected to contribute as high as $8.08 billion dollars (in terms of 2005 USD) in 2050 SSP 5 scenario and as low as $4.88 billion dollars (in terms of 2005 USD) in 2050 SSP 3 scenario.

Engine (SCTG: 34–machinery), transmission (SCTG: 34–machinery), plastic (SCTG: 24–plastic & rubber), Fabric (SCTG: 30–textiles, leather, and articles of textiles or leather), sheet metal (SCTG: 32–base metal in primary or semi-finished forms and in finished basic shapes) are the inbound commodities considered for the automotive industry in Bartholomew County. Assembled Car (SCTG: 36–motorized and other vehicles) is the outbound commodity considered for the automotive industry.

Figure A.25 shows the Bartholomew County map and Figure A.26 shows the exit ramps considered for the optimization model.

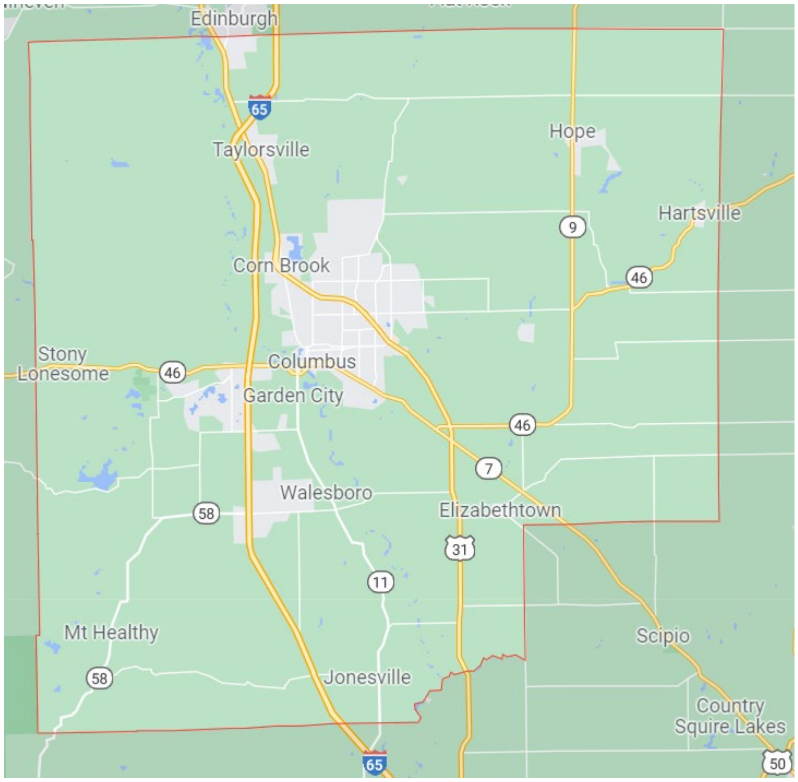

Figure A.25 Bartholomew County map.

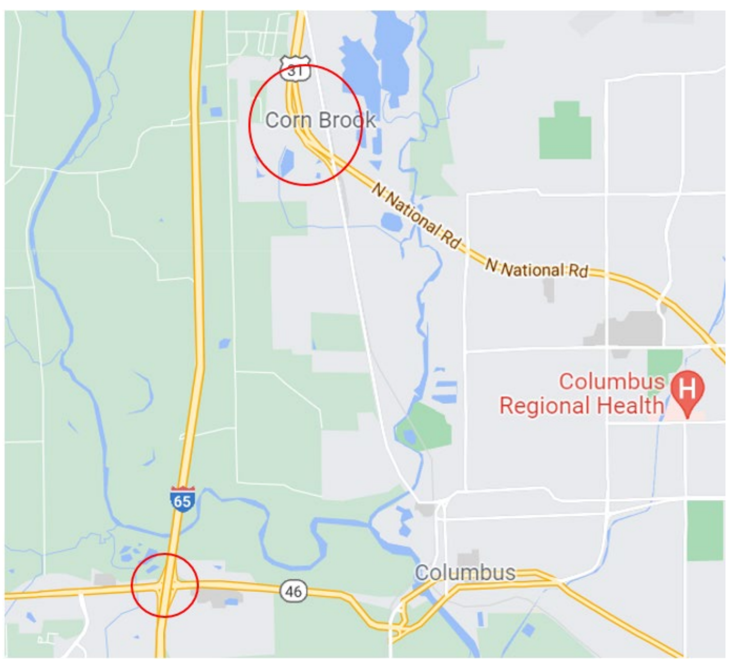

Figure A.26 Ramps close to the cluster.

For the optimization model we have considered thirteen major ramps in Bartholomew County: 31-073C, 65-064A, 65-064B, 65-064C, 65-064D, 65-068A, 65-068B, 65-068C, 65-068D, 65-068J, 65-068K, 65-068L, and 65-068M. Distance from these ramps to the center of the county is listed in Figure A.27. All the ramps described lie within 30 miles of the industry center. Figure A.28 details the distinction between inbound and outbound ramps.

Distance Matrix													
Inbound													
Ramp#	31 - 073C	65 - 064A	65 - 064B	65 - 064C	65 - 064D	65 - 068A	65 - 068B	65 - 068C	65 - 068D	65 - 068J	65 - 068K	65 - 068L	65 - 068M
Plastic	4.7	8.9	8.7	8.9	9.1	4.4	4.4	4.4	4.6	4.9	4.4	4.4	4.4
Engine	4.7	8.9	8.7	8.9	9.1	4.4	4.4	4.4	4.6	4.9	4.4	4.4	4.4
Transmission	4.7	8.9	8.7	8.9	9.1	4.4	4.4	4.4	4.6	4.9	4.4	4.4	4.4
Sheet Metal	4.7	8.9	8.7	8.9	9.1	4.4	4.4	4.4	4.6	4.9	4.4	4.4	4.4
Fabric	4.7	8.9	8.7	8.9	9.1	4.4	4.4	4.4	4.6	4.9	4.4	4.4	4.4
Engine	4.7	8.9	8.7	8.9	9.1	4.4	4.4	4.4	4.6	4.9	4.4	4.4	4.4
Outbound													
Ramp #	31 - 073C	65 - 064A	65 - 064B	65 - 064C	65 - 064D	65 - 068A	65 - 068B	65 - 068C	65 - 068D	65 - 068J	65 - 068K	65 - 068L	65 - 068M
Motorized Vehicle	4.7	8.9	8.7	8.9	9.1	4.4	4.4	4.4	4.6	4.9	4.4	4.4	4.4

Figure A.27 Distance matrix for Bartholomew County ramps.

Inbound	Inbound	Inbound	Outbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Outbound	Outbound
31 - 073C	65 - 064A	65 - 064B	65 - 064C	65 - 064D	65 - 068A	65 - 068B	65 - 068C	65 - 068D	65 - 068J	65 - 068K	65 - 068L	65 - 068M

Figure A.28 Inbound/outbound ramp classification.

Figure A.29 represents different costs associated with different values of UD and ECONG. The transportation cost is the cost of moving freight across the ramps. Delay cost is the cost due to congestion. Construction cost is the cost of constructing new ramp at an exit due increased congestion. As ECONG increases, the construction cost decreases and as UD increases, the delay cost increases. Figure A.30 provides results as to which exit ramps need additional construction. The model suggests higher number of ramps to be constructed with low ECONG value. A maximum of 14 new ramps are suggested to be constructed. The model suggests a maximum of 280 truck equivalent capacity to be added to the ramps across the county.

UD	ECONG	Transportation Cost	Delay Cost	Construction Cost	Objective function
10000	0	$ 30,292.45	$ 1,242,185.73	$ 21,000,000.00	$ 22,272,478.18
10000	50	$ 29,701.24	$ 2,842,185.74	$ 18,000,000.00	$ 20,871,986.98
10000	500	$ 29,597.10	$ 2,842,185.74	$ 18,000,000.00	$ 20,871,907.06

Figure A.29 Costs associated with different UD and ECONG.

UD	ECONG	31 - 073C	65 - 064A	65 - 064B	65 - 064C	65 - 064D	65 - 068A	65 - 068B	65 - 068C	65 - 068D	65 - 068J	65 - 068K	65 - 068L	65 - 068M
10000	0	3	0	2	0	0	3	0	3	0	3	0	0	0
10000	50	3	0	0	0	0	3	0	3	0	3	0	0	0
10000	500	3	0	0	0	0	3	0	3	0	3	0	0	0

Figure A.30 New ramp addition.

A.2.5 Automotive Manufacturing Cluster–Gibson County

Gibson County has a major automotive industry cluster in Indiana. Adient US LLC, Toyota Motor Manufacturing Indiana, Federal Assembly Inc, Vuteq Indiana, EnovaPremier of Indiana LLC, Bailey Chassis Co LLC are among the major automotive manufacturing companies in Gibson County. According to the US BEA, the county employed more than 9,250 employees in the manufacturing industry in 2019 with a $89,273 average earning per job. The manufacturing industry in Gibson County is expected to contribute as high as $2.77 billion dollars (in terms of 2005 USD) in 2050 SSP 5 scenario and as low as $1.67 billion dollars (in terms of 2005 USD) in 2050 SSP 3 scenario.

Engine (SCTG: 34–machinery), transmission (SCTG: 34–machinery), plastic (SCTG: 24–plastic & rubber), fabric (SCTG: 30–textiles, leather, and articles of textiles or leather), sheet metal (SCTG: 32–base metal in primary or semi-finished forms and in finished basic shapes) are the inbound commodities considered for the automotive industry in Gibson County. Assembled car (SCTG: 36–motorized and other vehicles) is the outbound commodity considered for the automotive industry.

Figure A.31 shows the Gibson County map and Figure A.32 shows the exit ramps considered for the optimization model.

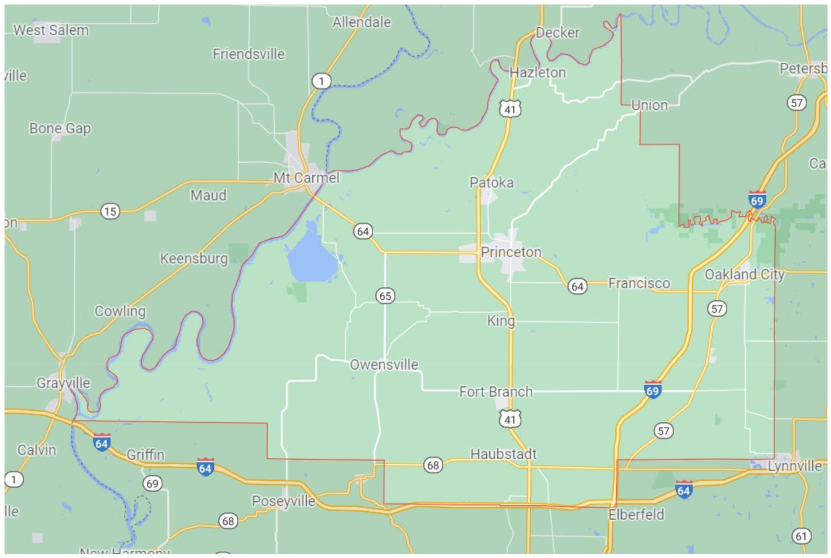

Figure A.31 Gibson County map.

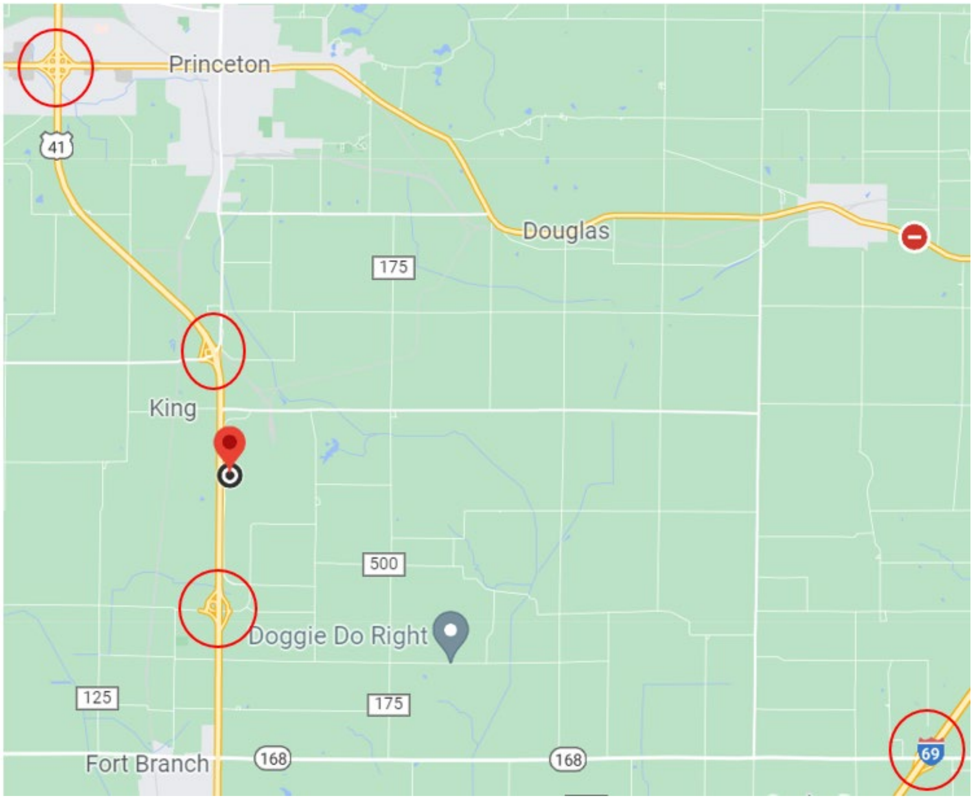

Figure A.32 Ramps close to the cluster.

For the optimization model we have considered about 22 major ramps in Gibson County and can be found in Figure A.33. Distance from these ramps to the center of the county is listed in the figure below. All the ramps described lie within 30 miles of the industry center. The distances are calculated using geo-coordinates. Figure A.34 details the distinction between inbound and outbound ramps.

Distance Matrix											
Inbound											
Ramp#	41 - 310	41 - 025A	41 - 025B	41 - 025C	41 - 025D	41 - 025G	41 - 027A	41 - 027B	41 - 027C	41 - 027D	41 - 027G
Plastic	6.2	1.8	3.4	2.2	2.7	2	1.8	2	2.9	1.9	2.1
Engine	6.2	1.8	3.4	2.2	2.7	2	1.8	2	2.9	1.9	2.1
Transmission	6.2	1.8	3.4	2.2	2.7	2	1.8	2	2.9	1.9	2.1
Sheet Metal	6.2	1.8	3.4	2.2	2.7	2	1.8	2	2.9	1.9	2.1
Fabric	6.2	1.8	3.4	2.2	2.7	2	1.8	2	2.9	1.9	2.1
Outbound											
Ramp #	41 - 310	41 - 025A	41 - 025B	41 - 025C	41 - 025D	41 - 025G	41 - 027A	41 - 027B	41 - 027C	41 - 027D	41 - 027G
Motorized Vehicle	6.2	1.8	3.4	2.2	2.7	2	1.8	2	2.9	1.9	2.1

Distance Matrix											
Inbound											
Ramp#	41 - 031A	41 - 031B	41 - 031C	41 - 031D	41 - 031F	41 - 031G	41 - 031H	69 - 027A	69 - 027B	69 - 027C	69 - 027D
Plastic	6	5.9	7.1	5.6	5.6	5.7	6.1	10.7	11.2	10.5	10.9
Engine	6	5.9	7.1	5.6	5.6	5.7	6.1	10.7	11.2	10.5	10.9
Transmission	6	5.9	7.1	5.6	5.6	5.7	6.1	10.7	11.2	10.5	10.9
Sheet Metal	6	5.9	7.1	5.6	5.6	5.7	6.1	10.7	11.2	10.5	10.9
Fabric	6	5.9	7.1	5.6	5.6	5.7	6.1	10.7	11.2	10.5	10.9
Outbound											
Ramp #	41 - 031A	41 - 031B	41 - 031C	41 - 031D	41 - 031F	41 - 031G	41 - 031H	69 - 027A	69 - 027B	69 - 027C	69 - 027D
Motorized Vehicle	6	5.9	7.1	5.6	5.6	5.7	6.1	10.7	11.2	10.5	10.9

Figure A.33 Distance matrix for Gibson County ramps.

Inbound	Inbound	Inbound	Inbound	Outbound	Outbound	Inbound	Inbound	Inbound	Inbound	Inbound
41 - 310	41 - 025A	41 - 025B	41 - 025C	41 - 025D	41 - 025G	41 - 027A	41 - 027B	41 - 027C	41 - 027D	41 - 027G

Inbound	Outbound	Inbound	Inbound	Outbound	Inbound	Inbound	Inbound	Outbound	Inbound	Outbound
41 - 031A	41 - 031B	41 - 031C	41 - 031D	41 - 031F	41 - 031G	41 - 031H	69 - 027A	69 - 027B	69 - 027C	69 - 027D

Figure A.34 Inbound/outbound ramp classification.

Figure A.35 represents different costs associated with different values of UD and ECONG. The transportation cost is the cost of moving freight across the ramps. Delay cost is the cost due to congestion. Construction cost is the cost of constructing new ramp at an exit due increased congestion. As ECONG increases, the construction cost decreases and as UD increases, the delay cost increases. Figure A.36 provides results as to which exit ramps need additional construction. The model suggests higher number of ramps to be constructed with low ECONG value. A maximum of four new ramps are suggested to be constructed. The model suggests a maximum of 80 truck equivalent capacity to be added to the ramps across the county.

#	UD	ECONG	Transportation Cost	Delay Cost	Construction Cost	Objective function
1	1000000	0	$ 2,322.01	$852,469.84	$ 4,500,000.00	$ 5,354,791.84
2	1000000	100	$ 2,322.01	$852,469.84	$ 4,500,000.00	$ 5,354,791.84
3	1000000	500	$ 2,322.01	$852,469.84	$ 4,500,000.00	$ 5,354,791.84
4	5000000	0	$ 2,005.16	$ -	$ 6,000,000.00	$ 6,002,005.16
5	5000000	100	$ 2,005.16	$ -	$ 6,000,000.00	$ 6,002,005.16
6	5000000	500	$ 2,005.16	$ -	$ 6,000,000.00	$ 6,002,005.16

Figure A.35 Costs associated with different UD and ECONG.

#	UD	ECONG	41 - 310	41 - 025A	41 - 025B	41 - 025C	41 - 025D	41 - 025G	41 - 027A	41 - 027B	41 - 027C	41 - 027D	41 - 027G	41 - 031A
1	1000000	0	0	1	0	0	0	0	1	0	0	1	0	0
2	1000000	100	0	1	0	0	0	0	1	0	0	1	0	0
3	1000000	500	0	1	0	0	0	0	1	0	0	1	0	0
4	5000000	0	0	1	0	0	0	0	1	1	0	1	0	0
5	5000000	100	0	1	0	0	0	0	1	1	0	1	0	0
6	5000000	500	0	1	0	0	0	0	1	1	0	1	0	0

41 - 031B	41 - 031C	41 - 031D	41 - 031F	41 - 031G	41 - 031H	69 - 027A	69 - 027B	69 - 027C	69 - 027D
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Figure A.36 New ramp addition.

A.2.6 Automotive Manufacturing Cluster–Howard County

Automotive and manufacturing are major industry clusters in Howard County in Indiana. Stellantis Indiana Transmission Plant, T L Tate Manufacturing Inc, Chrysler Transmission Plant, Stephens Machine Inc. Are some of the major automotive manufacturing companies in Howard County. According to the US BEA, the county employed more than 11,500 employees in the manufacturing industry in 2019 with a $108,593 average earning per job. The manufacturing industry in Howard County is expected to contribute as high as $6.22 billion dollars (in terms of 2005 USD) in 2050 SSP 5 scenario and as low as $3.76 billion dollars (in terms of 2005 USD) in 2050 SSP 3 scenario.

Engine (SCTG: 34–machinery), transmission (SCTG: 34–machinery), plastic (SCTG: 24–plastic & rubber), fabric (SCTG: 30–textiles, leather, and articles of textiles or leather), sheet metal (SCTG: 32–base metal in primary or semi-finished forms and in finished basic shapes) are the inbound commodities considered for the automotive industry in Howard County. Assembled car (SCTG: 36–motorized and other vehicles) is the outbound commodity considered for the automotive industry.

Figure A.37 shows the Howard County map and Figure A.38 shows the exit ramps considered for the optimization model.

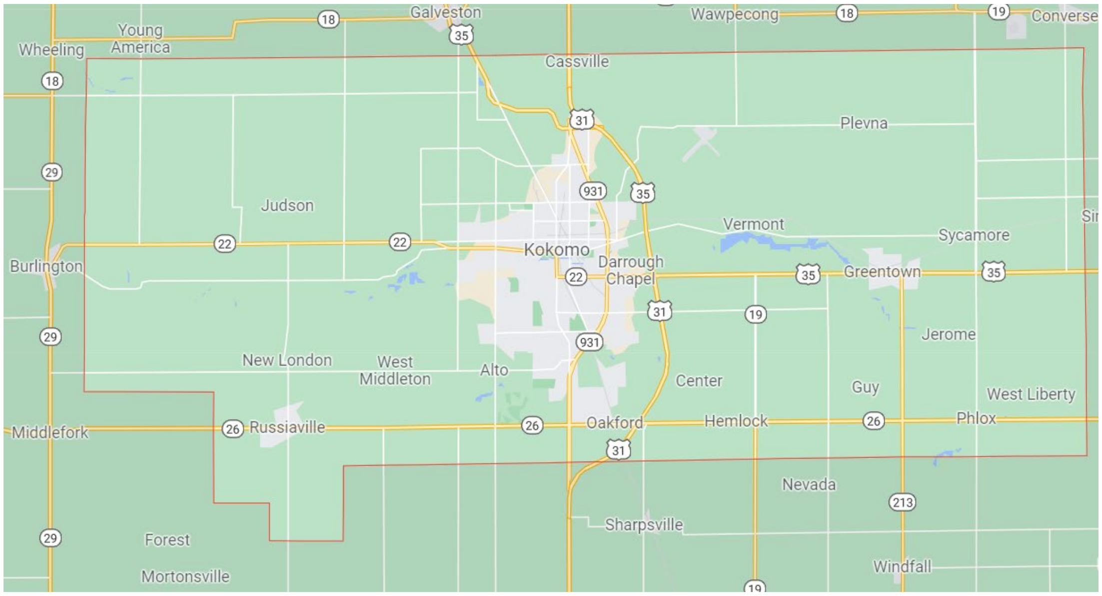

Figure A.37 Howard County map.

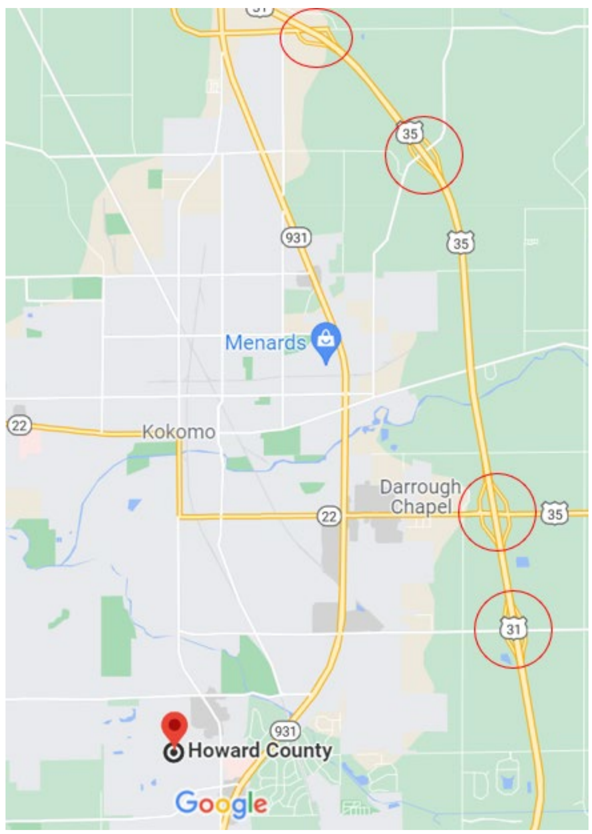

Figure A.38 Ramps close to the cluster.

For the optimization model, fourteen major ramps in Howard County are considered: 31-161A, 31-161B, 31-161C, 31-161D, 31-162A, 31-162B, 31-162C, 31-162D, 31-165A, 31-165B, 31-165B, 31-165-C, 31-165D, 31-166A, and 31-166D. Distance from these ramps to the center of the county is listed in Figure A.39. All the ramps described lie within 30 miles of the industry center. The distances are calculated using geo-coordinates. Figure A.40 details the distinction between inbound and outbound ramps.

Distance Matrix														
Inbound														
Ramp#	31 - 161A	31 - 161B	31 - 161C	31 - 161D	31 - 162A	31 - 162B	31 - 162C	31 - 162D	31 - 165A	31 - 165B	31 - 165C	31 - 165D	31 - 166A	31 - 166D
Plastic	3.9	3.9	3.8	3.8	4.7	4.8	4.5	4.5	5.9	7.1	5.6	5.6	5.7	6.1
Engine	3.9	3.9	3.8	3.8	4.7	4.8	4.5	4.5	5.9	7.1	5.6	5.6	5.7	6.1
Transmission	3.9	3.9	3.8	3.8	4.7	4.8	4.5	4.5	5.9	7.1	5.6	5.6	5.7	6.1
Sheet Metal	3.9	3.9	3.8	3.8	4.7	4.8	4.5	4.5	5.9	7.1	5.6	5.6	5.7	6.1
Fabric	3.9	3.9	3.8	3.8	4.7	4.8	4.5	4.5	5.9	7.1	5.6	5.6	5.7	6.1
Engine	3.9	3.9	3.8	3.8	4.7	4.8	4.5	4.5	5.9	7.1	5.6	5.6	5.7	6.1
Outbound														
Ramp #	31 - 161A	31 - 161B	31 - 161C	31 - 161D	31 - 162A	31 - 162B	31 - 162C	31 - 162D	31 - 165A	31 - 165B	31 - 165C	31 - 165D	31 - 166A	31 - 166D
Motorized Vehicle	3.9	3.9	3.8	3.8	4.7	4.8	4.5	4.5	5.9	7.1	5.6	5.6	5.7	6.1

Figure A.39 Distance matrix for Howard County ramps.

Inbound	Outbound	Outbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Outbpund	Outbound	Outbound
31 - 161A	31 - 161B	31 - 161C	31 - 161D	31 - 162A	31 - 162B	31 - 162C	31 - 162D	31 - 165A	31 - 165B	31 - 165C	31 - 165D	31 - 166A	31-166D

Figure A.40 Inbound/outbound ramp classification.

Figure A.41 represents different costs associated with different values of UD and ECONG. The transportation cost is the cost of moving freight across the ramps. Delay cost is the cost due to congestion. Construction cost is the cost of constructing new ramp at an exit due increased congestion. As ECONG increases, the construction cost decreases and as UD increases, the delay cost increases. Figure A.42 provides results as to which exit ramps need additional construction. The model suggests higher number of ramps to be constructed with low ECONG value. A maximum of 10 new ramps are suggested to be constructed. The model suggests a maximum of 500 truck equivalent capacity to be added to the ramps across the county.

UD	ECONG	Transportation Cost	Delay Cost	Construction Cost	Objective function
10	0	$ 13,053.32	$ 2,637.35	$ 15,000,000.00	$ 15,015,690.67
10	20	$ 12,701.14	$ 5,571.97	$ 9,000,000.00	$ 9,018,337.75
10	50	$ 12,562.63	$ 8,271.97	$ 4,500,000.00	$ 4,521,065.67
50	0	$ 13,053.32	$ 13,186.75	$ 15,000,000.00	$ 15,026,240.07
50	20	$ 12,701.14	$ 27,859.86	$ 9,000,000.00	$ 9,040,625.64
50	50	$ 12,562.63	$ 41,359.86	$ 4,500,000.00	$ 4,554,153.56
100	0	$ 13,053.32	$ 26,373.49	$ 15,000,000.00	$ 15,039,426.81
100	20	$ 12,701.14	$ 55,719.72	$ 9,000,000.00	$ 9,068,485.49
100	50	$ 12,562.63	$ 82,719.72	$ 4,500,000.00	$ 4,595,513.42
500	0	$ 13,053.32	$131,867.46	$ 15,000,000.00	$ 15,144,920.79
500	20	$ 12,701.14	$278,598.59	$ 9,000,000.00	$ 9,291,364.37
500	50	$ 12,562.63	$413,598.59	$ 4,500,000.00	$ 4,926,392.29

Figure A.41 Costs associated with different UD and ECONG.

UD	ECONG	31 - 161A	31 - 161B	31 - 161C	31 - 161D	31 - 162A	31 - 162B	31 - 162C	31 - 162D	31 - 165A	31 - 165B	31 - 165C	31 - 165D	31 - 166A	31 - 166D
10	0	2	-	-	-	2	-	2	-	2	-	2	-	-	-
10	20	2	-	-	-	2	-	2	-	-	-	-	-	-	-
10	50	2	-	-	-		-	1	-	-	-	-	-	-	-
50	0	2	-	-	-	2	-	2	-	2	-	2	-	-	-
50	20	2	-	-	-	2	-	2	-	-	-	-	-	-	-
50	50	2	-	-	-		-	1	-	-	-	-	-	-	-
100	0	2	-	-	-	2	-	2	-	2	-	2	-	-	-
100	20	2	-	-	-	2	-	2	-	-	-	-	-	-	-
100	50	2	-	-	-		-	1	-	-	-	-	-	-	-
500	0	2	-	-	-	2	-	2	-	2	-	2	-	-	-
500	20	2	-	-	-	2	-	2	-	-	-	-	-	-	-
500	50	2	-	-	-		-	1	-	-	-	-	-	-	-

Figure A.42 New ramp addition.

A.2.7 Automotive Manufacturing Cluster–Vigo County

Vigo county has a major automotive industry cluster in Indiana. Thyssenkrupp AG, Rumford Co, D & D Automation Inc., Advics Manufacturing Indiana, LLC, Reynolds & Co, Dede Tool & Machine Inc. Are some of the major automotive manufacturing companies situated in Vigo County. According to the US BEA, the county employed more than 5,900 employees in the manufacturing industry in 2019 with a $74,379 average earning per job. The manufacturing industry in Vigo County is expected to contribute as high as $2.29 billion dollars (in terms of 2005 USD) in 2050 SSP 5 scenario and as low as $1.38 billion dollars (in terms of 2005 USD) in 2050 SSP 3 scenario.

Engine (SCTG: 34–machinery), transmission (SCTG: 34–machinery), plastic (SCTG: 24–plastic & rubber), fabric (SCTG: 30–textiles, leather, and articles of textiles or leather), sheet metal (SCTG: 32–base metal in primary or semi-finished forms and in finished basic shapes) are the inbound commodities considered for the automotive industry in Vigo County. Assembled car (SCTG: 36–motorized and other vehicles) is the outbound commodity considered for the automotive industry.

Figure A.43 shows the Vigo County map and Figure A.44 shows the exit ramps considered for the optimization model.

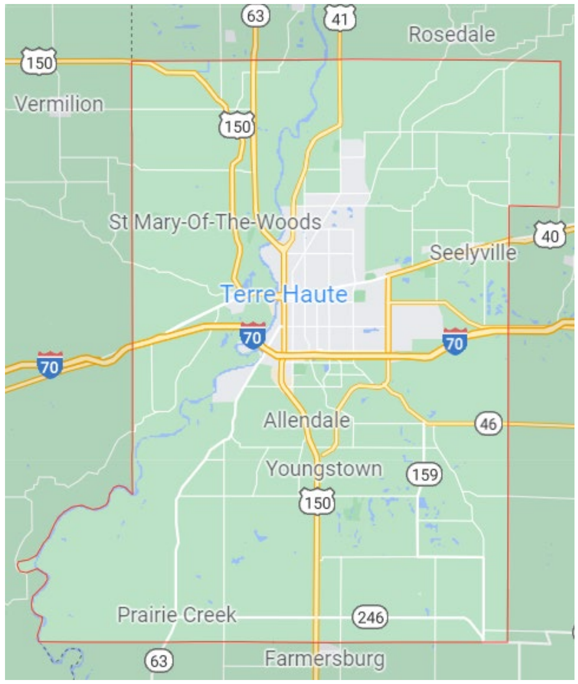

Figure A.43 Vigo County map.

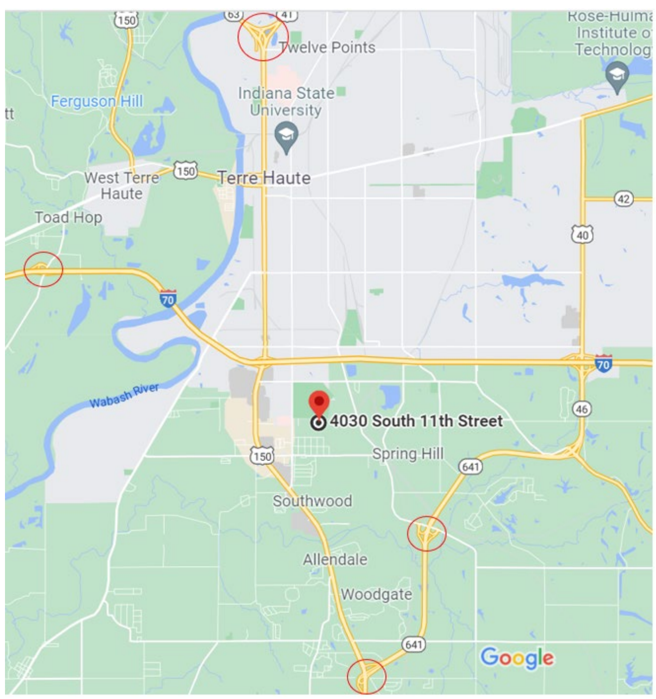

Figure A.44 Ramps close to the cluster.

For the optimization model we have considered the major ramps in Vigo County: 41-105A, 41-105B, 41-105D, 41-105H, 41-114C, 41-114D, 70-003A, 70-003B, 70-003D, 70-003H, 70-007A, 70-007C, 70-007D, 70-011A, 641-20, 641-002A, 641-002D, 641-002H, 641-005A, 641-005B, 641-005C, 641-005D. Distance from these ramps to the center of the county is listed in Figure A.45. All the ramps described lie within 30 miles of the industry center. The distances are calculated using geo-coordinates. Figure A.46 details the distinction between inbound and outbound ramps.

Distance Matrix											
Inbound											
Ramp#	41 - 105A	41 - 105B	41 - 105D	41 - 105H	41 - 114C	41 - 114D	70 - 003A	70 - 003B	70 - 003D	70 - 003H	70 - 007A
Plastic	5.6	4.1	5.4	4.4	6.7	6.2	5.1	4.9	7.5	5.3	1.7
Engine	5.6	4.1	5.4	4.4	6.7	6.2	5.1	4.9	7.5	5.3	1.7
Transmission	5.6	4.1	5.4	4.4	6.7	6.2	5.1	4.9	7.5	5.3	1.7
Sheet Metal	5.6	4.1	5.4	4.4	6.7	6.2	5.1	4.9	7.5	5.3	1.7
Fabric	5.6	4.1	5.4	4.4	6.7	6.2	5.1	4.9	7.5	5.3	1.7
Outbound											
Ramp #	41 - 105A	41 - 105B	41 - 105D	41 - 105H	41 - 114C	41 - 114D	70 - 003A	70 - 003B	70 - 003D	70 - 003H	70 - 007A
Motorized Vehicle	5.6	4.1	5.4	4.4	6.7	6.2	5.1	4.9	7.5	5.3	1.7

Distance Matrix											
Inbound											
Ramp#	70 - 007C	70 - 007D	70 - 011A	641 - 20	641 - 002A	641 - 002D	641 - 002H	641 - 005A	641 - 005B	641 - 005C	641 - 005D
Plastic	1.9	1.8	5.6	3.7	3.7	3.5	3.5	5.5	6.3	5.4	5.1
Engine	1.9	1.8	5.6	3.7	3.7	3.5	3.5	5.5	6.3	5.4	5.1
Transmission	1.9	1.8	5.6	3.7	3.7	3.5	3.5	5.5	6.3	5.4	5.1
Sheet Metal	1.9	1.8	5.6	3.7	3.7	3.5	3.5	5.5	6.3	5.4	5.1
Fabric	1.9	1.8	5.6	3.7	3.7	3.5	3.5	5.5	6.3	5.4	5.1
Outbound											
Ramp #	70 - 007C	70 - 007D	70 - 011A	641 - 20	641 - 002A	641 - 002D	641 - 002H	641 - 005A	641 - 005B	641 - 005C	641 - 005D
Motorized Vehicle	1.9	1.8	5.6	3.7	3.7	3.5	3.5	5.5	6.3	5.4	5.1

Figure A.45 Distance matrix for Vigo County ramps.

Outbound	Inbound	Inbound	Outbound	Outbound	Inbound	Inbound	Inbound	Outbound	Inbound	Inbound
41 - 105A	41 - 105B	41 - 105D	41 - 105H	41 - 114C	41 - 114D	70 - 003A	70 - 003B	70 - 003D	70 - 003H	70 - 007A
Inbound	Outbound	Inbound	Outbound	Inbound	Outbound	Inbound	Inbound	Outbound	Inbound	Outbound
70 - 007C	70 - 007D	70 - 011A	641 - 20	641 - 002A	641 - 002D	641 - 002H	641 - 005A	641 - 005B	641 - 005C	641 - 005D

Figure A.46 Inbound/outbound ramp classification.

Figure A.47 represents different costs associated with different values of UD and ECONG. The transportation cost is the cost of moving freight across the ramps. Delay cost is the cost due to congestion. Construction cost is the cost of constructing new ramp at an exit due increased congestion. As ECONG increases, the construction cost decreases and as UD increases, the delay cost increases. Figure A.48 provides results as to which exit ramps need additional construction. The model suggests higher number of ramps to be constructed with low ECONG value. A maximum of 30 new ramps are suggested to be constructed. The model suggests a maximum of 1,500 truck equivalent capacity to be added to the ramps across the county.

Automotive/Manufacturing Industry - Vigo						
#	UD	ECONG	Transportation Cost	Delay Cost	Construction Cost	Objective function
1	1000000	0	$ 21,510.70	$ 17,990,991.62	$ 45,000,000.00	$ 63,012,502.33
2	1000000	100	$ 19,322.66	$ 6,835,656.52	$ 45,000,000.00	$ 51,855,232.36
3	1000000	500	$ 16,252.29	$ 6,835,656.52	$ 45,000,000.00	$ 51,852,962.00
4	5000000	0	$ 21,510.70	$ 89,954,958.12	$ 45,000,000.00	$ 134,976,468.82
5	5000000	100	$ 19,322.66	$ 34,178,282.62	$ 45,000,000.00	$ 79,197,858.46
6	5000000	500	$ 16,252.29	$ 34,178,282.62	$ 45,000,000.00	$ 79,195,588.09

Figure A.47 Costs associated with different UD and ECONG.

#	UD	ECONG	41 - 105A	41 - 105B	41 - 105D	41 - 105H	41 - 105H	41 - 105H	41 - 114C	41 - 114D	70 - 002A	70 - 002B	70 - 003A	70 - 003B	70 - 003D	70 - 003H
1	1000000	0	0	2	2	0	0	0	0	2	2	2	2	2	0	2
2	1000000	100	0	2	2	0	0	0	0	2	2	2	2	2	0	2
3	1000000	500	0	2	2	0	0	0	0	2	2	2	2	2	0	2
4	5000000	0	0	2	2	0	0	0	0	2	2	2	2	2	0	2
5	5000000	100	0	2	2	0	0	0	0	2	2	2	2	2	0	2
6	5000000	500	0	2	2	0	0	0	0	2	2	2	2	2	0	2

70 - 007A	70 - 007B	70 - 007C	70 - 007D	70 - 011A	641 - 20	641 - 002A	641 - 002D	641 - 002H	641 - 005A	641 - 005B	641 - 005C	641 - 005D
2	0	2	0	2	0	2	0	2	2	0	2	0
2	0	2	0	2	0	2	0	2	2	0	2	0
2	0	2	0	2	0	2	0	2	2	0	2	0
2	0	2	0	2	0	2	0	2	2	0	2	0
2	0	2	0	2	0	2	0	2	2	0	2	0
2	0	2	0	2	0	2	0	2	2	0	2	0

Figure A.48 New ramp addition.

A.2.8 E-commerce/Retail Cluster–Marion County

Marion County has a major e-commerce/retail industry cluster in Indiana. According to the US BEA, the county employed more than 52,239 employees in the retail industry in 2020 with a $42,641 average earning per job.

Printed products (SCTG: 29–printed products), paper or paperboard articles (SCTG: 28–paper or paperboard articles), plastic and rubber (SCTG: 24–plastic and rubber), miscellaneous manufacturing products (SCTG: 40–miscellaneous manufacturing products) are the inbound commodities considered for the retail industry in Marion County. Finished Product (SCTG: 43–mixed freight) is the outbound commodity considered for the e-commerce industry.

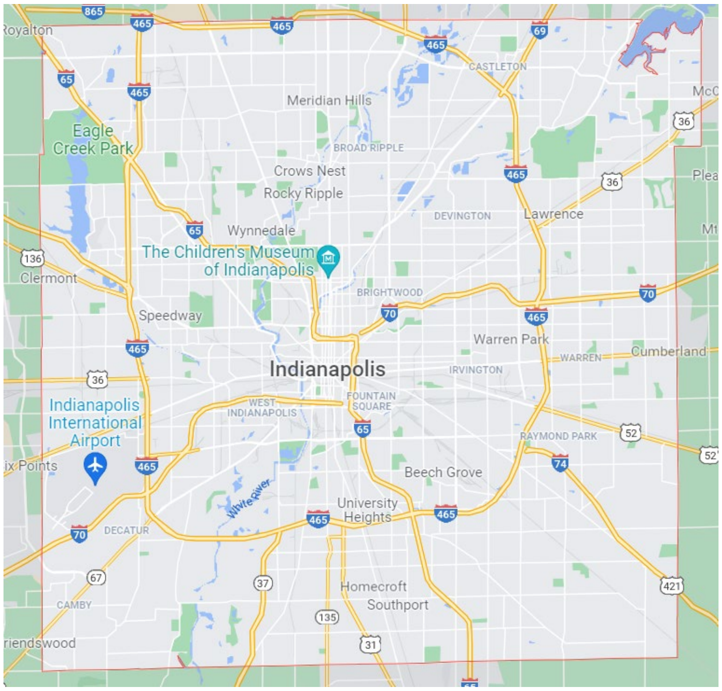

Figure A.49 Marion County map.

For the optimization model we have considered the major ramps in Marion County: 70-78A, 70-79A, 70-79B, 70-79D, 65-109A, 65-109C, 65-110A, 65-110C, 65-111C, 65-111D, 65-112Q, 65-112U, 65-113A, and 65-113D. Distance from these ramps to the center of the county is listed in Figure A.50. All the ramps described lie within 30 miles of the industry center. The distances are calculated using geo-coordinates. Figure A.51 details the distinction between inbound and outbound ramps.

Distance Matrix														
Inbound														
Ramp#	70-078A	70-079A	70-079B	70-079D	65-109A	65-109C	65-110A	65-110C	65-111C	65-111D	65-112Q	65-112U	65-113A	65-113D
Printed Products	2.6	1.1	1.2	1	2.7	2.2	1.1	1	1.5	1.4	2.5	2.1	2.1	1.8
Misc Manufac Products	2.6	1.1	1.2	1	2.7	2.2	1.1	1	1.5	1.4	2.5	2.1	2.1	1.8
Waste & Scrap	2.6	1.1	1.2	1	2.7	2.2	1.1	1	1.5	1.4	2.5	2.1	2.1	1.8
Mixed Freight	2.6	1.1	1.2	1	2.7	2.2	1.1	1	1.5	1.4	2.5	2.1	2.1	1.8
Outbound														
Ramp #	70-078A	70-079A	70-079B	70-079D	65-109A	65-109C	65-110A	65-110C	65-111C	65-111D	65-112Q	65-112U	65-113A	65-113D
Finished Product	2.6	1.1	1.2	1	2.7	2.2	1.1	1	1.5	1.4	2.5	2.1	2.1	1.8

Figure A.50 Distance matrix for Marion County ramps.

Inbound	Inbound	Outbound	Outbounc	Inbound	Outbound	Inbound	Inbound	Inbound	Inbound	Outbound	Outbound	Inbound	Outbound
70-078A	70-079A	70-079B	70-079D	65-109A	65-109C	65-110A	65-110C	65-111C	65-111D	65-112Q	65-112U	65-113A	65-113D

Figure A.51 Inbound/outbound ramp classification.

Figure A.52 represents different costs associated with different values of UD and ECONG. The transportation cost is the cost of moving freight across the ramps. Delay cost is the cost due to congestion. Construction cost is the cost of constructing new ramp at an exit due increased congestion. Figure A.53 provides results as to which exit ramps need additional construction. The model suggests higher number of ramps to be constructed with low ECONG value. A maximum of 19 new ramps are suggested to be constructed. The model suggests a maximum of 380 truck equivalent capacity to be added to the ramps across the county.

UD	ECONG	Transportation Cost	Delay Cost	Construction Cost	Objective function
1E+09	0	$ 1,938.99	$ 155,551,078,664.00	$ 25,500,000.00	$ 155,576,580,602.99

Figure A.52 Costs associated with different UD and ECONG.

UD	ECONG	70-078A	70-079A	70-079B	70-079D	65-109A	65-109C	65-110A	65-110C	65-111C	65-111D	65-112Q	65-112U	65-113A	65-113D
1E+09	0	2	2		1	2		2	2	2	2			2	2

Figure A.53 New ramp addition.

APPENDIX B. SUPPLEMENTAL MATERIAL

Indiana's Future Freight Traffic Optimization Model: https://purr.purdue.edu/publications/4131/1

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

About This Report

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