Automated Vehicle (AV) Freight Readiness and Recommendations Assessment

Prepared for the Indiana Department of Transportation

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AECOM

CONEXUS INDIANA

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Executive Summary

This report synthesizes efforts to evaluate the current state of the automated vehicle (AV) freight industry, analyze the economic factors driving goods movement in Indiana, identify specific freight corridors that may benefit from AV freight deployments, and conduct deployment feasibility assessments. The methodology encompassed the following tasks:

1. **Data Collection and Sector Analysis**
    1. Brief market scan on current state of the AV freight industry.
2. **Economic Incentivization**
    1. Review data from the market scan and identify key freight and delivery routes.
    2. Categorize these routes based on operational modes and stakeholder groups, such as Conexus Indiana's Advanced Industries Counsil.
    3. Propose corridors to INDOT and stakeholders for in-depth AV deployment feasibility assessment.
    4. Engage with stakeholders through interviews to gauge the impact of AV freight vehicle deployments.
3. **Roadway AV Deployment Assessment**
    1. Assess feasibility for AV freight deployment on each corridor.
    2. Identify potential infrastructure modifications to enhance deployment readiness.

As automated vehicles (AVs) begin to operate on our nation's roadways, stakeholders such as infrastructure owner operators (IOOs), law enforcement, and the traveling public are working to understand the implications of these vehicles on our roadways and society. There is currently no standardized testing or verification for AV capabilities, and the regulatory system is working to understand the right balance between restriction and innovation. While AVs boast advanced sensors that surpass human capabilities, their understanding of context is significantly limited; consequently, their deployment requires monitoring and management. It’s imperative that any environmental adaptations to facilitate AV deployment should primarily enhance the experience for human drivers, who will continue to dominate our transportation systems for the foreseeable future.

Corridors within the state of Indiana were identified and selected as candidates for AV freight vehicle deployment feasibility assessments, which included a variety of interstate and US highways, for a total of 3,100 miles (distance based on both directions, and not lane-specific). The analysis illustrates some of the challenges in the deployment of AV freight vehicles from an operational standpoint, which the AV freight industry is actively working to manage. The challenges identified are partly a result of the infrastructure-based environment, but more so due to the complex interaction with other road users.

Each roadway environment an AV operates in will have specific challenges, which are dynamic and can be affected by the level of congestion, weather conditions, work zones, road debris, and incidents like crashes. The feasibility assessment provides an aggregate view of these environmental complexities. The primary challenges identified on the corridors include:

- **High-Speed Merges and Exits**
  - These are dynamic zones of vehicle movement across lanes, occurring at high speeds, which requires faster decision-making and reactions from AVs.
- **At-Grade Railroad Crossings**
  - These crossings can be confusing depending on the types of visual cues and physical barriers that are present.
- **Non-Access-Controlled Roads with Speeds Above 45mph**
  - These roadways have many, ingress, egress, and crossing points for vehicles. They can also have non-standard vehicle types such as farm equipment and may have animal crossings.
- **Complex Cross Street Configurations**
  - These cross streets may have confusing and dynamic movements of vehicles and pedestrians, which could cause AVs to make a poor decision, or become stuck.

- **Long Overpasses (GPS Signal Degradation)**
  - Many AV companies over rely on GPS signals for their operation, and if the signal is degraded or absent, which occurs in tunnels or under long overpasses, the AV may execute a fallback behavior (such as pulling over to the side). Some companies are not affected by this type of outage.
- **Locations of Mixed Merging on Highways**
  - These zones have both merging and exiting vehicles, often within a very short distance, which can be confusing for an AV, especially for a large vehicle like an AV freight vehicle.

Each of these challenges may have mitigation components that include infrastructure, policy/regulation, data/information sharing, and technical capability maturity. This work forms the base for further work in the state to incentivize safe and effective integration of AV freight vehicles into the transportation system and the goods movement and manufacturing supply chain.

Background

The AV industry consists of three primary market sectors: passenger vehicles (robo-taxi), transit, and goods movement (Figure 1). The goods movement sector is further divided into middle-/last-mile vehicle types (e.g., box truck delivery vehicles) and Class VIII long-haul freight vehicles. Each of these market sectors are driven by their own market dynamics, operate in similar but specific roadway environments, and are regulated by different agencies within the US Department of Transportation (USDOT). The long-haul AV freight industry has made significant advances recently and has moved from conducting research and demonstration pilots to executing deployments and moving goods for customers on public roadways and in mixed traffic. Their success has come from a mixture of technical capability maturity, infrastructure readiness, and favorable state and federal policies. Indiana Department of Transportation (INDOT) and Conexus Indiana have commissioned this feasibility study on the deployment of automated freight vehicles in the state.

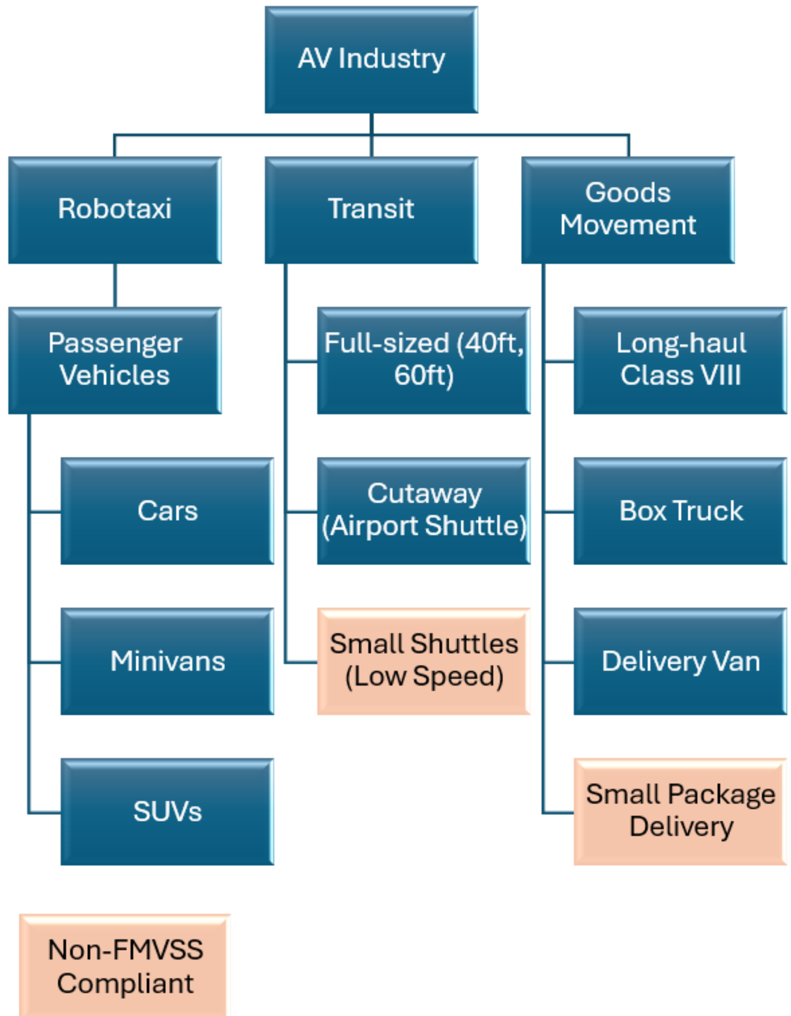

Figure 1: Automated Vehicle Market Vehicle Type Decomposition

Introduction

Conexus Indiana is the one organization focused on growing the Indiana industries that make and move products for the world and fuel Indiana's economy. In fact, more than $650 billion in goods are transported through Indiana each year and Indiana has ranked within the top five states for infrastructure, seven years in a row. This feasibility study is focused on the Primary Highway Freight System (PHFS) and corridors that connect major concentrations of manufacturing and distribution centers for advanced manufacturing and logistics (AML). This document presents the economic analysis of freight movement in Indiana, how that movement may be leveraged as AV freight corridors, and a deployment feasibility analysis of selected corridors using a tool called AV-Readi™. This effort included the following steps:

1. **Evaluated the results from Market Scan activity** – Data Collection and Market Scan and conducted an Economic Incentivization analysis to identify priority freight movement corridors within the state, including interstate highways, US highways, state highways, and local roadways.
2. **Classified these routes** according to characteristics including mode of operation (long-haul operation, intra-state vs. interstate, distribution hub access, etc.), and the relevant stakeholder groups, such as Conexus Indiana's Advanced Industries Counsil
3. **Presented a list of candidate routes** to INDOT and select stakeholders for consideration of a detailed assessment for AV freight deployment feasibility.
4. **Assessed selected priority roadways using the AV-Readi™ tool**:
    a. Generated complexity maps and calculated complexity index values for each route analyzed.
    b. Evaluated selected routes for overall readiness to deploy AV goods movement vehicles based on the likelihood and severity of conflict with other road users, including vulnerable road users (VRUs).
    c. Identified locations where likelihood and severity of conflict with other road users, or other environmental factors, was "High" to "Extreme".
    d. Identified possible infrastructure changes that may increase the readiness for AV freight and delivery deployment.

5. **Stakeholder comments** were also incorporated, which were gathered during a series of outreach meetings.

Economic Incentivization

As a nonprofit organization, Conexus focuses on growing the advanced manufacturing and logistics network needed to help fuel Indiana's economy. In addition to building connections and partnerships with other economic accelerators and public-section organizations to achieve this goal, the organization identifies progressive digital technologies for company and workforce adoption. By looking at AV Trucking and considering where it may be well suited to such industry and economic activity in the state, how it will interact with existing infrastructure and roadway networks, and understand ways to foster its use, Conexus will help accelerate Indiana's manufacturing and logistics industry success, and help the workforce excel in an ever-changing job market. This focus on the manufacturing and logistics industry is crucial to Indiana because the state has been ranked within the top five for infrastructure, seven years in a row, helping reach 80% of the contiguous United States within a 24-hour drive. This helps result in more than $650 billion worth of goods being transported through Indiana each year. By focusing on innovation and technology, Conexus looks to further advance this market and continue growth in this sector, acknowledging the potential benefits for roadway safety, the truck driver shortage, driver pay and working conditions, reduction of costs in goods movement, Indiana's economic growth, and logistics sector leadership. Conducting market research across future-oriented topics in the areas of embedded electric charging, truck platooning, vehicle probe data opportunities, sustainability in materials and reduction, and road funding mechanisms (e.g., tolling or tracking vehicle miles traveled) will help the state understand advanced technologies being implemented across the world, and how they can be utilized to help the state and its economy.

The I-70 Truck Automation Corridor Project, led by DriveOhio in partnership with INDOT, intends to demonstrate various levels of truck automation technology (SAE Level 2 and Level 4), including truck platooning. With a start date of June 2021 and expected completion of January 2027, this project aims to advance the adoption of automation in the logistics industry by integrating automation technologies into truck fleets' daily "revenue service" operations, to deliver products across Ohio and Indiana.

This study aims to evaluate how the economic drivers of freight movement in Indiana, and the associated corridors used for this movement, combine with the technical maturity of automated freight vehicles.

This may provide insights into State investment opportunities that foster and enable the AV freight industry to deploy into, and operate throughout, Indiana, supporting Indiana's advanced industries and infrastructure.

Economic Analysis of Freight Movement

Candidate corridors for AV deployment feasibility assessment were identified using economic activity data (Figure 2).

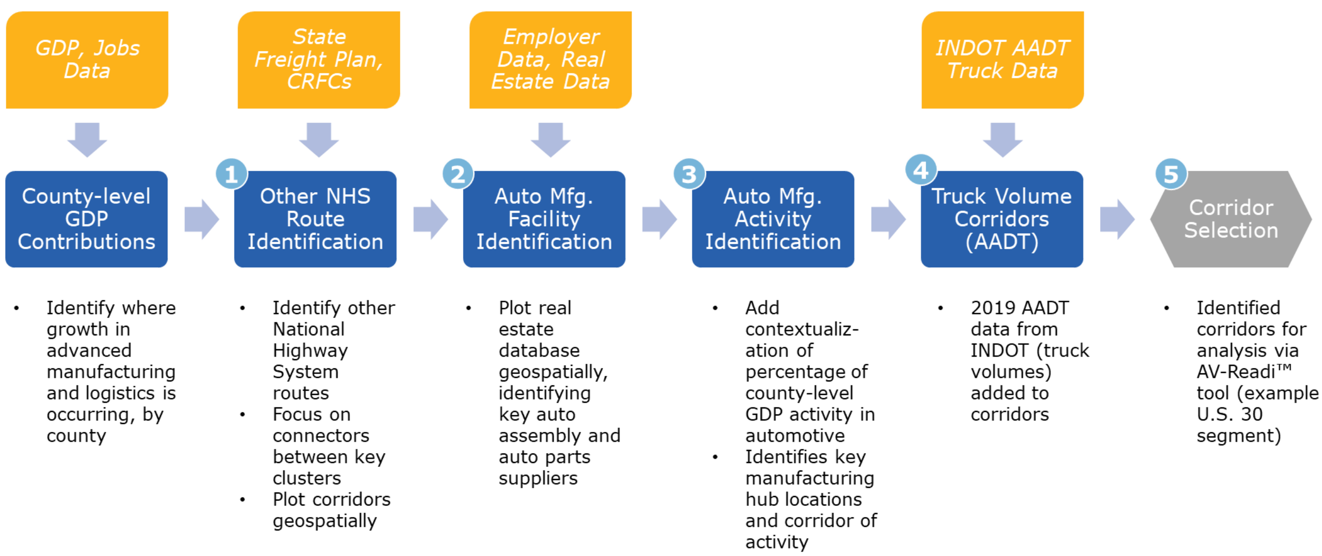

Figure 2: Corridor Identification Process

Specific data, such as county-level contribution to State Gross Domestic Product (GDP) in manufacturing, warehousing, wholesale, and truck transportation were analyzed. The Compound Annual Growth Rate (CAGR) for job increases in manufacturing stood at 1.5% from 2010 to 2022. In comparison, the CAGR for transportation and warehouse related industries during the same period was 2.5%.

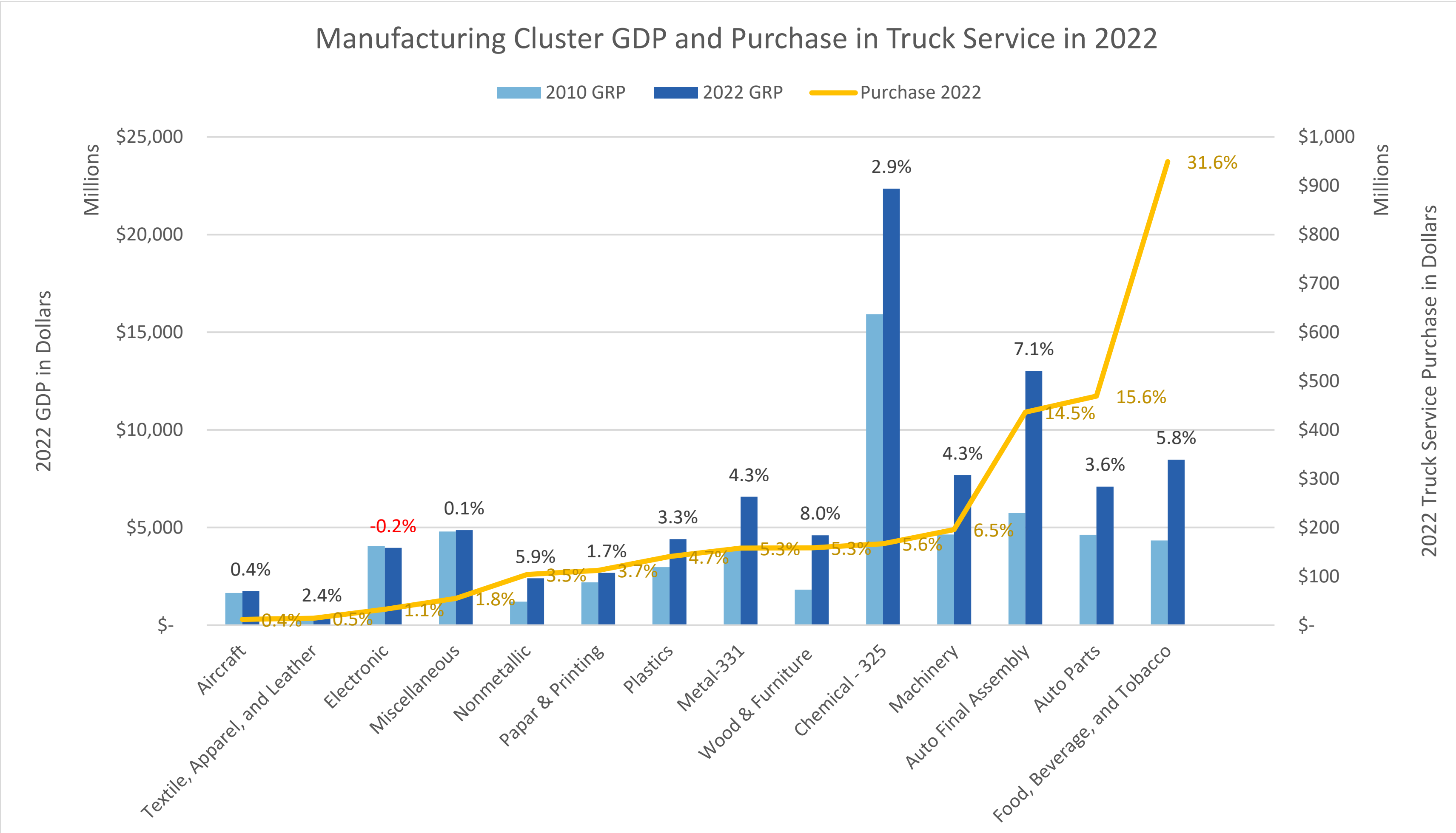

Figure 3: Manufacturing Cluster GDP and Purchase in Truck Service in 2022

Figure 3 provides a comparative analysis of GDP across manufacturing clusters in 2010 and again in 2022. Percentages in the green represent the CAGR of GDP in each cluster during this period, majority of clusters demonstrate an uptick in GDP from 2010 to 2022, indicating positive overall growth. The orange line displays spending patterns of different clusters on truck transportation services in 2022. This line provides valuable insights into clusters with significant demand for truck services to support their production processes. Food, beverage, and tobacco, auto parts, and auto final assembly clusters collectively account for over 60% of spending on truck transportation services. These clusters also contribute significantly to Indiana's GDP in 2022.

In 2022, the contribution of auto parts and final assembly combined to total manufacturing reached 19.3%. Automotive final assembly exhibits concentrated activity in several counties, while auto parts manufacturing is more widely dispersed. Lafayette in Tippecanoe County, Fort Wayne in Allen County, Elkhart and Goshen City in Elkhart County, and Princeton City in Gibson County emerge as key contributors with a higher share of GDP. This is visually represented in Figure 4 below:

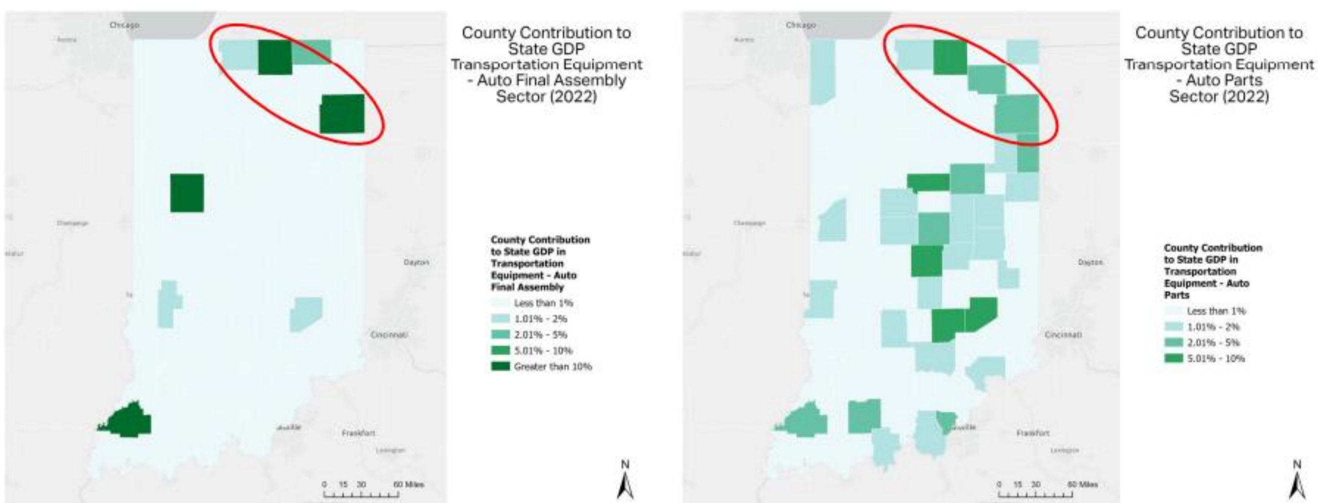

Figure 4: County Contribution to State GDP Transportation Equipment – Auto Final Assembly Sector 2022 (Left) and Auto Parts Sector 2022 (Right)

Primary Highway Freight System (PHFS) corridors and candidate Critical Rural Freight Corridors (CRFC)[1] were analyzed to help identify specific freight corridors as possible candidates for the AV-Readi analysis using a data-driven approach. The PHFS network is identified as the most critical roadway portion of the U.S freight transportation system (with over 953.98 miles in Indiana). These corridors, such as I-65, I-69, I-70 and I-80, see the greatest usage for both interstate and intrastate long-haul logistics movements, and were considered important to study from the outset- especially I-70, given its inclusion in the DriveOhio and INDOT Truck Automation Corridor Project. However, public roads and other highways outside urbanized areas that constitute identified CRFC, provide access and first / last-mile connectivity between the PHFS, Interstates, and areas of advanced manufacturing and logistics activity. They also enable crucial links to ports, public transportation facilities, or other intermodal freight facilities (194.25 miles in Indiana). Using 2019 AADT data from INDOT, truck movement volumes across different U.S highways were plotted. The key corridors that clearly became evident as high-truck-traffic routes were:

- US 30 from Gary/Chicago to Fort Wayne (E-W)
- US 31 from South Bend to Indianapolis (N-S)
- US 41 from Terre Haute to Evansville (N-S)

[1] Indiana identified a set of potential Critical Rural Freight Corridors (CRFC) and Critical Urban Freight Corridors (CUFC) in the 2018 State Freight Plan

None of these corridors are designated PHFS corridors, however; segments of these corridors are CRFC and other highways. As AV truck movements extend beyond just long-haul routes and use cases for the middle-mile and first / last-mile continue to mature, identifying a few additional enabling corridors to analyze complexity for automated movements, specifically connecting to concentrations of advanced manufacturing and logistics activity, was desired.

Figure 5: Truck Volume on U.S. Routes

After identifying where the growth in advanced manufacturing and logistics is occurring by county, the following 5 steps were taken to identify the specific corridors for analysis using the AV-Readi tool. Below are the steps and associated examples using actual analysis to highlight the methodology and reasoning for corridor identification:

Step 1: Identifying the U.S. Routes

The first step was to identify other National Highway System routes, particularly Critical Rural Freight Corridors (CRFC), and non-Primary Highway Freight System (PHFS) corridors, as PHFS corridors had been considered for analysis. The routes identified in this process were:

- South Bend, connecting to U.S. 33 heading SE, transferring onto U.S. 6 heading E a few miles, the re-connecting to U.S. 33 heading SE to Fort Wayne.
- Fort Wayne, connecting to U.S. 30 heading west, then to U.S. 31 heading north to South Bend. U.S. 30 was found to facilitate heavy traffic between Gary/Chicago (Northwest Indiana, Northeast Illinois) and Fort Wayne.

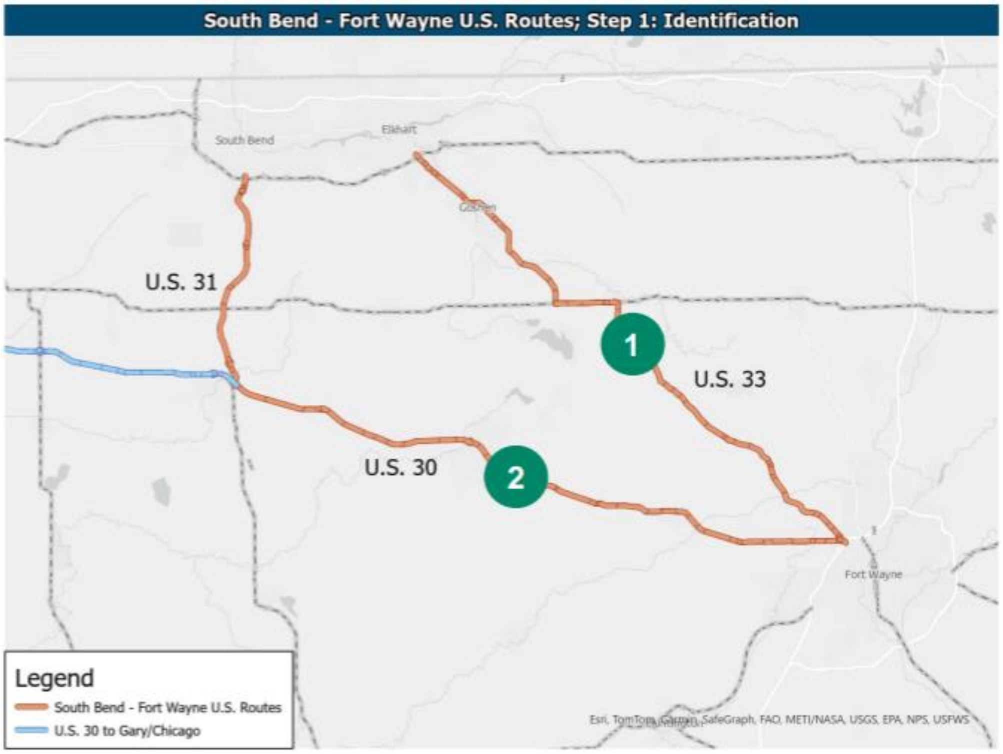

Figure 6: Identifying the U.S. Routes

Step 2: Identifying Automotive Facilities

To help identify automotive facilities, employer and real estate data were plotted geospatially to gain an understanding of the relationship between industrial facilities that act as starting points and destinations for trucks moving between South Bend and Fort Wayne. Conexus database data and CoStar tenant data were used to identify key facility locations, and locations of facilities whose employers and tenants are characterized as automotive parts or assembly were also identified. It was eventually found that there is a clear concentration of auto assembly and parts in both South Bend (A) and Fort Wayne (B). As seen in Figure 7 below:

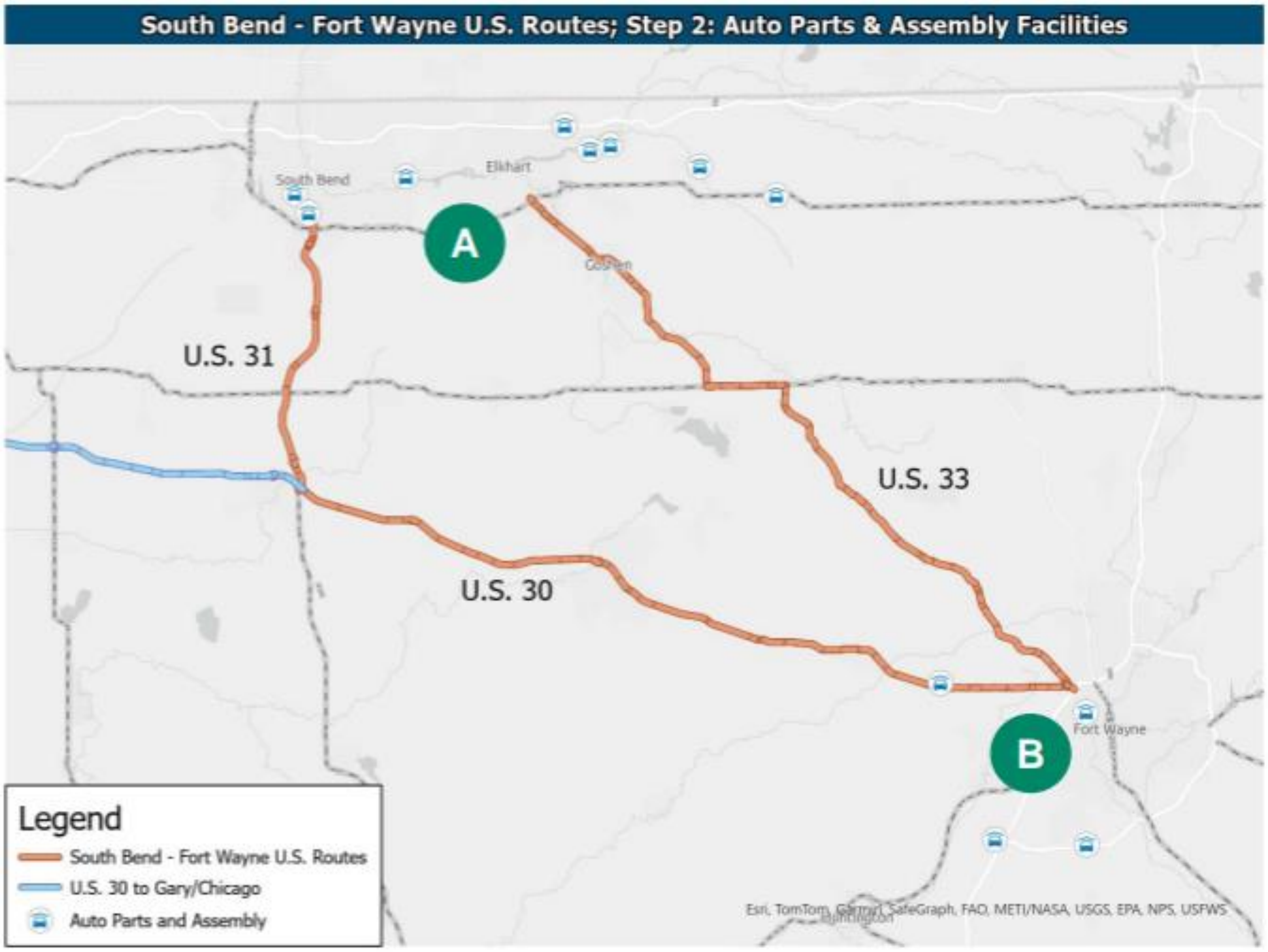

Figure 7: Auto Parts & Assembly Facilities (Step 2)

Step 3: Identifying Automotive Activity

County-level GDP estimates provided an additional source of understanding of these cities as hubs for automotive activity. An overlay of counties shaded by the percent of their GDP that consists of automative parts/assembly was added. Counties which contained higher shares of auto parts/assembly activity are shaded darker. The counties in and around these two cities are significant hubs for automotive parts/assembly activity. Along with U.S. 33, the counties that connect South Bend southeast to Fort Wayne form a chain of automotive activity centers (Figure 8).

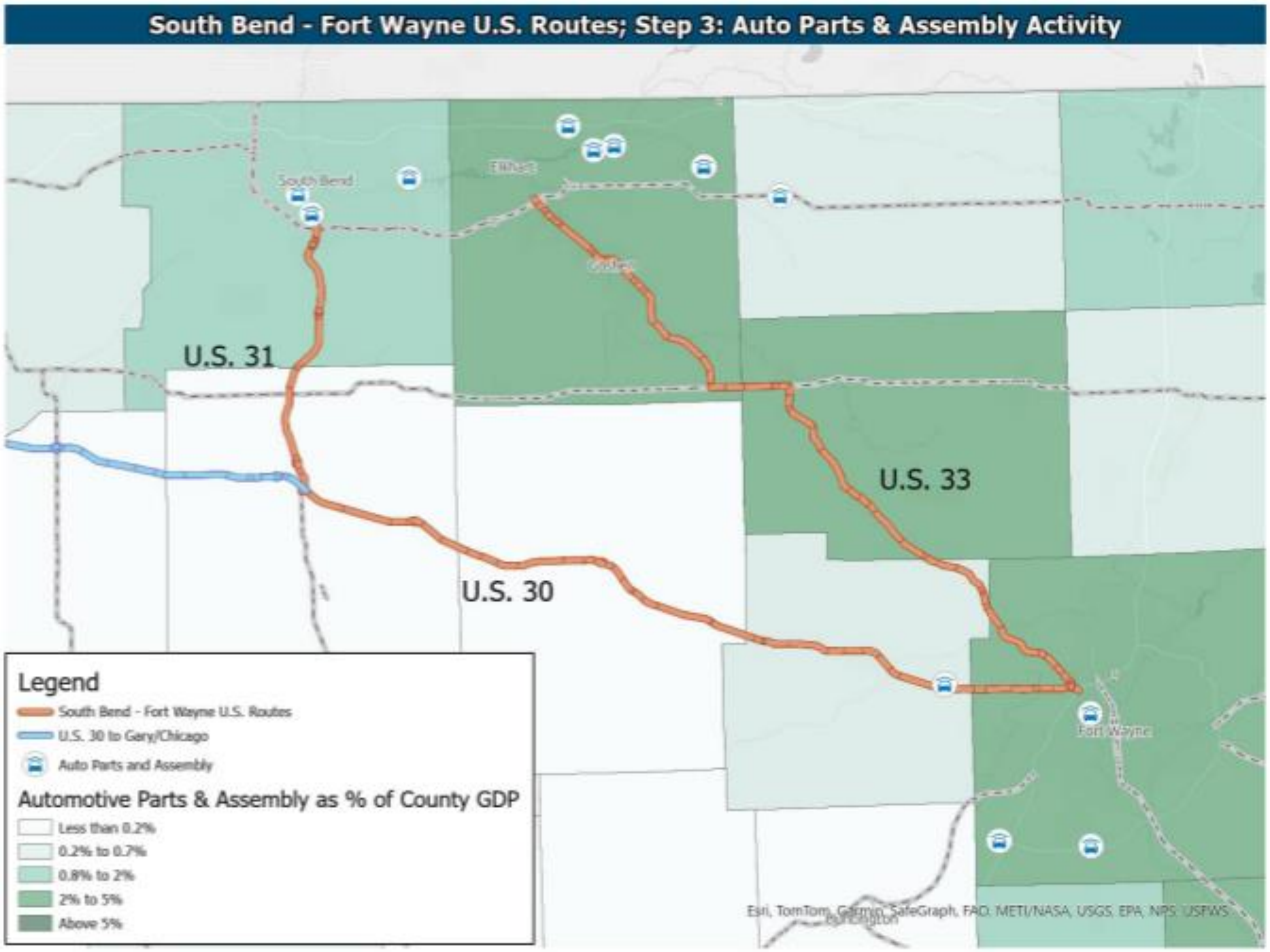

Figure 8: Automotive Activity (Step 3)

Step 4: Analyzing Truck Volumes

The last step was to validate both the presence and volume of trucking activity on these other U.S. Routes and determine whether the corridors identified represent a significant portion of total truck traffic. This helped with prioritization and selection across corridors. The map below quantifies and displays the volume of truck traffic present on these potential corridors using INDOT Average Annual Daily Traffic (AADT) data. The data for these corridors indicated, when compared to all U.S. Routes in Indiana, that they fell into the top 25% by total truck volume and validated their appropriateness to include from a freight movement perspective.

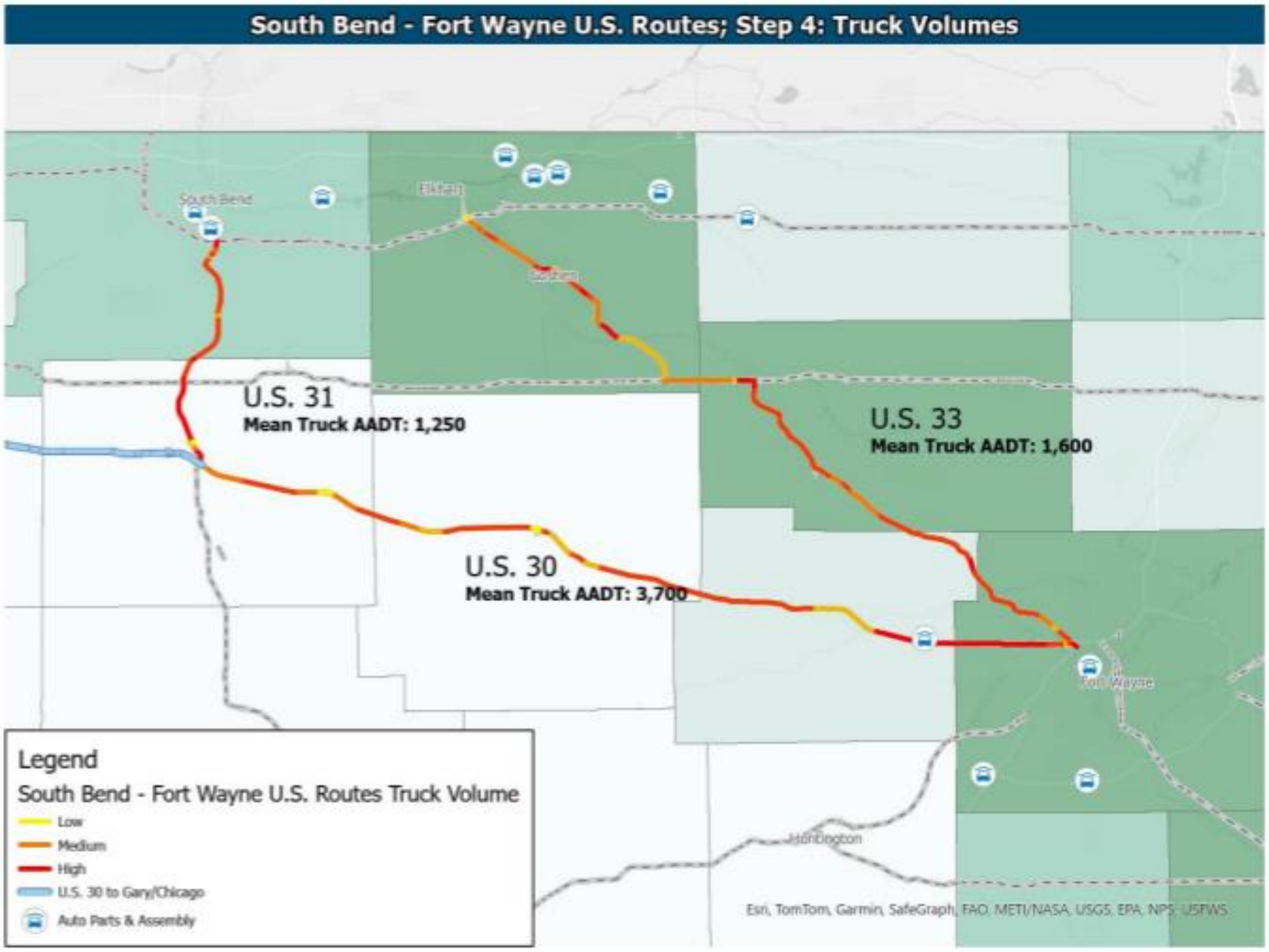

Figure 9: Truck Volumes (Step 4)

Step 5: Selecting Corridors for Analysis

Finally, the routes verified and selected from economics data were:

- South Bend, connecting to U.S. 33 heading SE, transferring onto U.S. 6 heading E a few miles, then re-connecting to U.S. 33 heading SE to Fort Wayne
- Fort Wayne, connecting to U.S. 30 heading W, then to U.S. 31 heading N to South Bend

Initial routes identified early in the project and analyzed using the AV- Readi™ tool were I-70 (border to border), I-65 (border to border), I-69 (border to border), as well as well as U.S. Routes 41 and 30. Additional economic analysis produced almost twenty more potential routes, of which four were selected. The final routes selected for analysis are shown in Table 1, where Figure 10 illustrates the distances analyzed by direction.

Table 1: Route Names and Lengths Assessed using AV-Readi™

Route Name	Total Route Length (Miles)
I-65	520
I-69	680
I-70	310
I-80	300
US 30	250
US 31	270
US 33	200
US 41	210
US 52	360

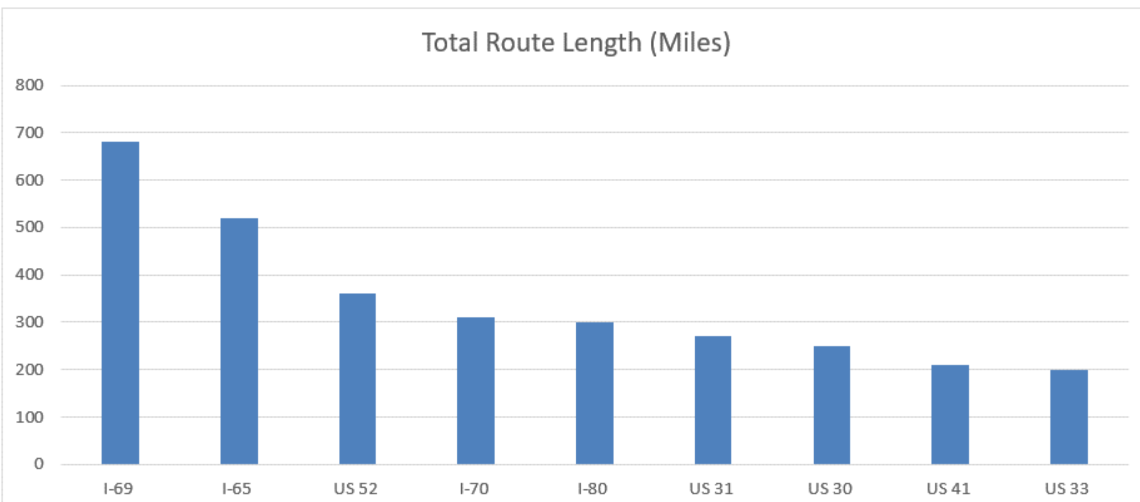

Figure 10: Routes Assessed Sorted by Distance

Stakeholder Engagement

As part of the effort to understand the perceptions of, practical considerations, the specific technical and operational aspects of AV trucking and how they relate to Automated Vehicle (AV) Freight Readiness, a set of stakeholders were identified and engaged after the market scan and during economic and corridor assessment phases. These stakeholders consisted of:

- **Industry Stakeholders**: Larger industrials with a high volume of in-state freight on specific routes, engaged to weigh in on adoption/deployment considerations as well as last-mile opportunities
- **Technical Advisors**: Subject matter specialists engaged to provide insights into the technologies associated with AV trucking and supporting equipment, as well as specific considerations for Indiana adoption

A series of eight stakeholder engagement sessions were held, each of approximately an hour in duration, to collect feedback on a series of questions, tailored to the participant(s) and their position within the AV Trucking and logistics ecosystem, from both group work sessions and individual discussions.

Key outcomes from the discussions held were segmented into six groups, covering Public and User Perception, Infrastructure, Regulatory and Liability, Operations, Market and Financial, and Workforce and Enablers:

Public and User Perception

- Many stakeholders are highly interested in the technology, but not willing to pay more and introduce risk as a "first-mover"
- Current AV Freight technology is developing rapidly and appears to be able to be employed in a useful way that can make a significant difference in the industry
- Some trucking industry stakeholders expressed the notion that AV Freight may be "the right technology for our time" and will be greatly beneficial to the broader logistics industry

- Trucks are not America's favorite vehicle out on the roadway already- they are “big, scary, unpredictable.” They're all those things that that the general public perceive, but seldom remember that everything they have comes out of a truck. Public perception will be one of the biggest challenges for AV Freight movement
- Testing for autonomous Class 8 vehicles don’t appear to have had any major incidents, however; many lump AV freight vehicles in with all the other passenger vehicles and robotaxis- which has a negative impact to perception given publicly visible safety issues with those other modes
- Automation is a “known entity” within the Advanced Manufacturing and Logistics (AML) sector, so many of the lessons learned and the benefits gained from higher levels of automation over the last few decades reduce the barrier of entry for many organizations in this space
- Stakeholders broadly expressed an interest in working together with Infrastructure Owner Operators and AV Freight technology providers to bring the technology and trucks closer to the public and elected officials in “up close” engagement sessions
- Reduction of diesel emissions associated with the movement of goods are driving electrification opportunities that also may spur automated vehicle deployments due to perceived efficiency gains from the technology, however; the scale of efficiency gain is seen as an unknown

Infrastructure

- Many stakeholders held the view that AV Freight technology requires infrastructure quality and investments greater than what required for manually driven vehicles, and were concerned about the costs associated with infrastructure improvements
- Participation in, and encouragement of dialogue with the AV freight industry and infrastructure owner operators, including IOOs that manage signalized intersections, will help advance application of the technology

- Investment in shared enablers (work zone data sharing, communications, infrastructure quality, launch-land yards) seen as a public and public-private opportunity and responsibility
- Micro-weather capabilities and communications may be necessary for AV Freight technology deployments in such areas as Indiana with all four seasons
- “Hand off points” for transition from manually operated to automated trucking, facilitated by shared “launch and land zones” may be needed to establish AV Freight within the marketplace
- Standardized “launch-land” zones, perhaps at truck stops or on truck parking locations, would likely facilitate the deployment of AV Freight by providing efficiency and defined locations for manual-automated load handoffs along freight corridors
- It was generally unclear whether the impact to truck parking would be an increased need or a lessened need, something stakeholders voiced a need to study more
- Segmented roadways, with managed “truck” or “automated freight” lanes, may be a solution that helps advance AV Freight deployment, addressing some public fears and perception issues and real safety considerations present in more complex shared environments

Regulatory and Liability

- The regulatory environment around AV Freight technology and application is seen as evolving and patchwork, which poses significant challenges as freight is often across state borders
- Questions exist around liability for incidents, how cargo handling, loading and ownership are impacted, cyber-security requirements
- Uncertainty around liability and regulatory environment make insuring AV Freight difficult or unavailable
- Trucking is the biggest customer of the rail system- some felt liability of freight movement under an AV Freight operator could be considered as a similar arrangement, whereby liability for “putting your container on a train”

- Many stakeholders expressed a need for greater Federal-level direction on AV Freight technology, providing regulatory guidance and structure that sets a bar for safety and requirements and allowing for market introduction and competition for those that are able to operate within those parameters

Operations

- Many stakeholders shared that they were contracting their logistics services, including many of the largest players, with third-party logistics providers (3PLs), therefore; their engagement with AV Freight technology would likely come through those providers and not directly
- The trucking industry may be able to handle a lot more freight, higher asset utilization, and greater service levels from AV Freight movement, given utilization during overnight hours, less constraints from hours of service (HOS) requirements, through-driving
- There is a perception that service levels may be positively impacted, by consistency and integration of AV Freight with Transportation Management Systems (TMS) for customers
- Both trucking operators and those hiring trucking services expressed concerns about the risks of introducing the technology today into live operations, especially those related to the Just-in-Time (JIT) manufacturing environment
- Starting with smaller-scale deployments to enable learning and reduce risk to operations or investments was perceived to be a way to overcome this risk
- Process and technical maturity will be required to take full advantage of AV Freight movements within the logistics industry, and are a key enabler and should be studied further (perhaps as a role by Conexus)
- Many processes within trucking operations are rudimentary and manual, and may pose a barrier for wider AV Freight applications or benefits attainment
- Proving the technology is viable, what the risks are and the cost profile in real-world operations is a precondition for further application

- Service level ratings and load tender acceptance are key metrics to compare traditional manually operated trucking with AV Freight technology
- Deployment of AV Freight technology will likely impact trailer quantities, systems needed, and truck parking / hubs for higher asset utilization afforded by the technology and necessary for investment
- Higher asset utilization of automated tractors may drive the need for higher numbers of staged trailers and associated yard parking, but the level of impact is unknown
- Many stakeholders held the position that long-haul freight was the most promising application for AV Freight technology
- "First mile" and "Last mile" movements were identified by stakeholders as the more complex environments for AV Freight movement than the longer-haul segments
- Larger players saw less opportunity on inbound to manufacturing operations side than outbound trucking
- Inbound raw materials logistics would likely be a one pick, one drop operation, to be applicable for AV Freight usage in initial use
- Closed-loop moves, such as "milk-runs" between manufacturers and their middle-distance supply base was consistently brought up as a good use-case for AV Freight technology within the state of Indiana
- "Milk-run" type moves are attractive, yet concerns about risk and maturity limiting application to JIT Mfg.
- Box van-focused logistics operations in "closed-loop" configuration appear to be another high-interest use case, similar to the model currently being employed for grocery store chains and bakeries, supply inbound from distribution centers to retail outlets
- Platooning was brought up a number of times, as an application for AV Freight movement that helps to aid in cost reduction, operations efficiency, and sustainability benefits

- Sustainability benefits may be facilitated, even with existing diesel-powered vehicles, due to more consistent driving and slower speeds afforded by automated movement
- Just-in-Time advanced manufacturing facilities saw risk in introducing AV Freight technology for their inbound operations, and would likely prioritize outbound or to-warehouse / sequencing facility moves within their upstream supply chains
- In-yard operations complexity and associated risks between manual and automated operations appear to be a challenge that will need to be resolved in conjunction with over-the-road operations readiness
- Coupling AV Freight movement with in-yard automated docking or undocking was perceived as a significant opportunity for manufacturers
- Many logistics operations have privately-owned relay points that incur additional costs for real estate, operators and technicians, which may be relieved or eliminated with the use of AV Freight technology
- Agricultural uses of the technology appeared to be favorable, especially given for many commodities there is high-volume application with a low-risk freight profile
- “Smart trailer” technologies may be needed to allow for readiness checks and status during operations, however; any changes to trailers mean reducing standardization and interchangeability for trailer usage
- Indiana climatologically was seen as a good next test for AV Freight technology application given the challenges present related to four season operations

Market and Financial

- AV freight deployment is largely driven by supply and demand but requires a supportive policy and regulatory environment

- None of the stakeholders engaged were experiencing demand today for AV Freight technology applications, but most were either aware of or actively learning about the technology
- Perception of the technology from the general public is one of the biggest obstacles for AV freight, however; uncertainty around the enablers of the technology and then the cost are the biggest from an actual application perspective
- Concerns about cost of new tractors being two to three times that of a new non-automated tractor are a big factor for adoption, especially for private owner-operators
- Given concerns around liability, many expressed the expectation that costs may increase for insurance coverage for AV Freight operations, until the regulatory and safety benefits of automated operations are established
- A model whereby AV Trucking companies provide an “automated driver” and equipment more likely than an ownership-focused model
- Both trucking operators and users of trucking services are focused on cost reduction, and AV Freight movement will have to demonstrate a total cost reduction or parity including other benefits to be considered for large scale deployment
- Increased asset utilization was perceived to be a significant opportunity for AV Freight usage, but will likely be necessary and work to offset increased costs due to higher equipment costs
- Other ancillary costs for the organization employing AV Freight technology (e.g., process redesign costs, technology investments, yard security, hiring new skills) are unknown and needed as they are a part of the total cost equation and may serve as a barrier for deployment
- Frequent swings within the trucking logistics market make deploying AV Freight technology difficult, especially when down markets occur, as costs plummet and overcapacity lessen or negate the service level attractiveness and cost benefit of the technology

Workforce and Enablers

- A prominent use case for AV Freight technology is long-haul, which has a significant potential to address unfilled gaps in the trucking workforce that are often the hardest to fill
- Given the types of trucking services addressable and not addressable by AV Freight technologies, specialization may drive higher-paying wages in the industry (e.g., HAZMAT, overweight and over dimension, “white-glove” services)
- Additional workforce needs (new jobs and new roles) and upskilling will be necessary to address changes that come about due to automated trucking, with the perception that these jobs may fit better with today’s current workforce capabilities and expectations than the historical trucking workforce
- AV Freight movement will require new trades and an associated skilled workforce in areas that traditionally are not employed in most trucking operations
- New maintenance techs, data scientists, “sensor cleaners,” load inspectors are some of the new roles identified as needed for AV Freight applications

AV-Readi™ Analysis of Selected Corridors

The readiness of a roadway to support automated vehicle (AV) freight deployment is multifaceted and nuanced and has both infrastructure and technology capability maturity components. The technologies needed for AV operation in environments shared with humans are maturing; however, barriers remain such as certain types of weather that affect the effectiveness of sensors and the ability of the vehicle to maintain traction, the unpredictability of human road user behavior, and temporary changes in the environment, such as work zones, all of which can cause additional uncertainty and risk in the operation of an AV. Assessing deployment readiness requires the AV freight vehicle's perspective of the roadway environment to determine the type and severity of challenges along the intended route or corridor. The accumulation of challenges over the length of the route is also a factor as this compounds overall risk for completing the route safely.

The corridors assessed in this feasibility study include Interstate highways and U.S. Routes. Each of these corridors poses specific challenges for an AV freight vehicle to detect its environment and react appropriately for safe navigation. Some challenges may have an infrastructure solution, such as converting a permissive left turn into a protected left turn, but other challenges require either a behavioral change from the vehicle, like switching lanes in a weaving section, or an increase in the capability maturity of the technology.

AV-Readi™ Process

The AV-Readi™ automated driving system (ADS) complexity analysis discretizes a proposed route of arbitrary length into separate segments, which are defined by changes in the environment that are likely to require an ADS to evaluate a change in its behavior. The environment in this context includes the built environment, such as roadway geometry, speeds, intersections, and enabling infrastructure, as well as the likely behavior of other road users. These characteristics are used to assign a numerical score to each segment representing the level of difficulty an ADS is likely to experience at different points along the route. The segment scores are captured in a GIS database as one attribute for the segment, which enables visualization using GIS tools by associating the index values with colors, referred to as the route's "complexity map". The entire route is then processed through a separate algorithm to assign an overall index score, which can be used as one characteristic to compare multiple routes. The AV-Readi™ process is summarized and illustrated in Figure 10.

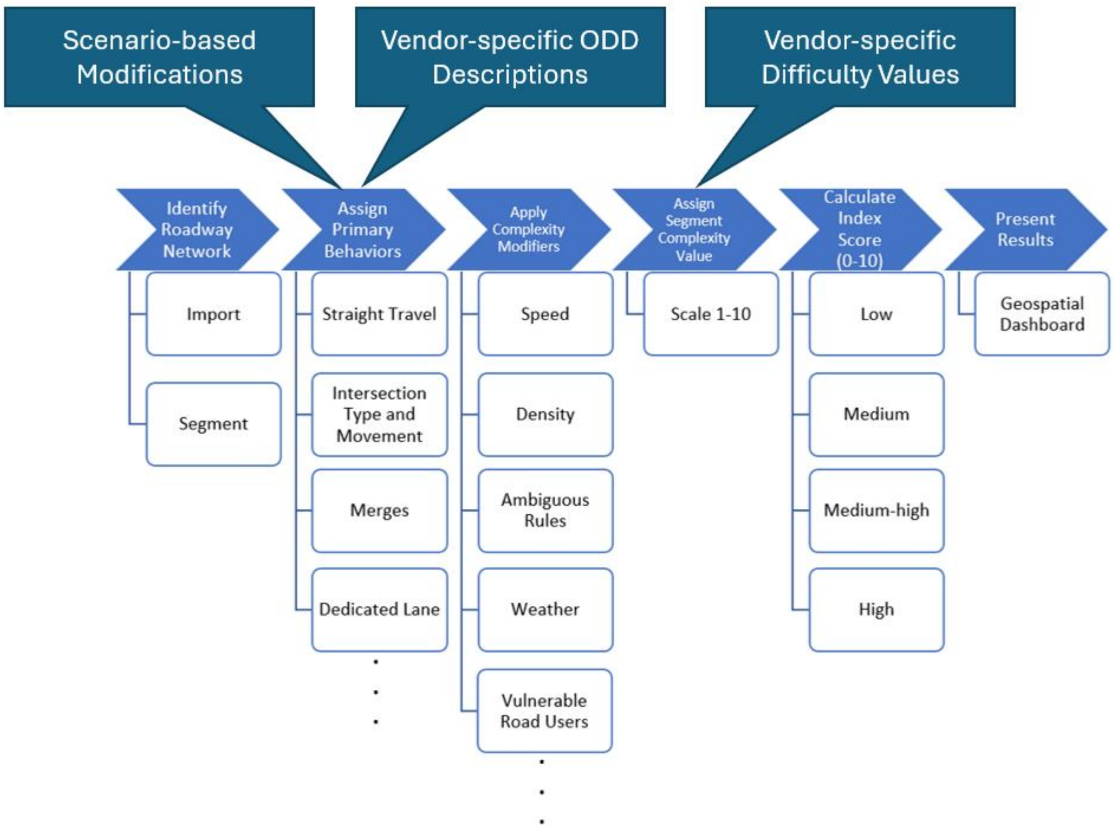

Figure 10: AV-Readi™ Process

Once roadways are incorporated into the GIS environment, they are segmented according to changes in the environment that may cause the vehicle to change its behavior. These behaviors then have a numerical score associated with them, with higher numbers representing a more difficult (higher risk) environment to navigate. For example, an entrance or exit ramp on a highway is identified as a "high-speed merge", and this ramp along with a portion of the highway is captured by the segment, whereas the interstate highway between exits/entrances is a single segment identified as "Default Highway

Protected". These two segment types have a specific score associated with them, which is used for complexity map visualizations, as well as route index calculations.

The primary roadway environments in this study can be summarized as an environment with the following characteristics:

- Access-protected interstate highways
- US highways (not access-protected)
- Local roads

These elements are assigned a complexity value in the AV-Readi™ analysis from 1 (very low complexity) to 10 (very high complexity), and these values are represented visually in the complexity maps as colors from green to yellow to orange to red to purple. A quality control (QC) process is then implemented where the route is examined to check for segments that may have been mistyped.

The AV-Readi™ results Include the following items:

- Complexity map
- Complexity pie-chart distributions
- Complexity index score gauge
- Analysis and discussion of findings

The AV-Readi™ process is flexible and can accommodate both scenario-based modifications as well as AV vendor-specific operational design domain (ODD) descriptions at the route segment level. The complexity values assigned to ODD elements can also be modified to reflect local customs and norms or the specific values as defined by an AV vendor.

The AV-Readi™ analysis in the state of Indiana involved the routes illustrated in Figure 11 including:

- Four interstate highways from border to border:
    - I-70 illustrated in Figure 13
    - I-80 illustrated in Figure 14
    - I-65 illustrated in Figure 15

    - I-69 illustrated in Figure 16
- Three U.S. Routes:
    - U.S. 30 illustrated in Figure 17
    - U.S. 31 illustrated in Figure 18
    - U.S. 33 illustrated in Figure 19
    - U.S. 41 illustrated in Figure 20
    - U.S. 52 illustrated in Figure 21

The AECOM team created an automated process for segmenting long stretches of highways, taking into consideration the change in behavior associated with the merging and exiting maneuvers. The interstate highways between exits/entrances are assigned a default behavior type, which is different from the default roadway type used for US highways. All figures present the AV-Readi™ complexity map including the complexity distribution pie chart as well as the complexity score gauge.

Figure 11 shows all the routes together on a single map, without any pie charts or score gauges. This illustrates the breadth of scope the team analyzed, which totals more than 3,000 miles. This is the single largest AV-Readi™ study to date, suggesting Indiana now has the most extensive network of freight corridors assessed for the readiness to deploy automated freight vehicles. At the scale of the entire state, the details of any given roadway are not easy to identify; however, some of the details found in our analysis will be presented and discussed in the Interpretation of Results section.

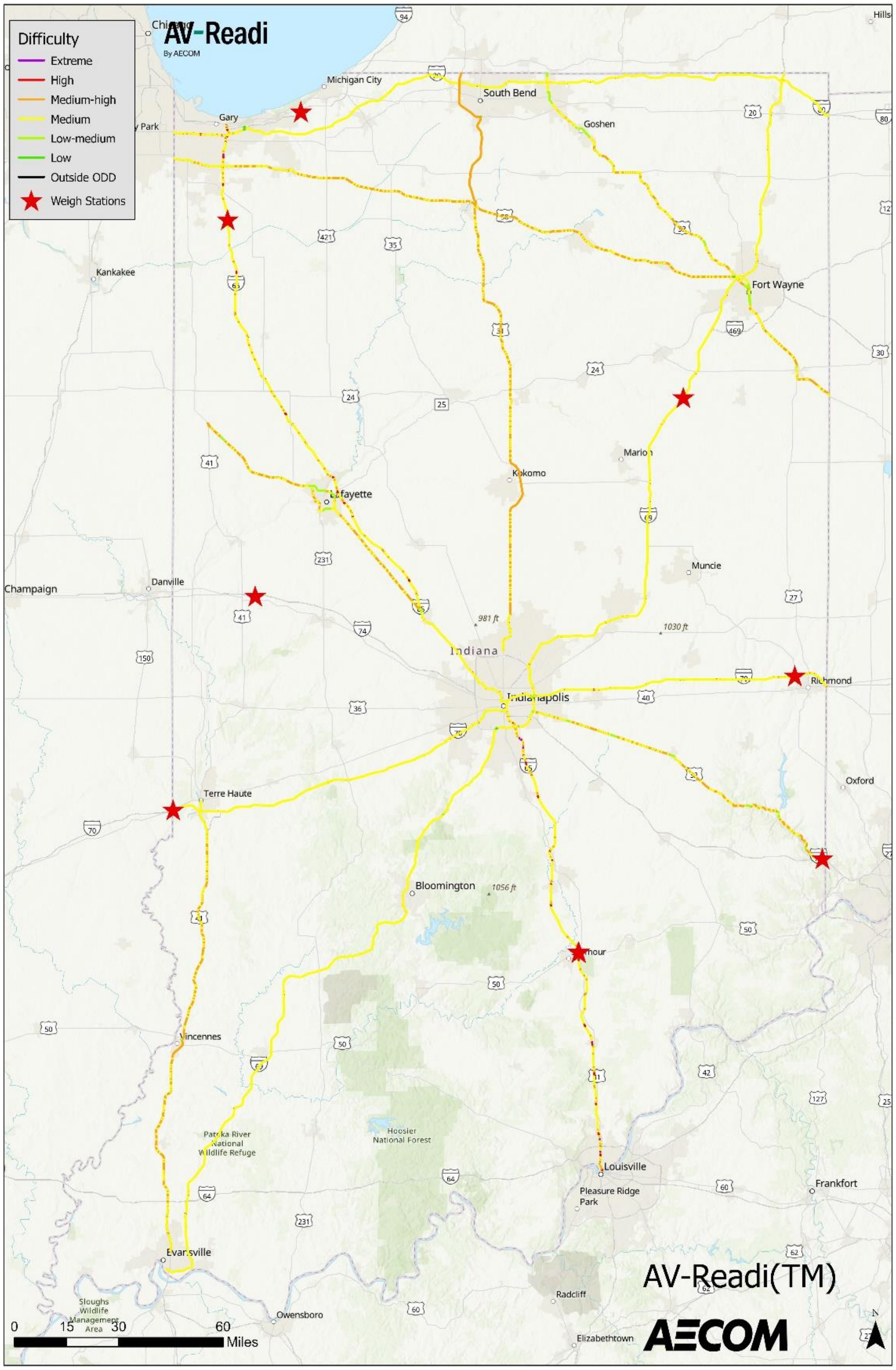

Figure 11: Assessed Interstate Highways and U.S. Routes, with Weigh Stations

In addition to these full corridors, the team examined a handful of interchanges, such as the I-69 and US30 interchange shown below. This illustrates the variety of operating environments an AV can experience over a relatively short distance. This interchange shows four potential paths an AV may traverse, each of which has its unique challenges and sequence of segment complexity.

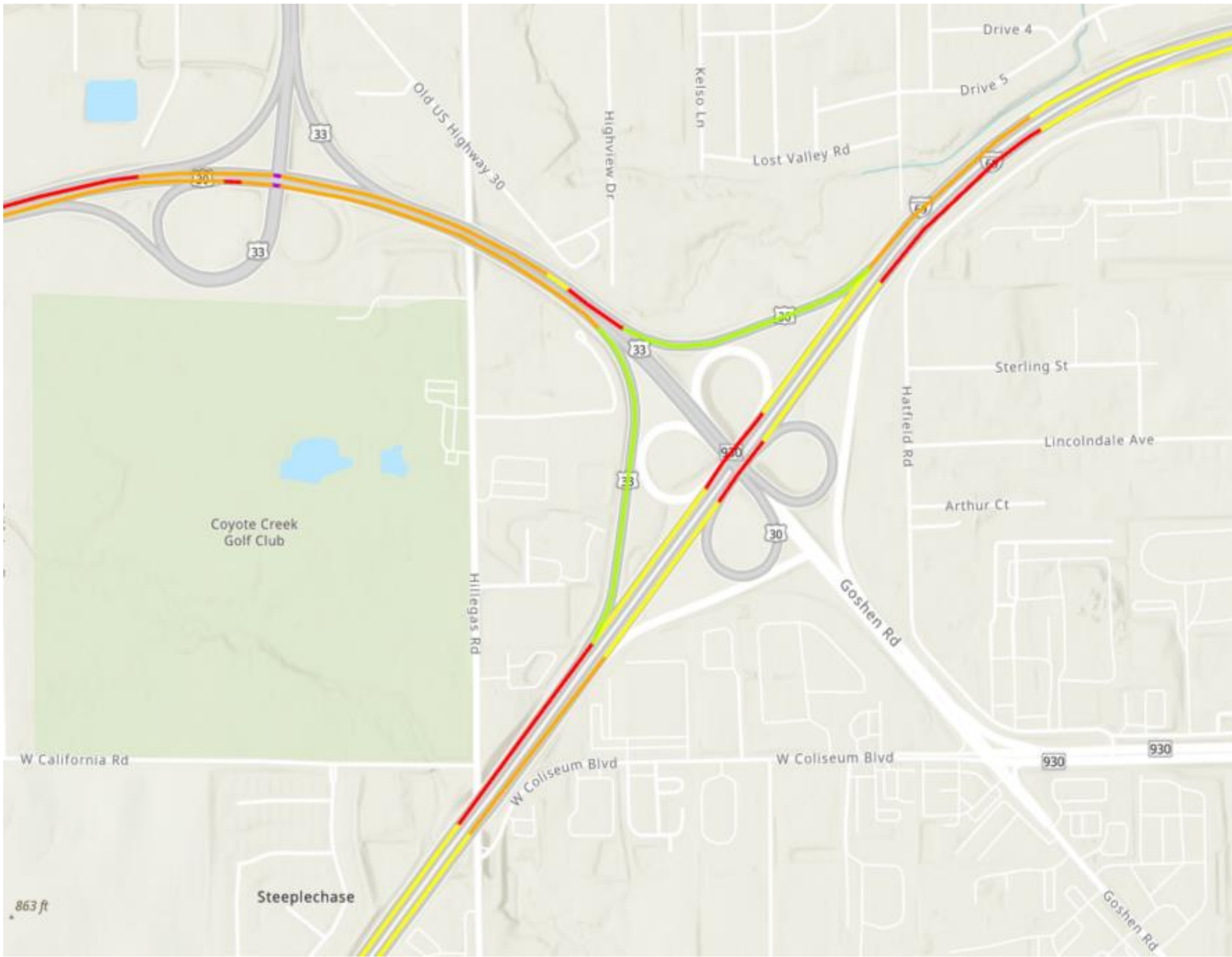

Figure 12: I-69 / US30 Interchange Detail

Interstate Highways Complexity Map Results

The figures in this section show the AV-Readi™ results for I-70, I-80, I-69, and I-65, border-to-border in the state of Indiana. The segments of high complexity are colored in red and typically are due to merge points. Other challenges for AVs often encountered on highways are tunnels, or long stretches of road that are covered by an overpass, and construction zones. Although some long overpasses were identified during this analysis, construction zones were not included and could provide critical insight into the difficulty of operating on a given route. This may not affect a company's decision to deploy on that route but may cause them to consider alternate routes while the construction is underway. At the scale of these long corridors, there is not a significant difference in complexity score between the two directions, and so, only one direction is shown in the maps below, with the alternate direction provided in Appendix A: Additional Results. Differences in direction become more apparent when shorter routes are considered in greater detail (see Figure 27).

Segments of medium-high complexity are colored in orange and typically represent exit lanes, when not combined with an incoming merge (mixed merge). The most common segment complexity on highways is medium, colored yellow, which is due to the high-speed nature of the operational environment. Similar speeds on US Highways are orange (medium-high) because the roadway is not access-protected like an interstate highway. As mentioned, the team identified locations where long underpasses exist and assigned these segments an "extreme" complexity, colored in purple. This is due to the possibility of GPS signal degradation or loss in these environments. Many AV companies overly rely on GPS for their primary function of "localization"; however, some companies do also employ very robust "relative localization", which allows them to function normally without GPS, at least for some time.

AV-Readi™ considers a typical AV for the sake of this project; however, specific vendors could be assessed using this tool, and their individual route complexity results may differ. Other high-complexity locations identified include locations where both merging and existing traffic exist (mixed merge).

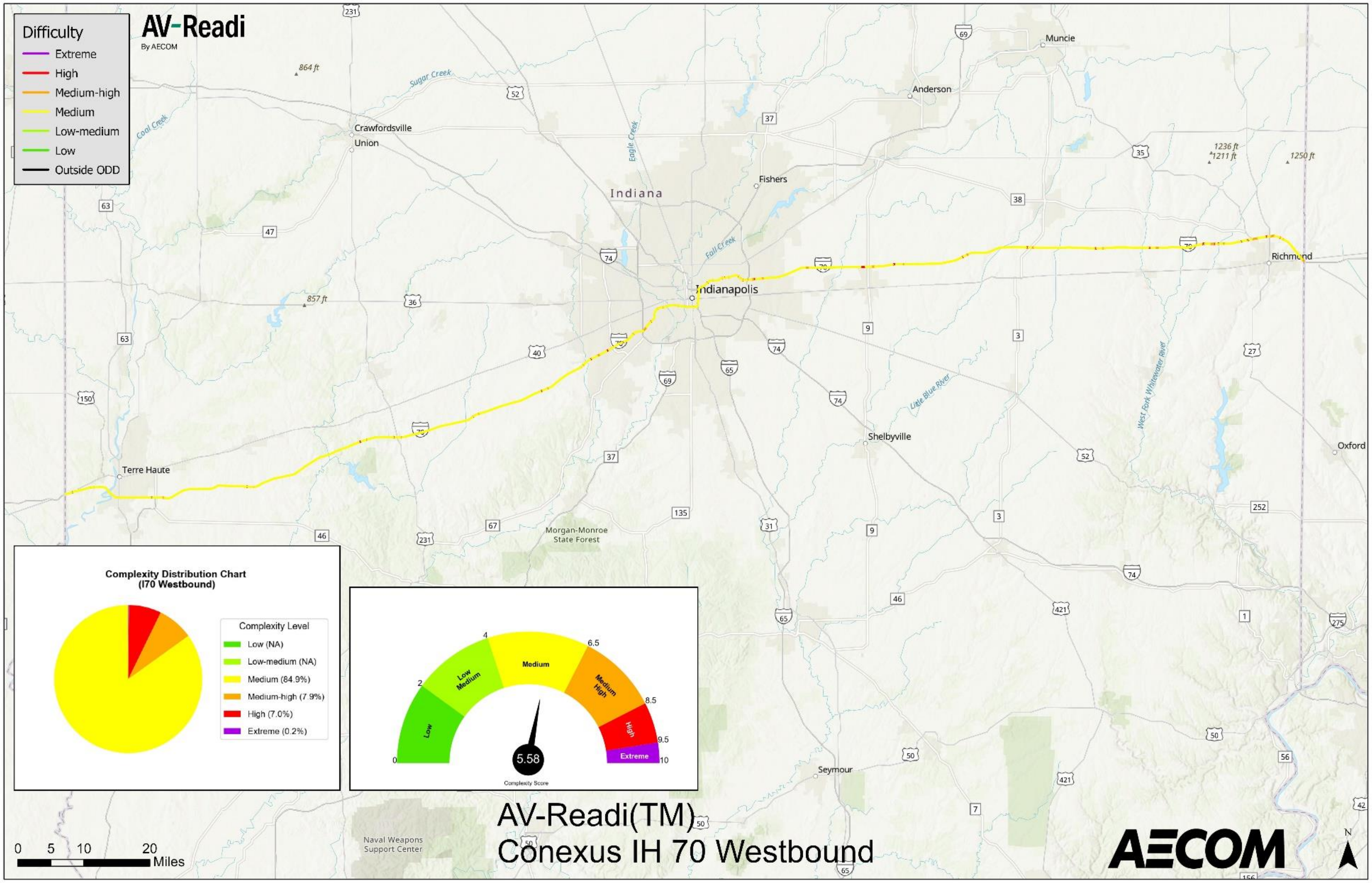

Figure 13: Westbound I-70 Complexity Map

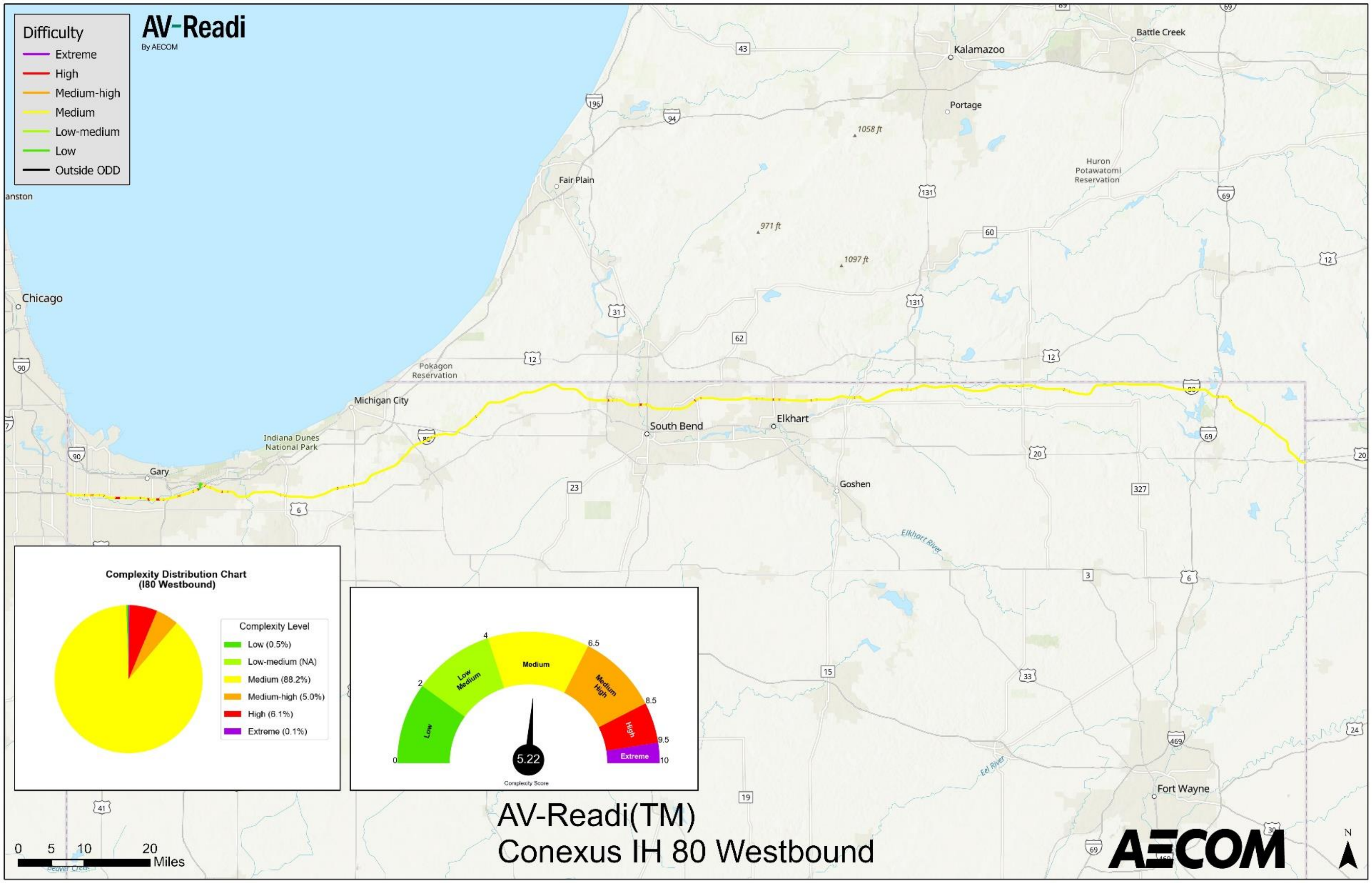

Figure 14: I-80 Westbound Complexity Map

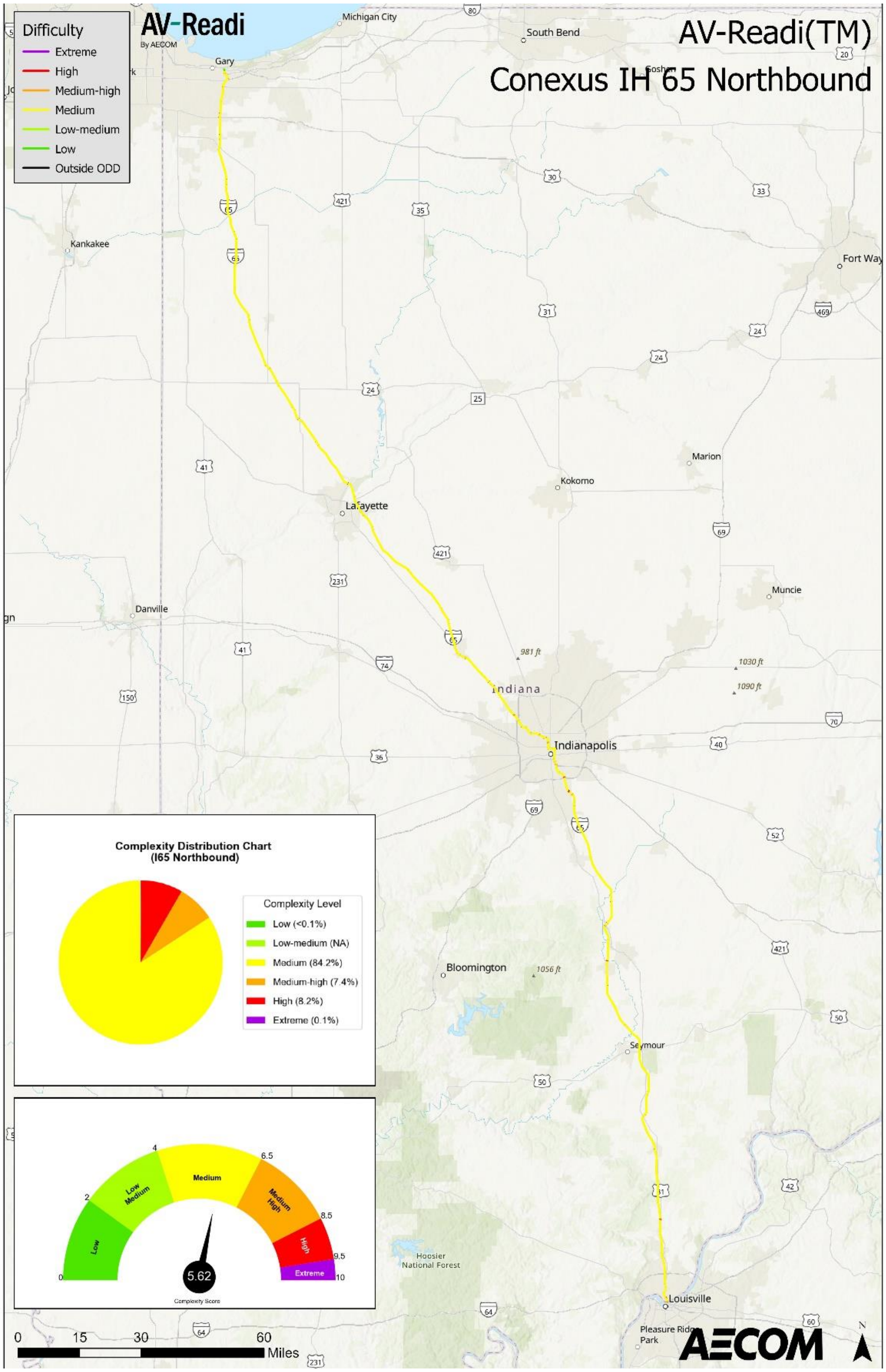

Figure 15: Northbound I-65 Complexity Map

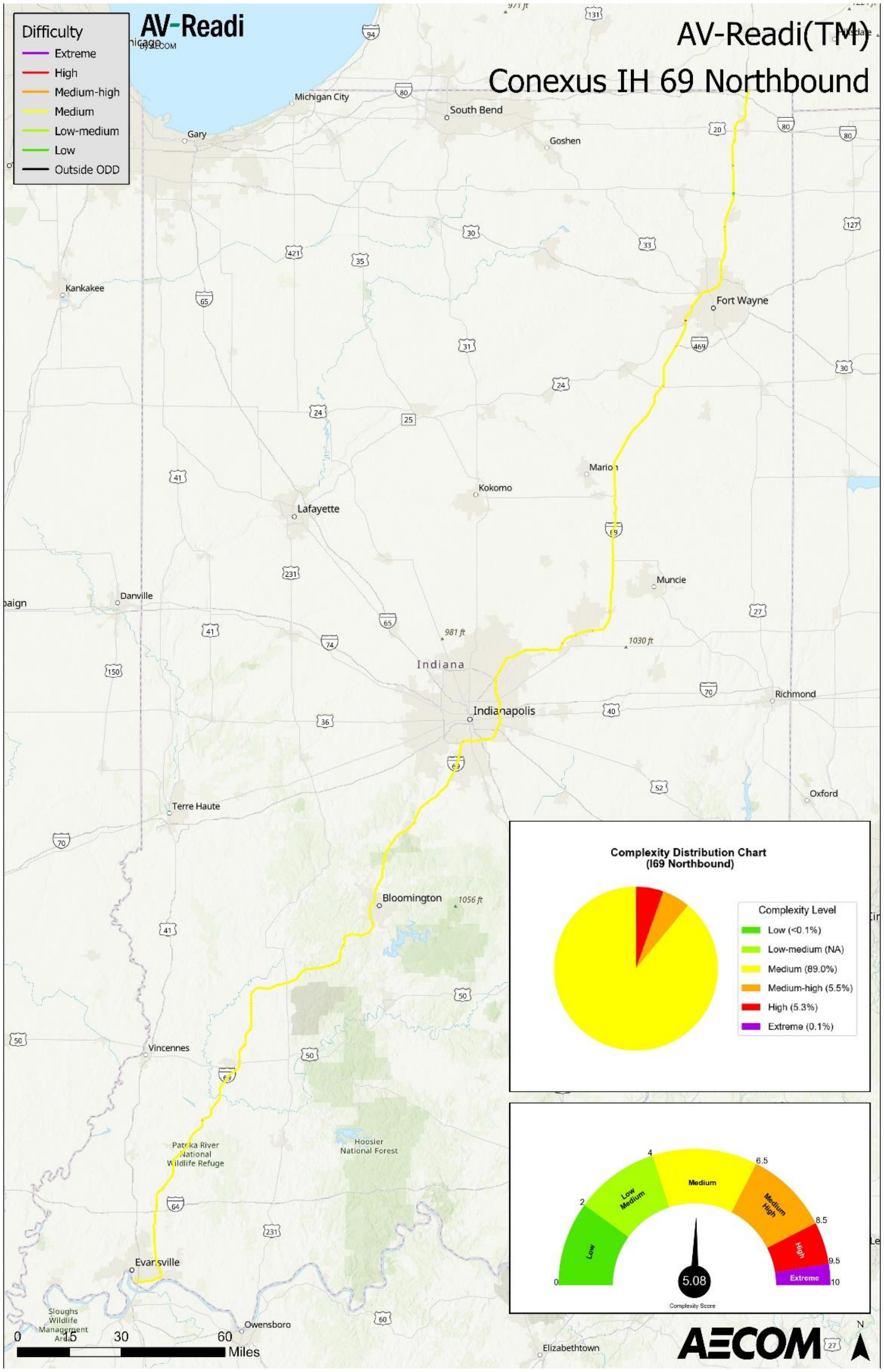

Figure 16: Northbound I-69 Complexity Map

In summary the interstate highways analyzed have a complexity score ranging from 4.82 to 5.66 implying an overall **Medium Readiness for AV deployment**, and we can see from this analysis how long stretches of roadways that are essentially similar environments will score similarly in AV-Readi™. The most challenging portions of these highways are in traversing major cities, like Indianapolis; however, those details are "washed out" at the scale of an entire state. AV freight vehicles traversing these roadways would need to operate alongside human drivers, and in city environments, there are more of those, as well as more conflict zones like merges. Other areas that may prove challenging are work zones, and weigh/inspection stations.

U.S. Routes Complexity Map Results

The figures in this section show the complexity maps for U.S. 30, U.S. 31, U.S. 33, U.S. 41, and U.S. 52 respectively. The primary segments of **high complexity** colored in red are:

- High-speed merges
- At-grade railroad crossings

The primary segments of **medium-high complexity** colored in orange are:

- High-speed exits
- Non-access-controlled segments of US highways that aren't associated with a specific behavior
- Complex cross street configurations or the presence of multiple possible conflicts

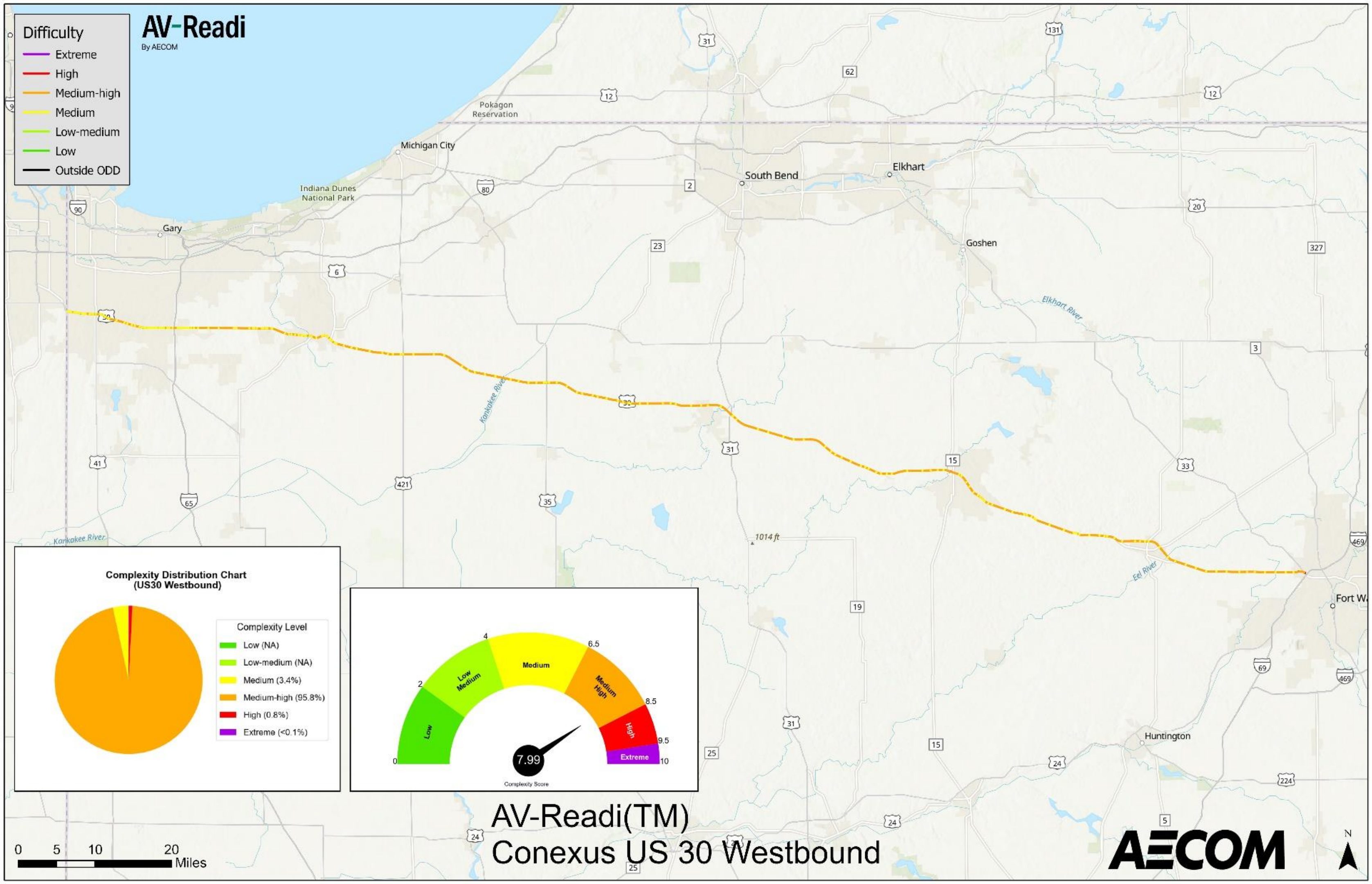

Figure 17: U.S. 30 Route Westbound Complexity Map

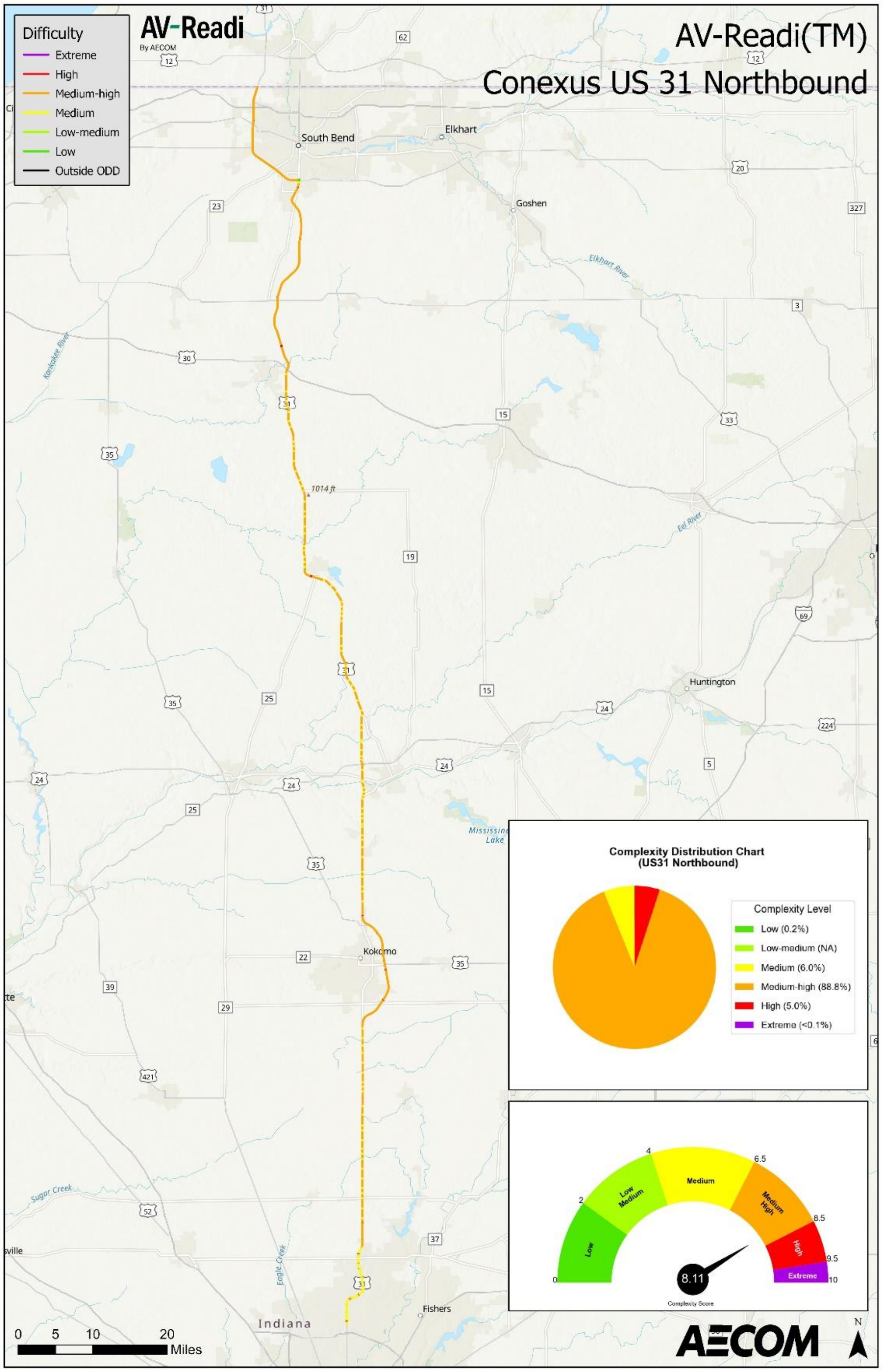

Figure 18: U.S. 31 Route Northbound Complexity Map

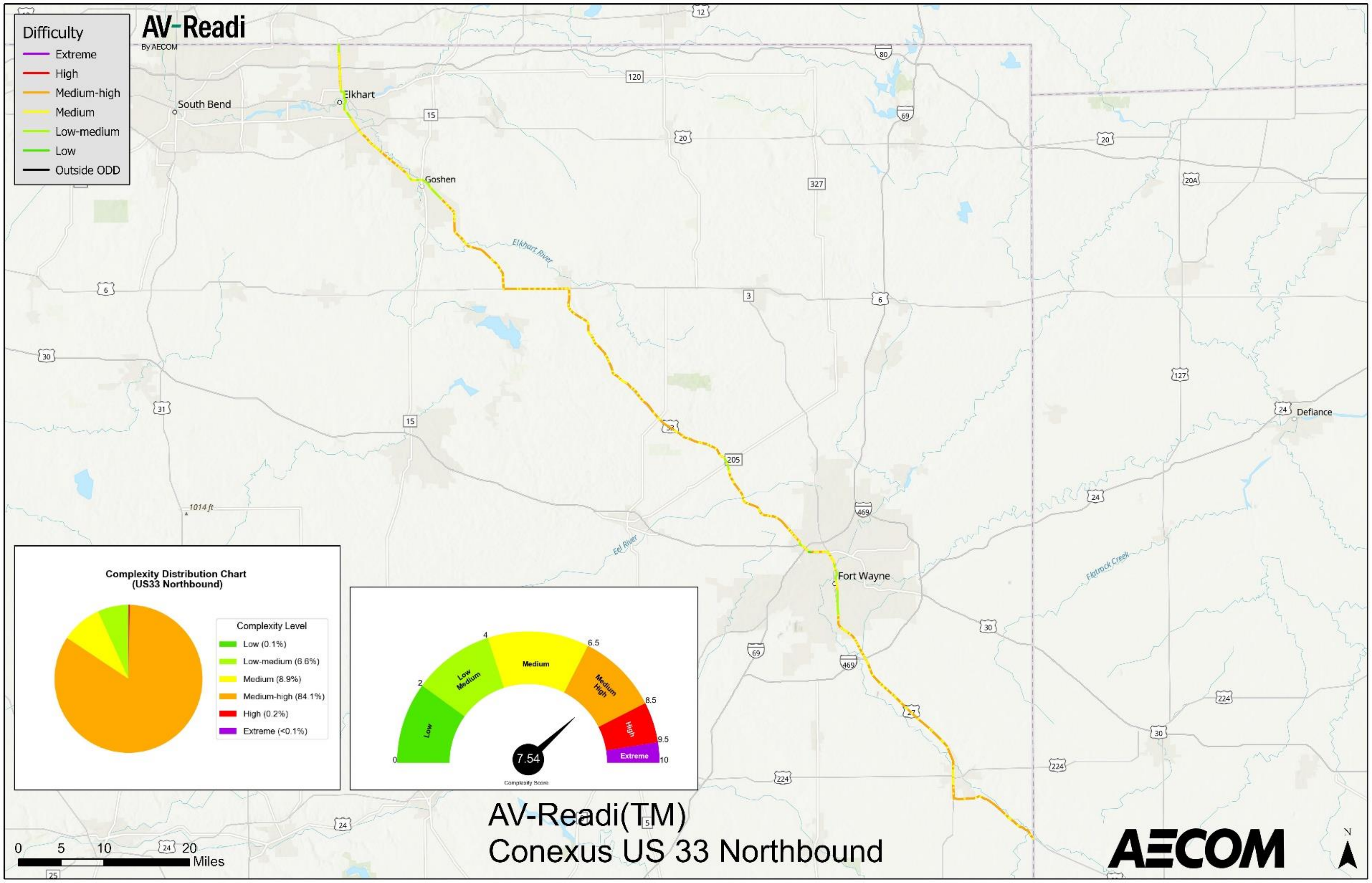

Figure 19: U.S. 33 Northbound Complexity Map

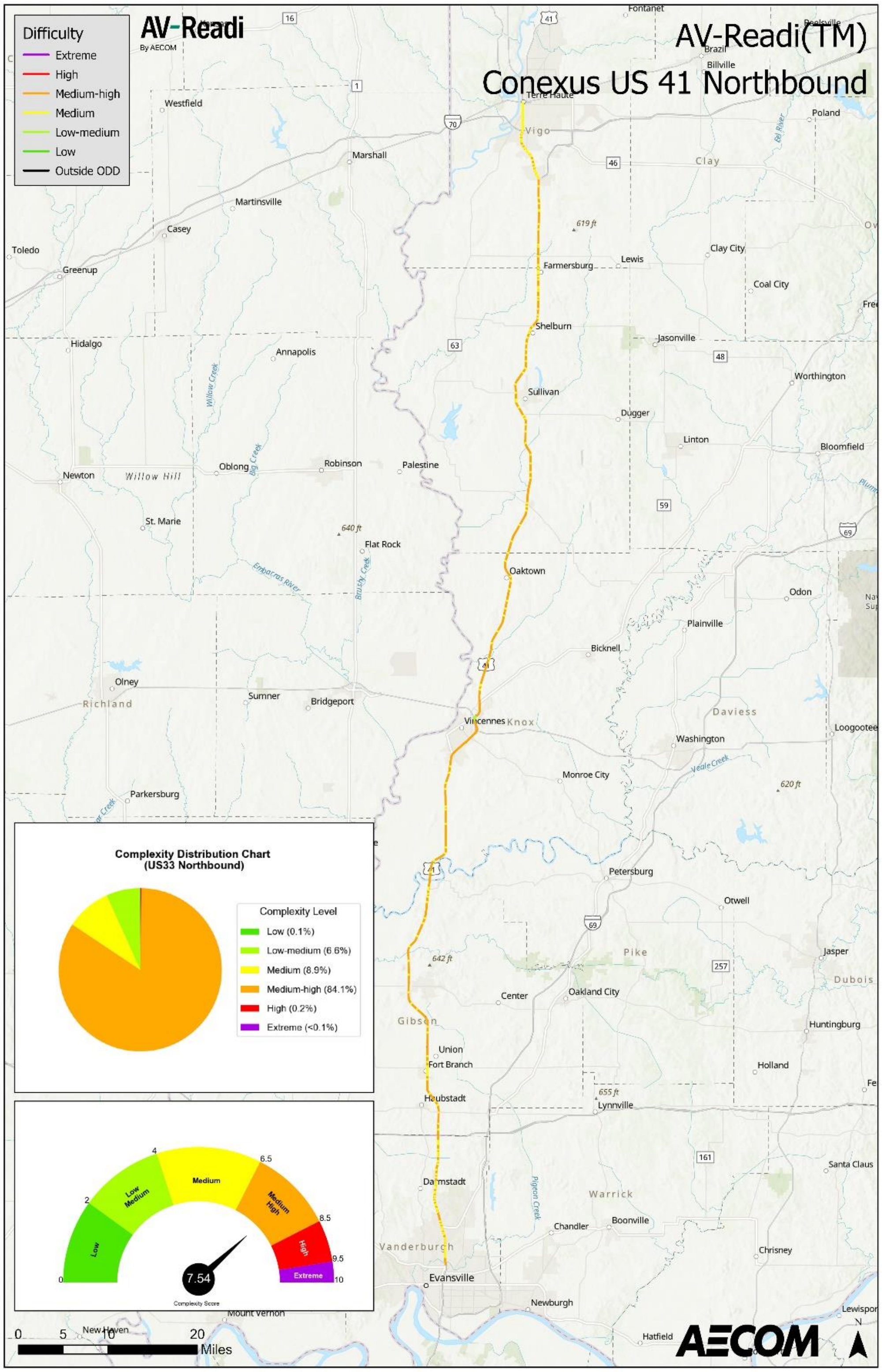

Figure 20: U.S. 41 Northbound Complexity Map

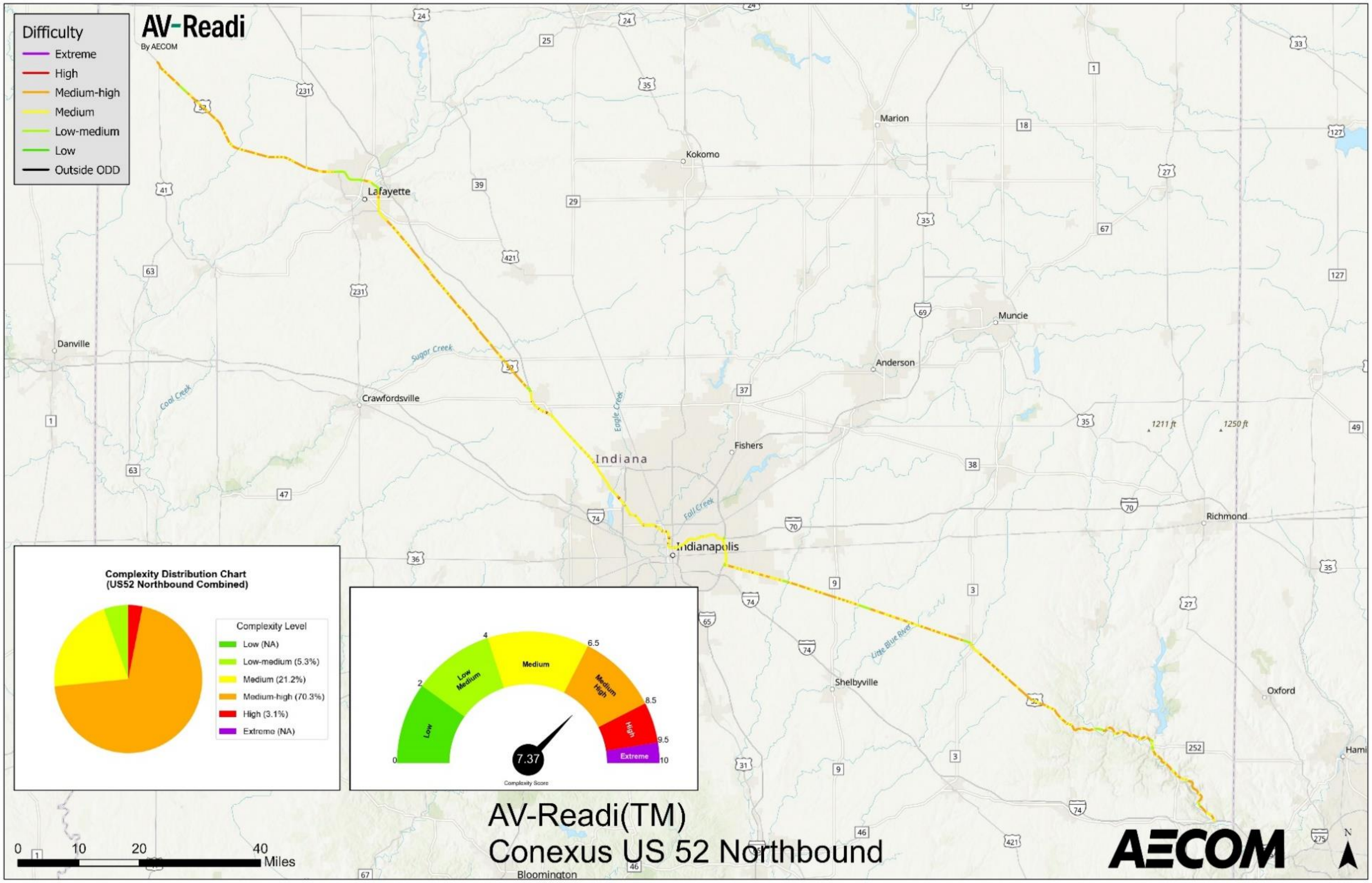

Figure 21: U.S. 52 Northbound Complexity Map

In summary the U.S. routes analyzed have a complexity score ranging from **7.37 to 8.13** implying an overall **Medium-Low Readiness for AV deployment**. Similar to the interstate highways, this assessment is a generalization of not only the environment but also the capabilities of an AV. US Highways are not access-protected, which means they are a constant source of potential conflict from humans and animals, thus the higher default complexity level. As the highway passes through smaller towns and cities, the operational environment changes, and usually includes a lower speed, but can also introduce a greater density of potential conflict zones. The slight differences in the complexity value based on direction, for both interstate and US highways, is due to the non-symmetry of the operating environments; however, this analysis was done at a course level of overall detail, which is reflected in the almost identical complexity values by direction. More detailed analyses, especially through towns and cities, would yield more significant differences, particularly if there are work zones on one side of the road and not the other. Work zones can be complicated environments for humans and AVs, alike, due to various factors such as additional traffic control devices (e.g., barrels, message signs, temporary speed limit signs), and temporary lane closures or lane shifting. The behavior of other human drivers in work zones also causes additional challenges for AVs because it can be erratic, sudden, and not expected.

Interpretation of Results

The results presented above have identified several specific locations where automated freight vehicles are likely to encounter challenges, which largely relate to the behavior of other road users, but can also be due to GPS outages, such as might occur while passing under long overpasses. The specific areas of concern for AVs on the roadways analyzed are described below:

1. **High-Speed Merges:**
   - These locations are colored in red on the complexity maps.
   - High speeds combine with the movement of other vehicles entering or exiting.
   - The behavior of human-driven vehicles at these locations can be unpredictable.
2. **At-Grade Railroad Crossings:**
   - Also colored in red, these crossings pose unique challenges.

- AVs must detect and respond appropriately to railroad crossings, considering laws, regulations, and safety protocols.

3. **High-Speed Exits:**
   - High-speed exits from highways, represented with an orange color.
   - AVs may need to slow or coordinate with other exiting vehicles.
   - The behavior of human-driven vehicles at these locations can be unpredictable.
4. **Non-Access-Controlled Highways:**
   - High-speed roads that are not controlled can cause significant challenges.
   - AVs may encounter vehicles entering or exiting at significantly lower speeds. Cross-traffic is also possible, as well as pedestrian and animal crossings.
5. **Complex Cross-street Configurations:**
   - Intersections with multiple approaches, complicated movement patterns, or ambiguous right-of-way (e.g., yields or unprotected left turns).
6. **Long Underpasses:**
   - Long underpasses affect sensor performance, including GPS signal accuracy and availability, and camera function due to extreme light level fluctuation.
   - AVs without robust sensor redundancy, such as strong relative localization and multi-modality sensor fusion, may fail at these locations.
7. **Merging and Existing Highway Traffic:**
   - Highway segments where both merging and existing traffic are using the same lane provide additional challenges for AVs, even if the AV is continuing straight.
   - Mixed exiting and entering traffic cause significant challenges due to unpredictable behavior by human-driven vehicles, often affecting multiple lanes.
8. **Combination of These Factors:**
   - Locations where 2 or more of the above factors are present will provide additional challenges for AVs.

Automated freight vehicles may face enhanced operational challenges in the environments described above, which may be caused by specific infrastructure characteristics and/or the behavior of other road users. For automated vehicle deployments, the vehicles must be considered in context with their intended function (use case), and their environment.

Specific Example Locations

The below examples illustrate the AV-Readi™ findings that may cause specific challenges to AV freight vehicles, including those locations that rate at the top of the complexity scale, shown in purple. For example, Figure 22 illustrates a section of I-69 that contains the mixed merging/exiting situation while also passing under a long overpass, which may cause GPS outages and temporary camera "blindness". The sections of this example where mixed merging and exiting can occur are a High complexity (red), and the addition of the overpass causes that portion of the road to elevate to Extreme (purple).

Potential infrastructure-based mitigation factors that could be applied to this situation include:

- Lighting in the overpass to reduce light level fluctuations,
- Sensors detecting and tracking vehicles as they progress along the entrance ramp and a communication mechanism to provide approaching AVs with the estimated position of each tracked vehicle for a period of time (e.g., 10 seconds).

For longer overpasses, additional and more exotic approaches can be taken to provide "surrogate GPS"; however, for overpasses like this, AVs will need to be capable of traversing it even if their GPS signal is degraded or absent. Alternatively, an AV freight company who has a safety driver on board could plan to manually drive the vehicle through this type of environment.

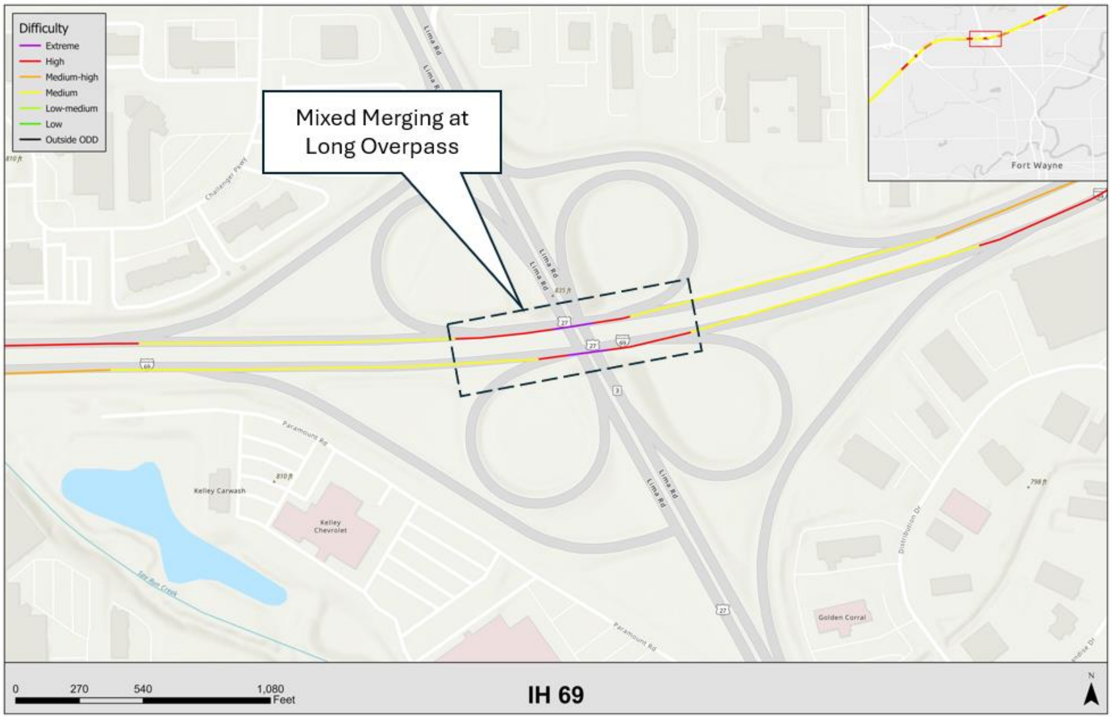

Figure 22: AV-Readi™ Extreme Complexity Example (I-69)

Another example of a long overpass is shown in Figure 23 along US 33 in Fort Wayne.

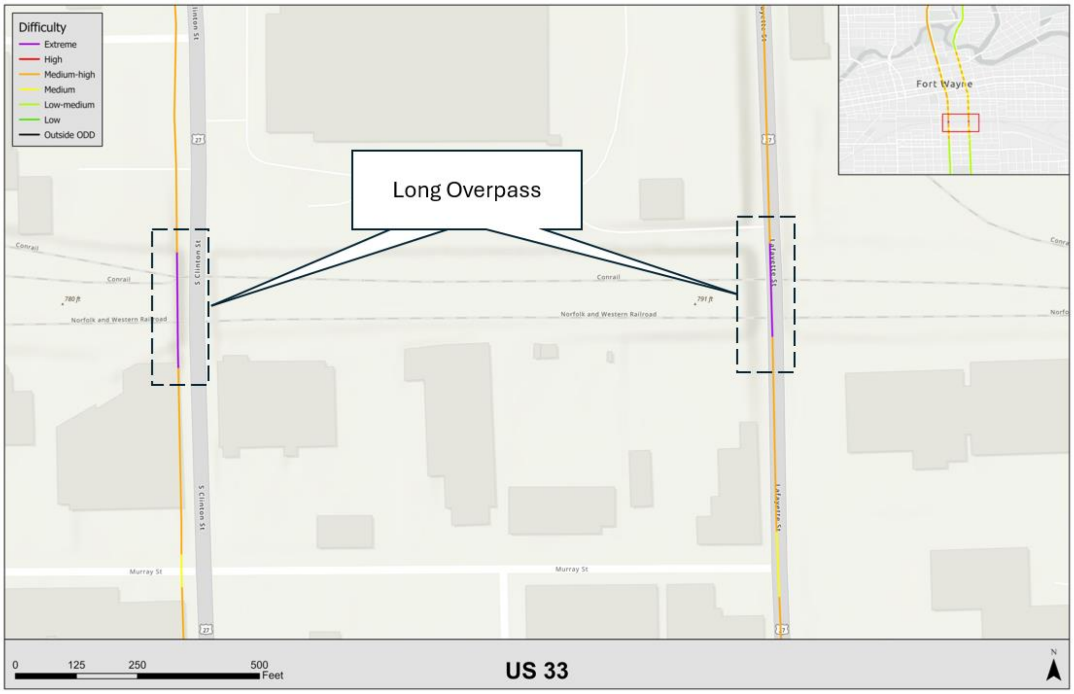

Figure 23: AV-Readi™ Extreme Complexity Example (US 33)

Figure 24 illustrates a third example of a long overpass, this location at the interchange of I-465 and I-69 south of Indianapolis. This segment also shows the long "High" complexity segment for the merge from I-69 to I-465.

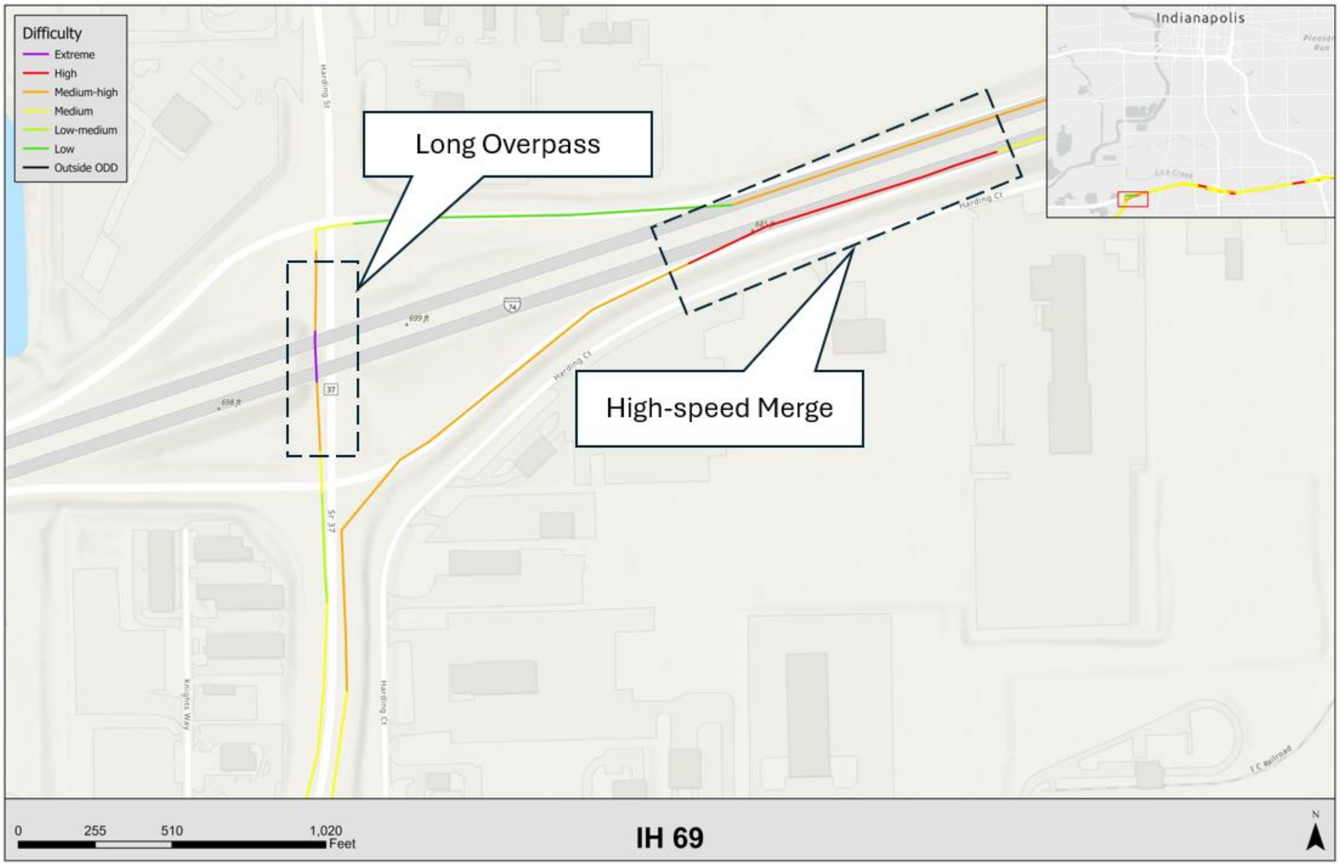

Figure 24: AV-Readi™ Enhanced Complexity Example (I-69 / I-465)

Examples of multiple interacting merges and other conflicts are shown below in Figure 25 Figure 26. The AV-Readi™ analysis highlights the areas of low complexity, in this case due to single-lane exits, as well as locations of elevated complexity, such as the high-speed merge locations. These are good examples of the variety of challenging interactions an AV freight vehicle might expect traveling through an urban environment, or at the interchange of major highways.

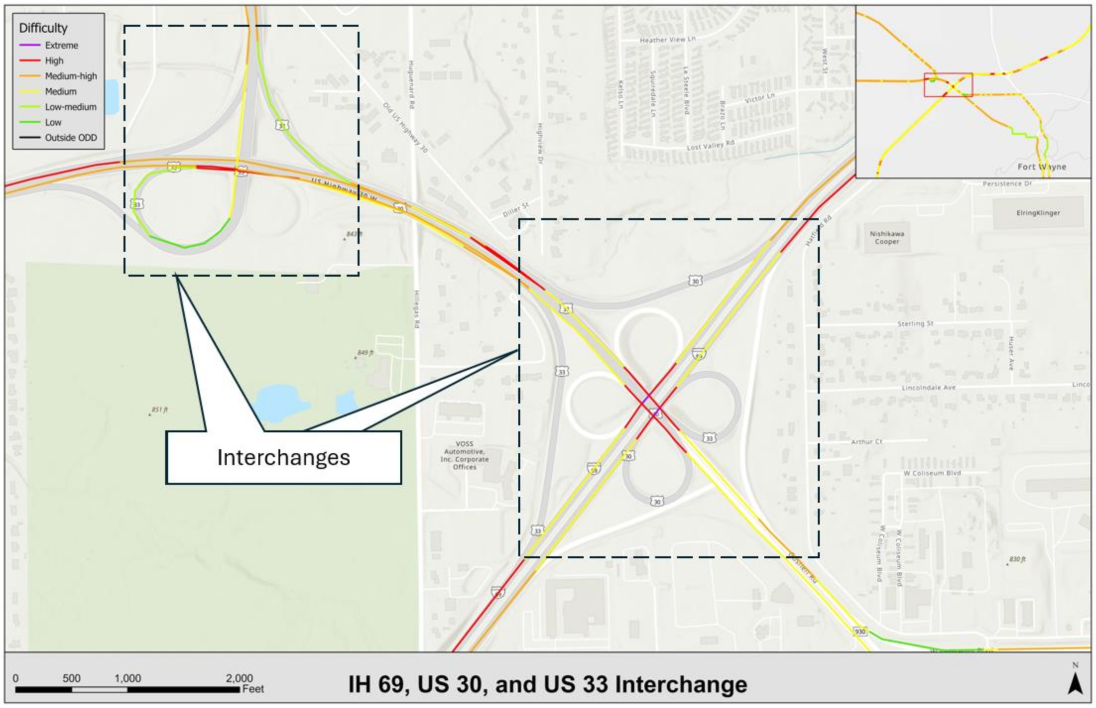

Figure 25: AV-Readi™ Enhanced Complexity Example (I-69 / US 30 / US 33)

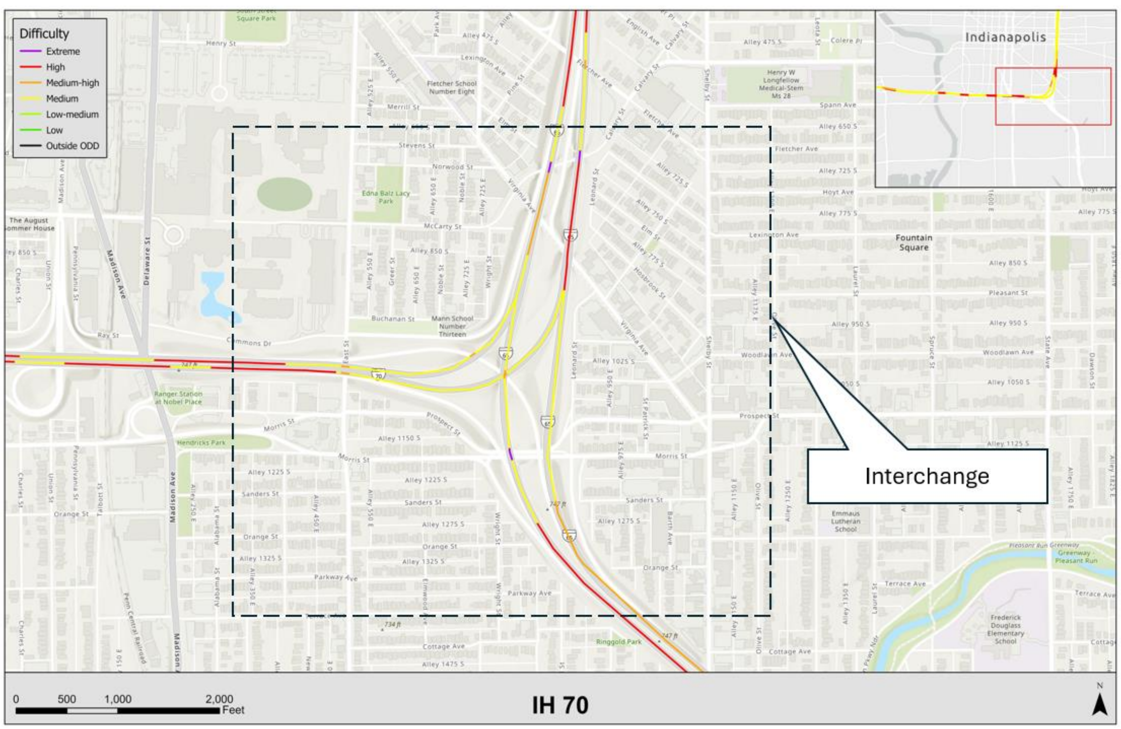

Figure 26: AV-Readi™ Enhanced Complexity Example (I-70)

AV-Readi™ is capable of very detailed analysis of the environment, which is particularly visible in less dense environments. Figure 27 shows the two directions of US33 as it transits part of Fort Wayne. With slower speeds, the analysis shows areas of low complexity.

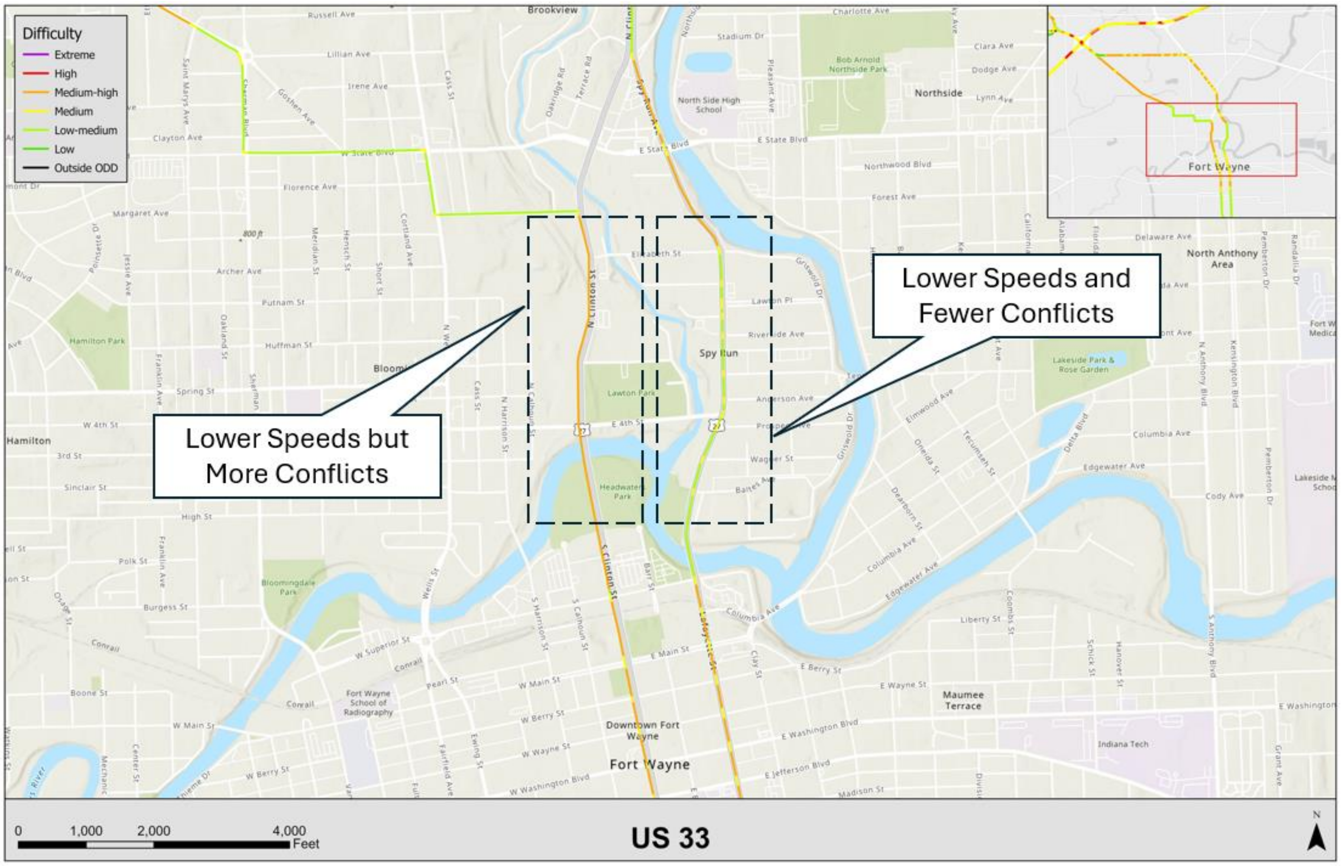

Figure 27: AV-Readi™ Complexity Example (US 33 at Fort Wayne)

Similarly, Figure 28 shows the interchange of I-65 and US 30, where a variety of complexity categories are represented. This section also contains insights that were gained using video collected as described in the next section. The video shows absent lane markings at a "complex intersection" that has multiple safety hazards for humans, which may also affect AVs.

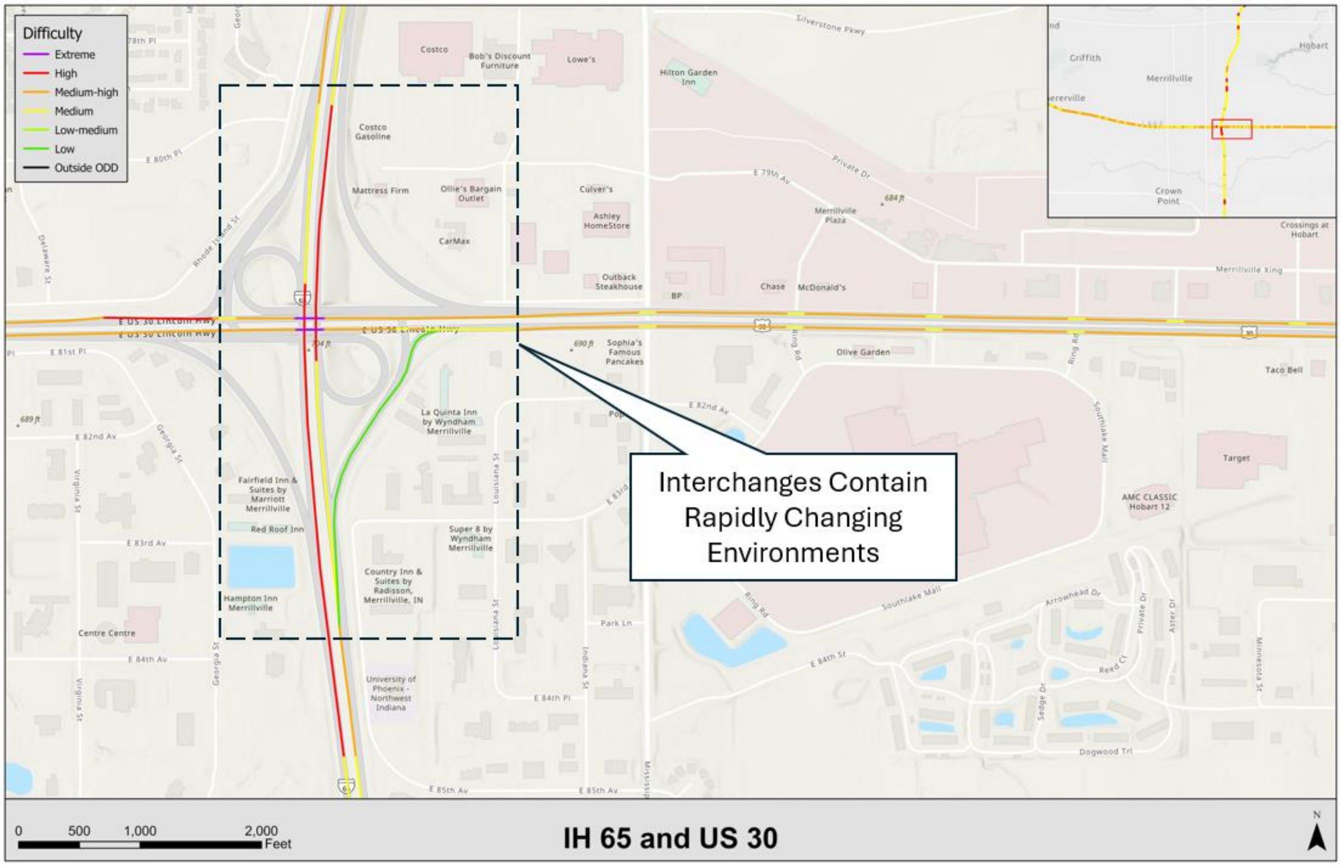

Figure 28: AV-Readi™ Enhanced Complexity Example (I-65 and US 30)

Data Collection

Some of the roadways assessed by AV-Readi™ were also driven and the video, GPS, and 3-axis accelerometer data were recorded. Figure 29 shows the routes driven, along with the vertical accelerometer data shown as a heatmap. The routes driven that coincide with this report include I-65, US 30, I-69, and US 31. The vertical accelerometer represents the surface roughness of the roadways driven, and the data shown in this figure represents only the locations of for the highest values. These represent roadway features that cause a sudden jolt to the vehicle such as potholes, bridge/roadway joints, damaged pavement, etc.

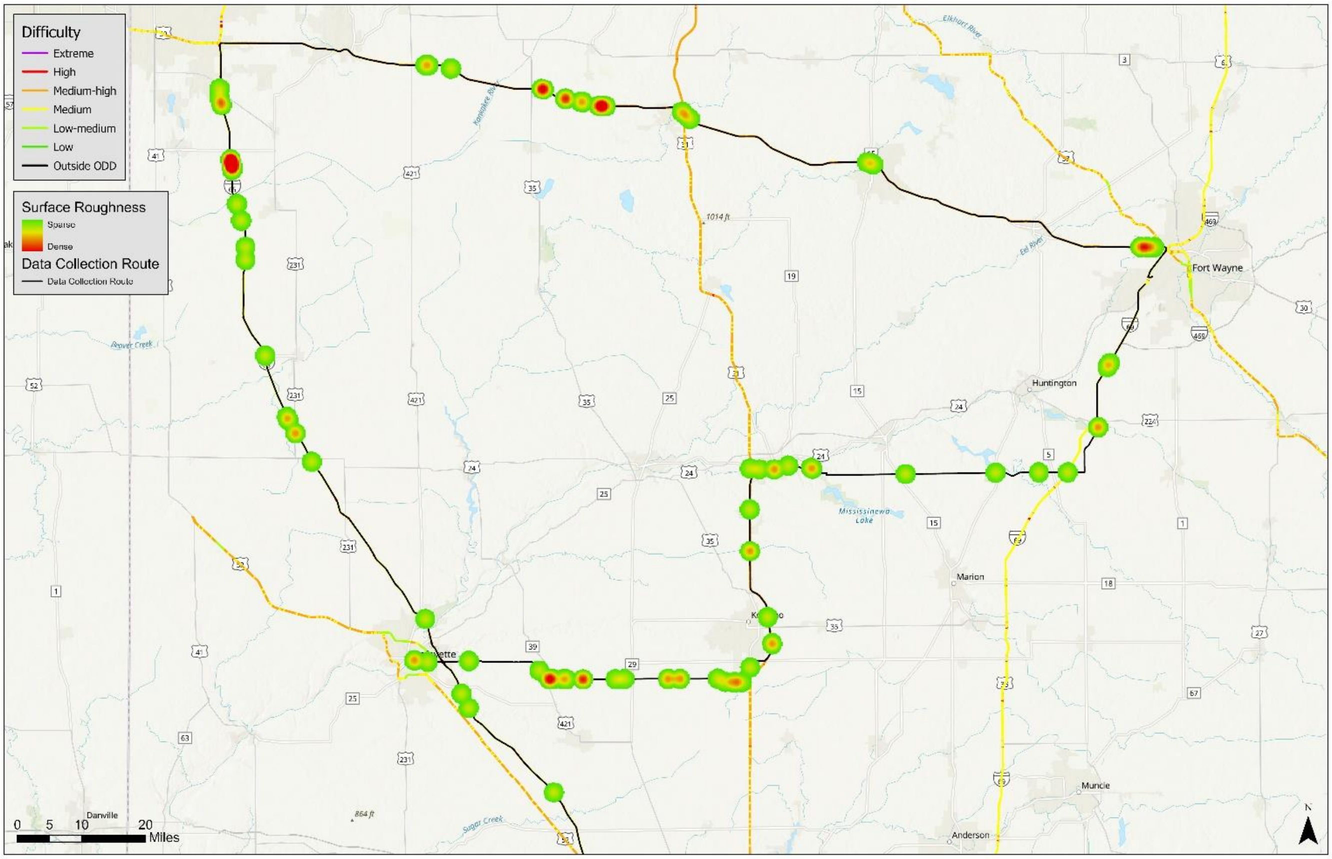

Figure 29: Data Collection Route with Surface Roughness Highlights Overlaid

Similar analysis was performed for the lateral and longitudinal accelerometer data, indicating locations on the route where higher values of acceleration/deceleration or turning occurred. This data contains less detail on the majority of the routes driven because high values of accel/decel and turning only occur under special conditions, largely influenced by dynamic conditions in the environment, such as the behavior of other road users, whereas the vertical acceleration values are due to roadway pavement conditions. The longitudinal and lateral accelerometer results are included in Appendix A: Additional Results.

AV-Readi™ can also integrate external data from various sources to help inform the level of complexity for a roadway segment. One of the premises of AV freight vehicles is that they can optimize the use of their power band better than human drivers; meaning, they can drive more efficiently, which is useful for a variety of driving conditions. Part of the collected data included speed, in which the variation encountered on different roadway types becomes apparent. The speed data in Figure 30 is for a two-hour period, while traveling between the I-65/US 30 Interchange and Fort Wayne on US 30, and clearly shows periods of relative stability in the speed, and other periods of extreme variability, indicative of “stop-and-go” traffic and intersections encountered while transiting towns on US highways. An AV freight vehicle may see energy/fuel savings in these locations through efficient management of their power bands, anticipating slowdowns, and accelerating at a gentler rate. This data also illustrates why roadway segments on US highways in AV-Readi™ are assessed at a higher complexity level. The risk for conflict with other road users between towns primarily comes from non-access-controlled incursions by vehicles, VRUs, and animals, but the risk in towns is largely due to dense interaction with other vehicles, and intersections.

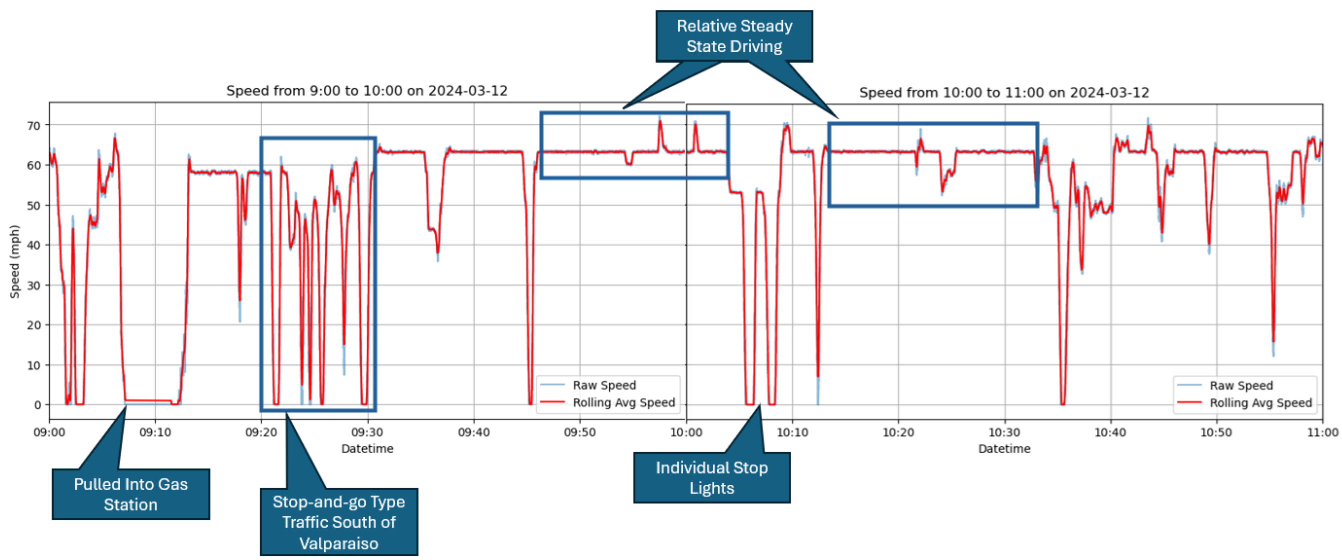

Figure 30: Speed Data Over Two Hours of Driving on US30

Estimated cost savings due to more efficient power band management by an AV freight vehicle could be incorporated into AV-Readi™ by incorporating this type of data. If a route is considered critical for freight movement under specific circumstances, this data could also lead to an understanding of where an adaptive signal system, or Freight Signal Priority, could be implemented.

As mentioned above regarding Figure 28, Figure 31 provides an image of the intersection for traffic exiting northbound I-65 onto eastbound US 30. According to AV-Readi™, this exit ramp is low complexity because it is a single lane for most of the exit, only splitting into multiple lanes near the intersection. Traffic exiting to eastbound US 30 consists of two lanes which come to a controlled intersection as shown below; however, as seen there are no road markings indicating the individual lanes, or the paths vehicles should follow for a double-lane merge. Although there is no painted lane separator, this is a joint in the road between two pavement sections, which can also be interpreted by sensors as a lane; however, this is ambiguous and is combined with other similar joints that do not represent a lane.

Figure 31: Ambiguous Pavement Markings at an Offset Intersection

During data collection, it was observed that vehicles at this intersection did not treat it as a red light, but as a yield, and if there were no vehicles approaching from the left, they would run the red light and merge onto US 30, adding to the potential hazards at this intersection.

Summary

This report is the culmination of an effort to assess state of the AV freight industry, assess the economic drivers of goods movement in Indiana, identify and select specific freight corridors for AV deployment feasibility assessment, and then assess those corridors using AV-Readi™. These steps are further described below:

1. **Evaluated the results from Data Collection and Sector Scan** – Collected data and conducted a sector scan that led to an Economic Incentivization analysis to identify priority freight movement corridors within the state, including interstate highways, US highways, state highways, and local roadways.
2. **Classified these routes** according to characteristics including mode of operation (long-haul operation, intra-state vs. interstate, distribution hub access, etc.), and the relevant stakeholder groups, such as Conexus Indiana's Advanced Industries Counsel
3. **Presented a list of candidate routes** to INDOT and select stakeholders for consideration of a detailed assessment for AV freight deployment feasibility.
4. **Assessed selected priority roadways using the AV-Readi™ tool**:
    a. Complexity maps and calculated complexity index values for each route analyzed.
    b. Evaluated selected routes for overall readiness to deploy AV goods movement vehicles based on the likelihood and severity of conflict with other road users, including VRUs.
    c. Identified locations where likelihood and severity of conflict with other road users, or other environmental factors, was "High" to "Extreme".
    d. Identified possible infrastructure changes that may increase the readiness for AV freight and delivery deployment.
5. **Stakeholder comments** were also incorporated, which were gathered during a series of outreach meetings.

The economic analysis of freight movement in Indiana, and the various market and demographic drivers for that movement, produced a list of corridors that warranted an AV deployment feasibility analysis using the AV-Readi™ tool. This selection included corridors from the critical freight network, as well as numerous smaller roads that showed significant freight movement. These corridors were then filtered using factors such as annual average freight traffic volume on the corridor, the economic activity in either the source or destination county. The resulting set of corridors selected for further analysis using AV-Readi™ are listed in Table 1.

The resulting AV-Readi™ analysis on the selected corridors illustrates some of the challenges in the deployment of AV freight vehicles from an operational standpoint, which the AV freight industry is actively working to manage. The challenges identified are partly a result of the infrastructure-based environment, but more so due to the complex interaction with other road users. Each roadway environment an AV operates in will have specific challenges, which are dynamic and can be affected by the level of congestion, weather, work zones, and incidents like crashes; however, the AV-Readi™ assessment provides an aggregate view of these environmental complexities. The primary challenges identified on the corridors include:

- High-Speed Merges
- At-Grade Railroad Crossings
- High-Speed Exits
- Non-Access-Controlled Roads Above 45mph
- Complex Cross Street Configurations
- Long Overpasses
- Locations of Mixed Merging

The real-time severity of each of these environments will depend on factors such as the amount of vehicle and VRU traffic, weather conditions, transient conditions like work zones or incidents, and the ability of an AV to manage these challenges will depend on the capability maturity of the automated driving system. These results may also be leveraged in discussions with potential vendors to build consensus on the location, circumstances, and severity of deployment challenges, and to draft mitigation strategies and operational contingency plans.

Building on the data listed in Table 1, Table 2 shows the aggregate results for all assessed corridors, including the route complexity score, total miles, and the percent of the route that has a complexity value in either the "High" or "Extreme" categories. This table further breaks out the information from Table 1 by direction, since both directions of each corridor were assessed.

Table 2: Assessed Route Results, Sorted by Complexity Index Score

Route Name	Direction	Complexity Index Score	Total Route Length (Miles)	% Length "High" or "Extreme"
I-69	Northbound	5.08	340	5.45
I-69	Southbound	5.18	340	5.98
I-80	Eastbound	5.18	150	6.36
I-80	Westbound	5.22	150	6.26
I-65	Southbound	5.48	260	7.92
I-70	Eastbound	5.55	155	7.46
I-70	Westbound	5.58	155	7.22
I-65	Northbound	5.62	260	8.33
U.S. 52	Northbound	7.37	180	3.11
U.S. 52	Southbound	7.42	180	2.53
U.S. 33	Northbound	7.54	100	0.25
U.S. 33	Southbound	7.54	100	0.28
U.S. 30	Eastbound	7.99	125	0.74
U.S. 30	Westbound	8.00	125	0.84
U.S. 41	Northbound	8.01	105	1.66
U.S. 41	Southbound	8.04	105	2.07
U.S. 31	Northbound	8.11	135	5.03
U.S. 31	Southbound	8.13	135	5.42

The results are sorted by the complexity index score. Altogether, the assessed routes include 3,100 miles of interstate highway and US highway in Indiana, which are shown in Figure 32 in descending order of total length (both directions). Figure 33 shows the corridors sorted in descending order of the percent length of the corridor with either high or extreme complexity categories.

The results in Table 2 support the argument that AV freight companies will look to deploy on access-controlled roadways first. Based on the economic analysis, and these results, **I-70 is a top candidate for investment in infrastructure that supports and enables AV freight deployments**. This also supports the

“AV Corridor” initiative between Indiana and Ohio. These results do not preclude investment in the US Highway corridors and can be used to identify specific areas of highest concern on these routes, and potential infrastructure solutions to lower the complexity of part or all of the route.

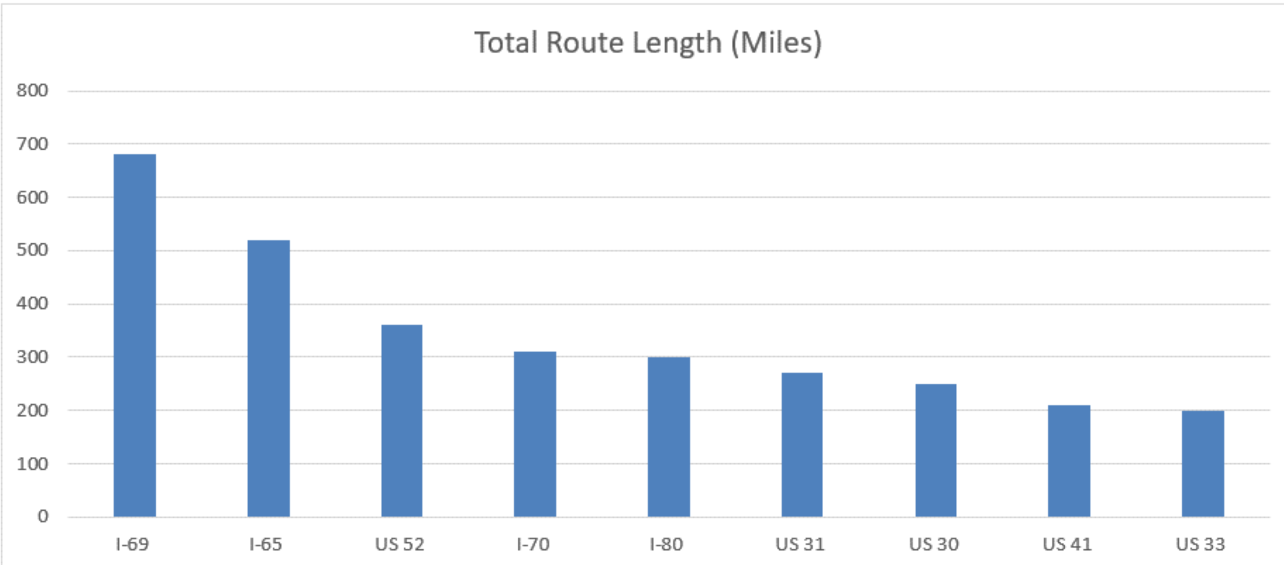

Figure 32: Total Route Length (Both Directions)

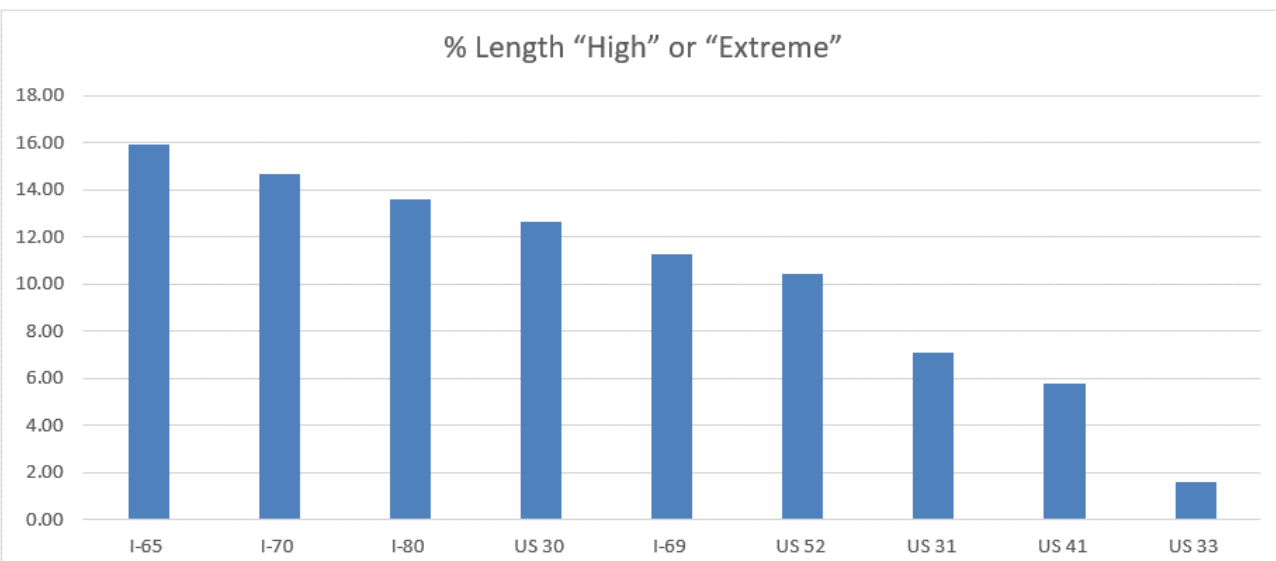

Figure 33: Percent by Distance of High and Extreme Segments

Additionally, Figure 34 overlays the percent high/extreme data with the corridor complexity index scores (sorted in ascending order). This illustrates an interesting artifact produced by the types of roadways analyzed, which is an almost inverse relationship between the complexity index score and the percent length of high/extreme segments. This is largely due to the length of these corridors overshadowing a greater variety of details that would normally be included. US highways are represented by an underlying complexity category of medium-high (orange), with pockets of other complexity types. Whereas interstate highways are predominantly a medium complexity (yellow), with larger sections of high-complexity segments (red) and a greater chance for extreme segments (purple). The AV-Readi™ index score is calculated using weighting factors, in which medium segments are weighted less than medium-high segments, which results in the US highways by default scoring higher on the index calculation than interstate highways.

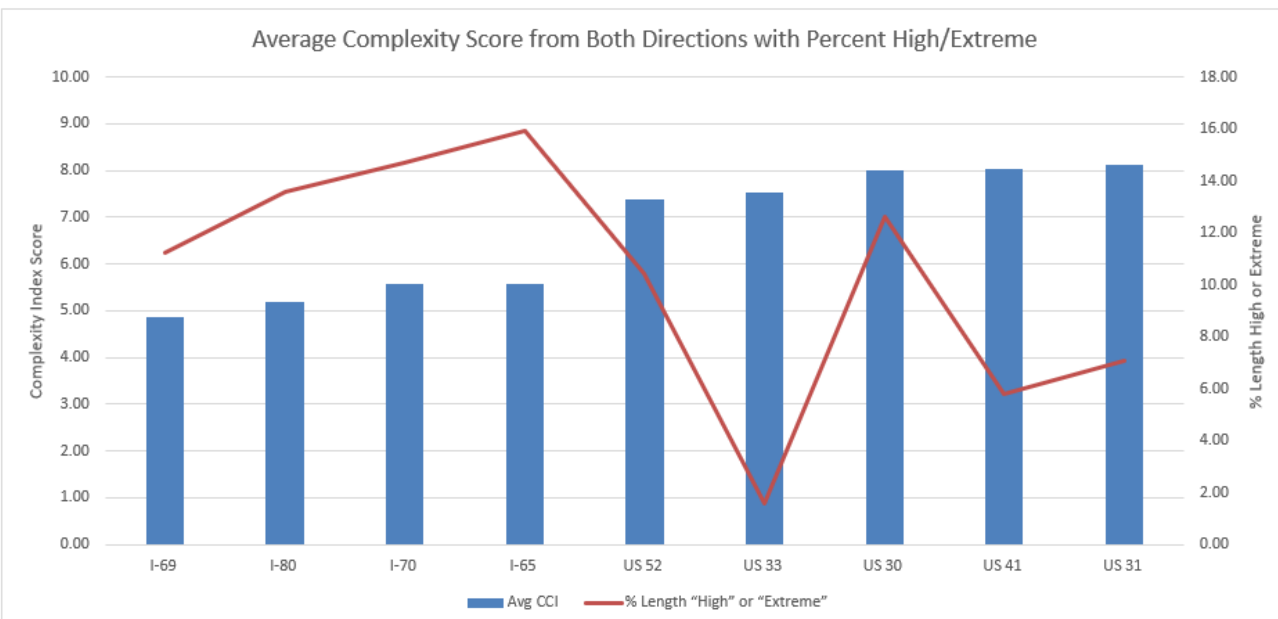

Figure 34: Average Complexity Score Overlay with Percent High/Extreme

Infrastructure and Data Considerations to Improve Readiness

Improving the deployment readiness for AV freight vehicles, including last- and middle-mile vehicle types and service models, involves a combination of infrastructure enhancements, data considerations, and

AV capability maturity improvement. Some of these items were previously addressed in the Market Scan; however, additional insights are discussed below based on the results of the economics analysis and corridor identification, stakeholder engagement, and subsequent analysis of corridors using the AV-Readi™ tool. The AV industry is developing their systems to operate in the built environment, as it currently exists, so specific infrastructure changes are not necessarily required for AV deployment; however, there are physical and digital enhancements to infrastructure that would improve the ability of AVs to operate. Some of these improvements benefit human drivers as well, and some will largely be applicable only to AVs, or other vehicles that can access specific data feeds.

Infrastructure Considerations:

Infrastructure improvements on interstate and US highways may include:

- **Road Pavement and Marking Quality**: Ensuring well-maintained road surfaces and road markings may enhance the effectiveness of camera-based lane detection systems. The recent update to the Manual on Uniform Traffic Control Devices (MUTCD) recommends a 6" width for lane markings, which is more visible for humans, as well as ADAS and ADS systems.
- **Interchanges and Ramps**: Modify interchange design to avoid mixed-merging environments, and merges that occur underneath long overpasses. Pilot sensor systems that track merging vehicles and provide that information via API or other means for AV freight vehicles to make lane-change or speed reduction changes as soon as possible.
- **Weigh/Inspection Stations**: Pilot programs with FMCSA for AV freight vehicles to bypass weigh/inspection stations.
- **Work Zones**: Participate in the USDOT Work Zone Data Exchange. Work with AV Freight deployers on the integration of Indiana WZDx data for both strategic route planning as well as tactical lane positioning and speed reduction.

Last/middle mile routes may also use interstate or US highways but are likely to primarily operate on local roadways. Improvements here may include:

- **Urban Planning**: Integrating freight routes with urban development plans to minimize congestion and optimize access.

- **Local Roads**: Ensuring local roads leading to manufacturing and distribution centers are well-maintained, properly marked, and suitable for truck traffic.
- **Traffic Signals and Signs**: Clear signage and synchronized traffic signals to facilitate truck movements and minimize speed fluctuations.
- **Launch-and-Land Zones**: Designating specific areas for AV freight loading/unloading near manufacturing centers.
- **Emergency Responder Interaction Plans**: Work with emergency responders and AV freight deployers to develop and implement interaction plans.

Data Considerations:

Data considerations are key enablers for AV freight deployment success, including data sharing agreements and data management/governance plans. It's recommended that IOOs, including INDOT, explore opportunities to create and promote API-based data exchanges, working closely with the AV goods movement industry to support specific use cases. Automated vehicles can operate more effectively if they have data available to them that cannot be provided by onboard sensors. Infrastructure owner operators also benefit from receiving data from AV freight vehicles in operation on their roadways, including information about their movements throughout the state, incident detection, adverse weather conditions, and road surface or other asset damage. Some items to consider include:

- Access to real-time traffic information helps optimize routes and avoid congestion.
- Data sources include traffic management centers, sensors, and connected vehicles.
- Implementing vehicle tracking systems allows efficient management of freight movements.
- Tracking cargo from manufacturing centers to distribution hubs enhances supply chain visibility.
- Protecting freight data and communication channels from cyber threats.
- Robust security measures must safeguard against unauthorized access.
- Weather forecasts, road conditions, and air quality data may aid in route planning.
- Extreme weather events can impact freight operations.

Advanced Manufacturing and Logistics (AML):

Finally, AML centers play a crucial role in the freight ecosystem. Considerations specific to AML include:

- **Supply Chain Integration**: Coordinating AML processes with AV freight movements.
- **Inventory Management**: Identify appropriate use cases for AV freight vehicles in the management of inventory and work-in-process.
- **Collaboration Platforms**: Leveraging digital platforms for communication between manufacturers, distributors, and carriers.

Appreciation of Stakeholder Engagement Participants

Conexus, INDOT, and the project team would like to extend a sincere thank you in appreciation for both the time spent and the valuable insights provided to help advance this body of work. The following organizations were engaged in peer discussions and individual interviews as part of the stakeholder engagement efforts to create this report:

- Backhaul Direct
- Baylor Trucking
- Buchanan Hauling and Rigging, Inc
- Cummins, Inc.
- Indiana Motor Truck Association
- Indiana Soybean Alliance
- Jasper Group
- Kent Corporation
- Ports of Indiana
- Team Cruiser
- Toyota Material Handling
- Wabash

Appendix A: Additional Results

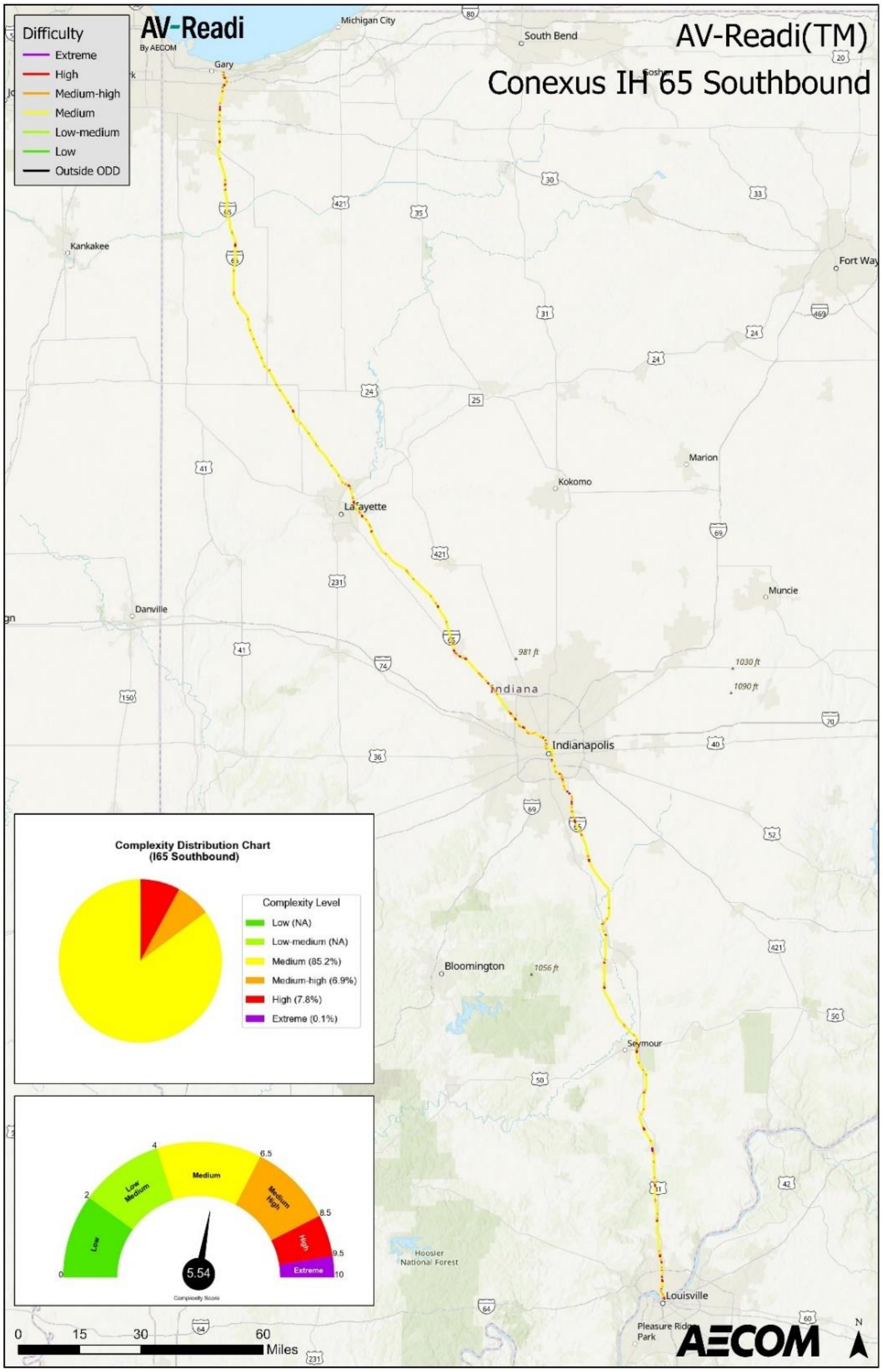

Figure 35: Southbound I-65 Complexity Map

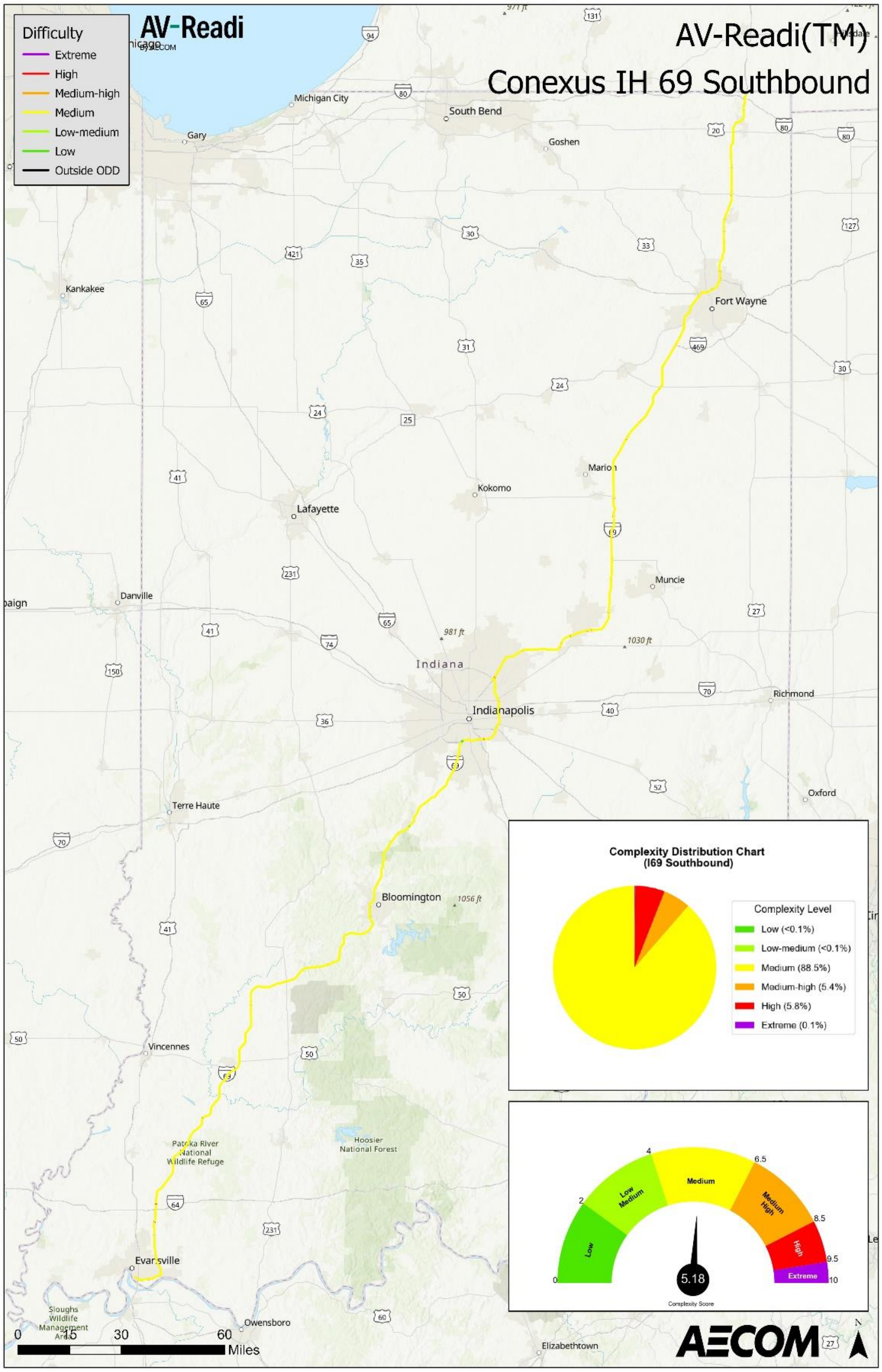

Figure 36: Southbound I-69 Complexity Map

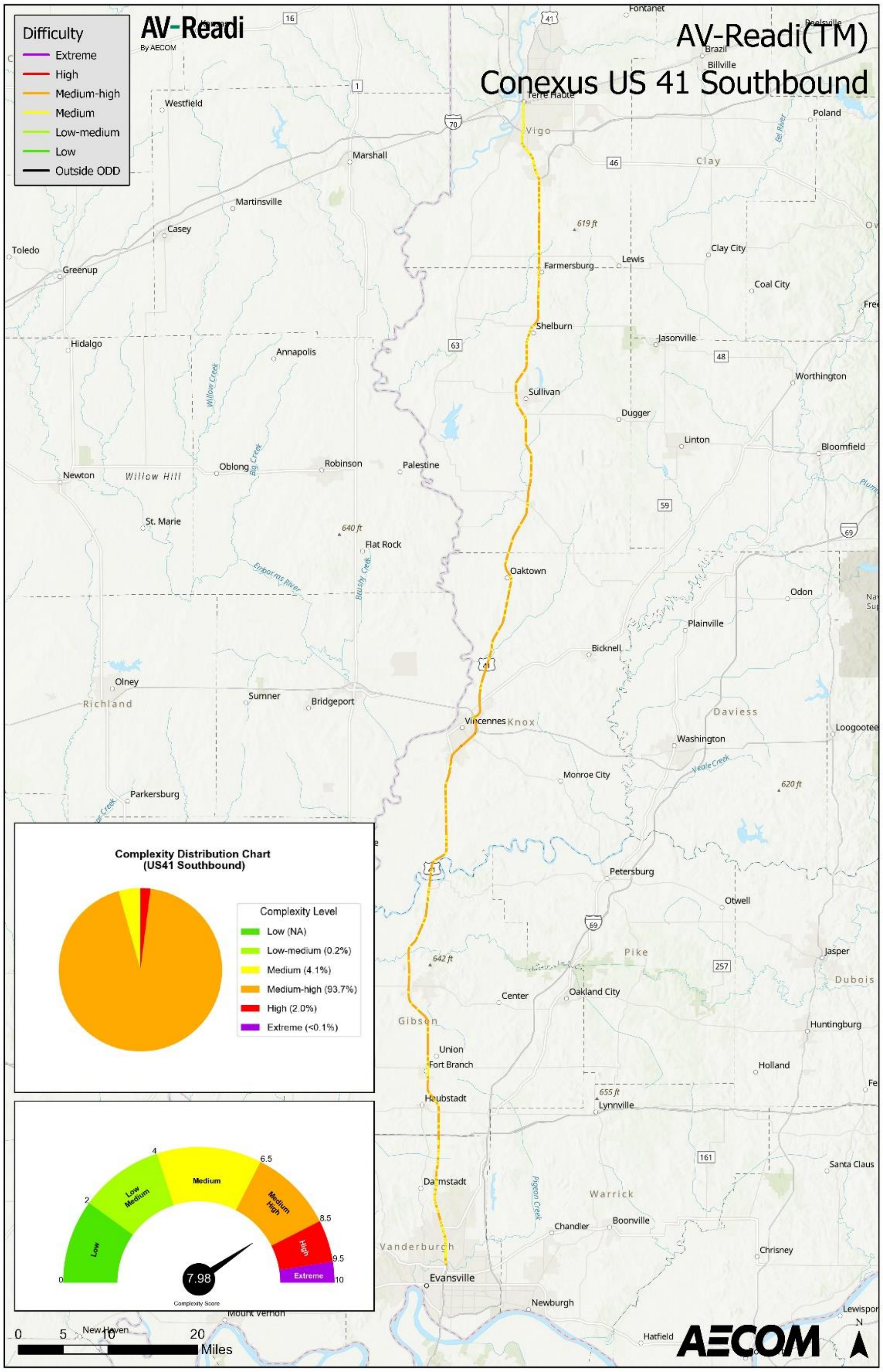

Figure 37: Southbound US 41 Complexity Map

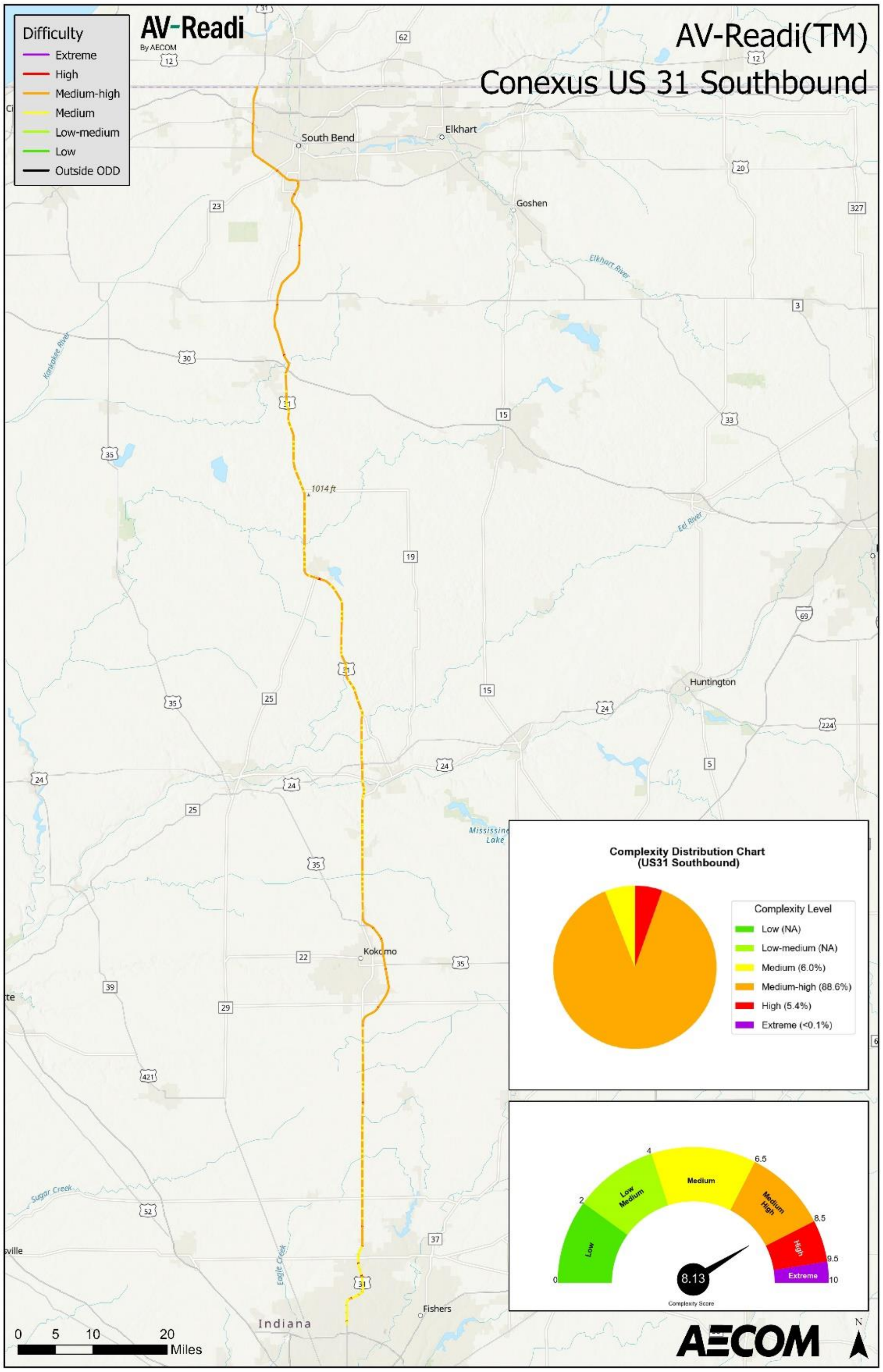

Figure 38: Southbound US 31 Complexity Map

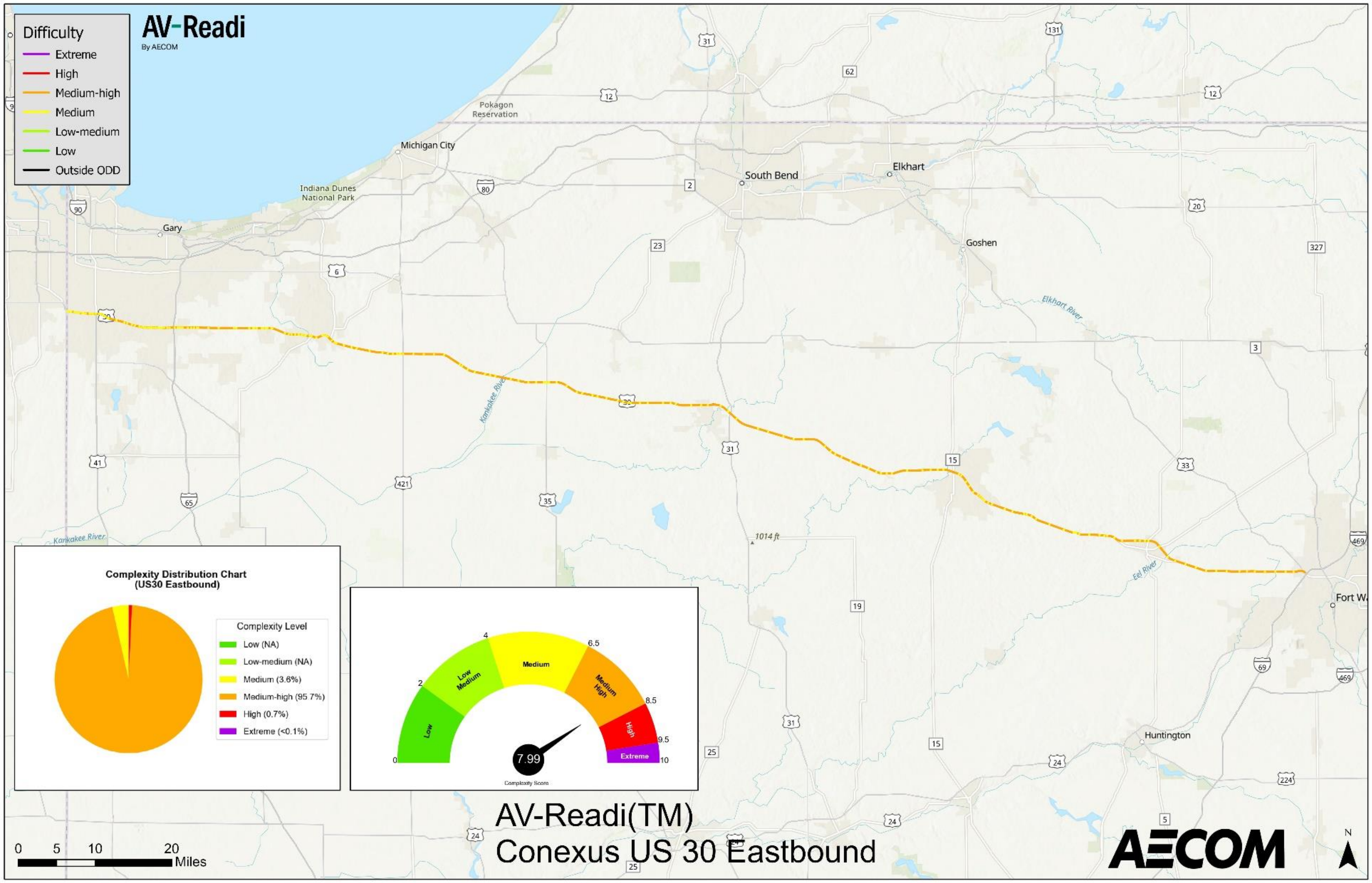

Figure 39: Eastbound US 30 Complexity Map

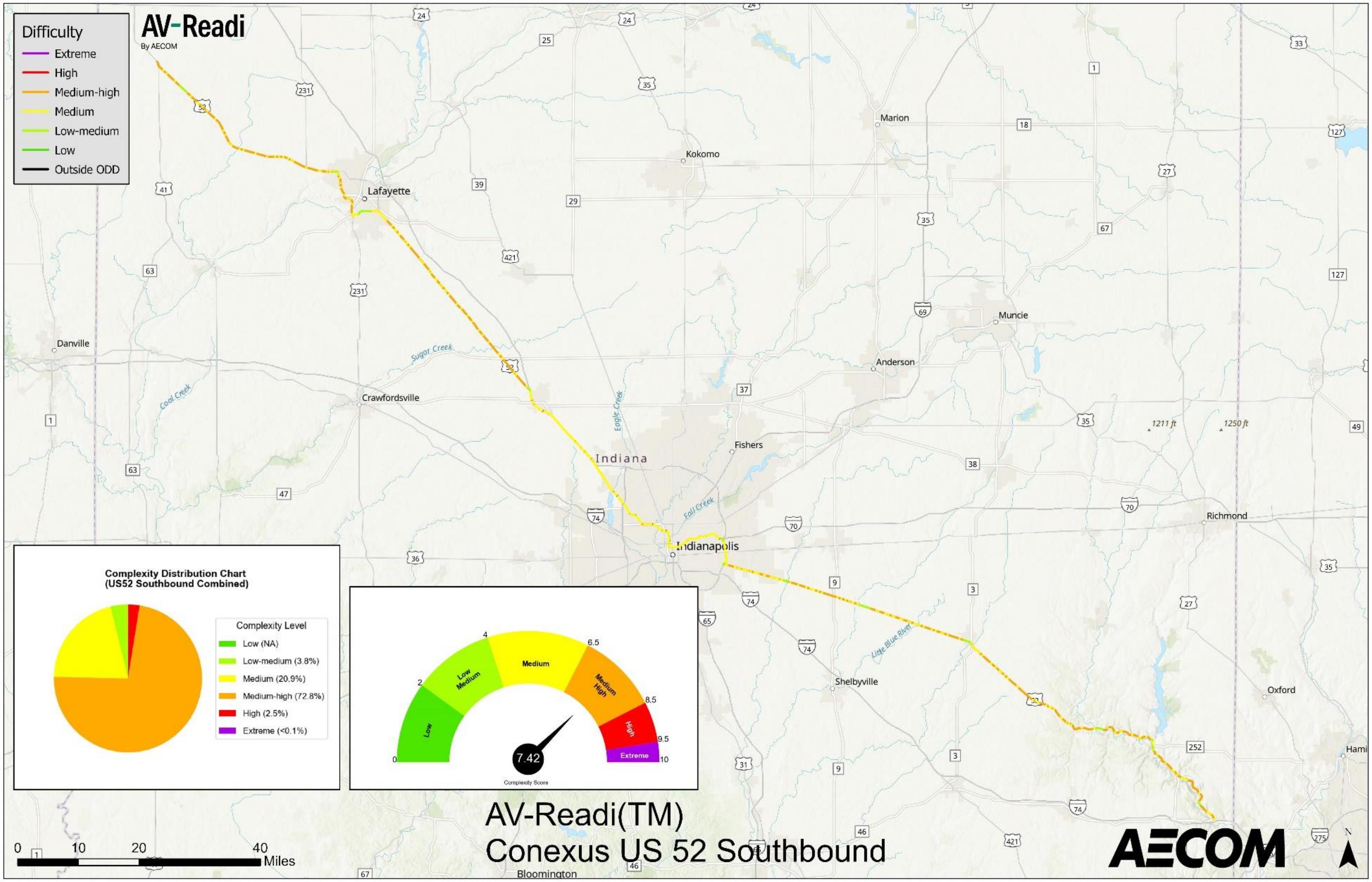

Figure 40: Southbound US 52 Complexity Map

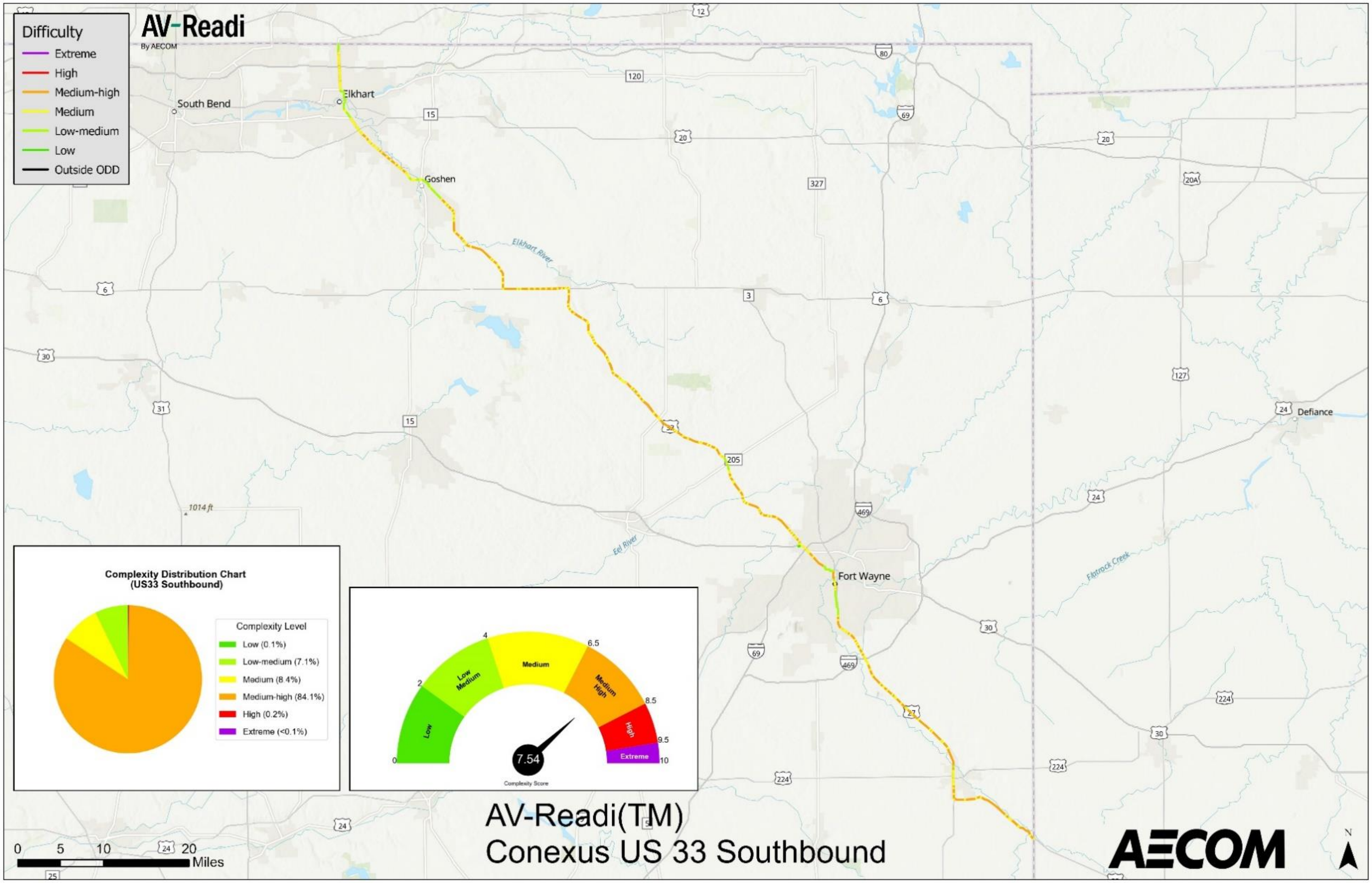

Figure 41: Southbound US 33 Complexity Map

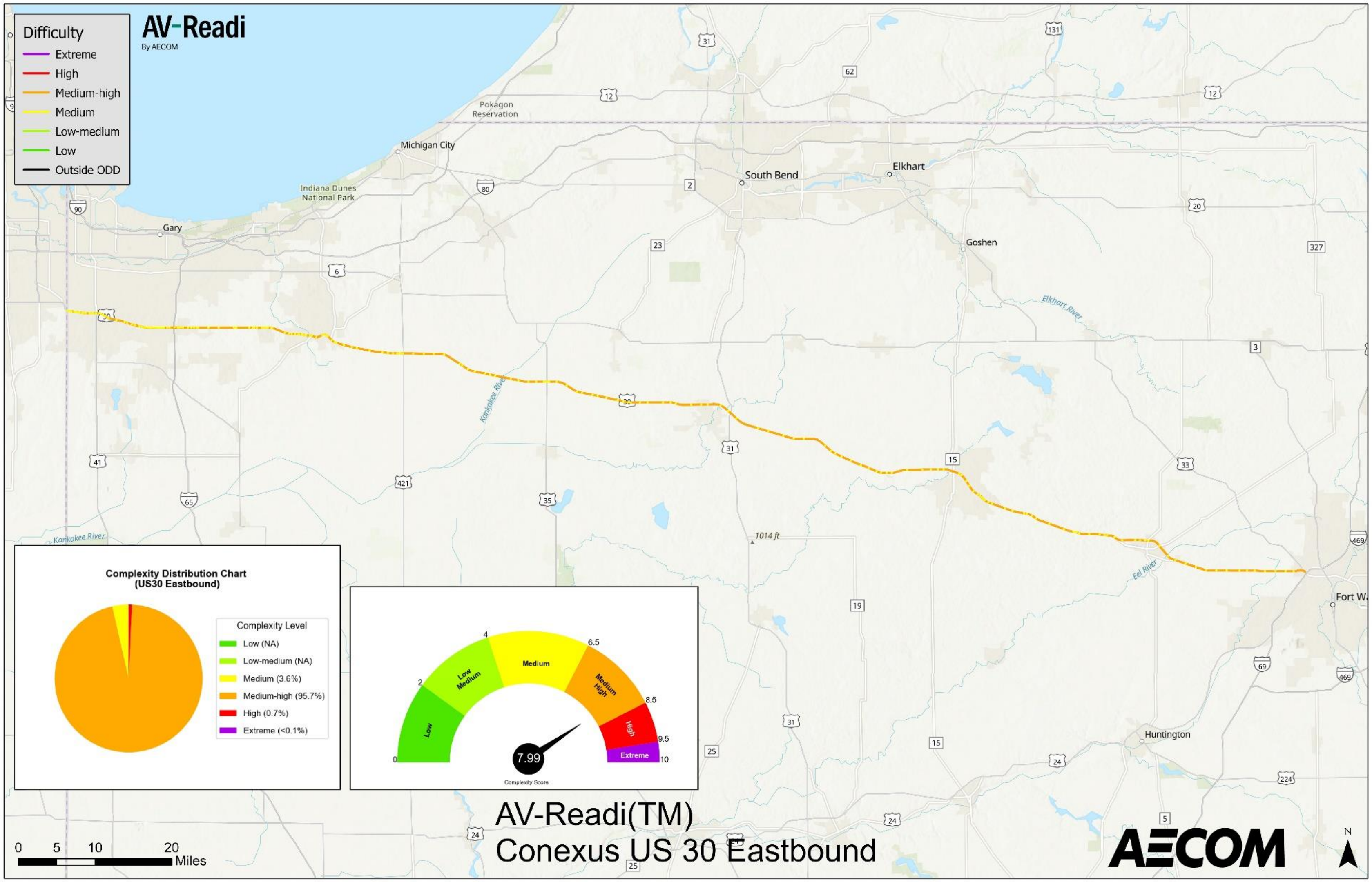

Figure 42: Eastbound US 30 Complexity Map

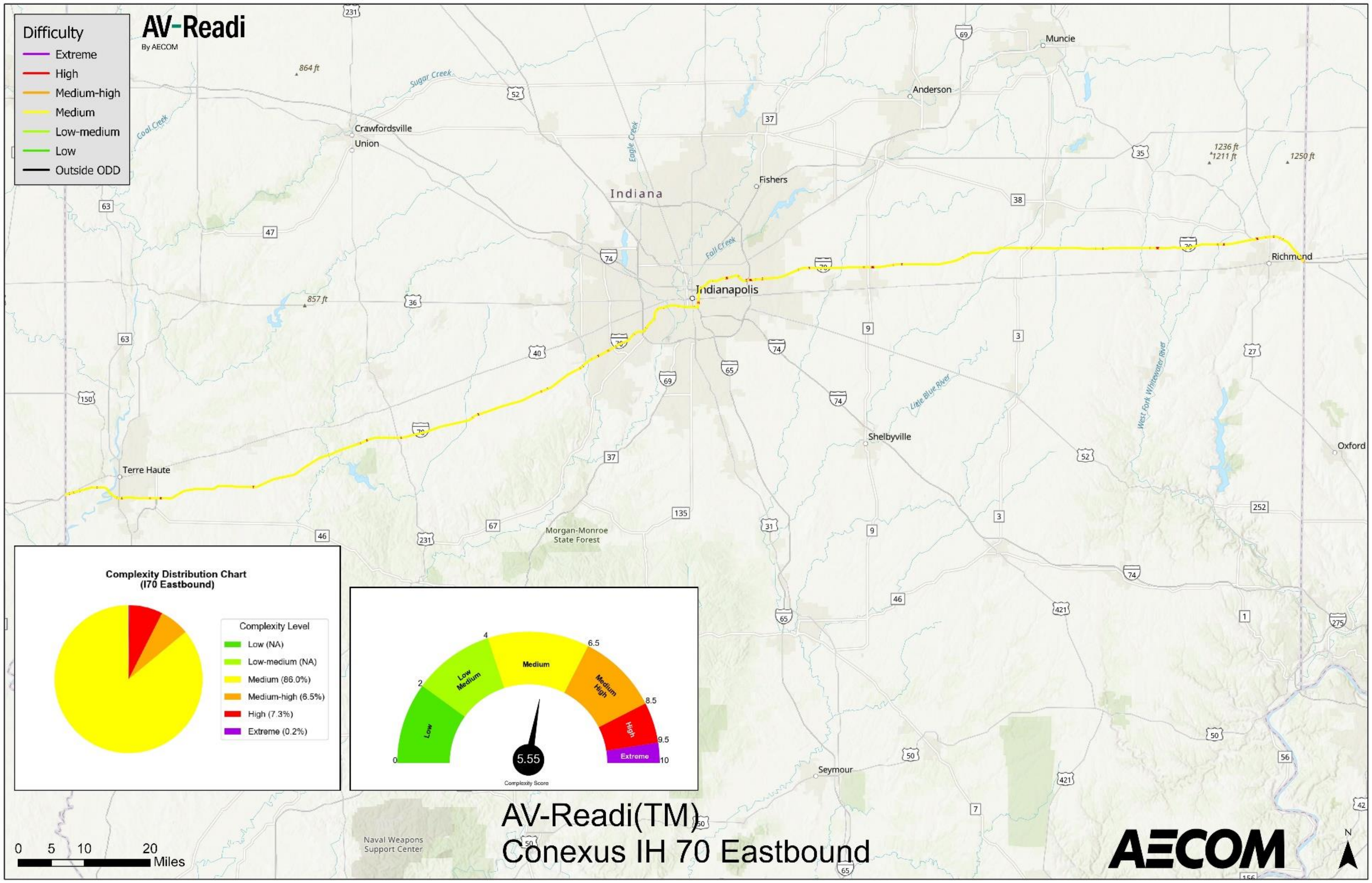

Figure 43: Eastbound I-70 Complexity Map

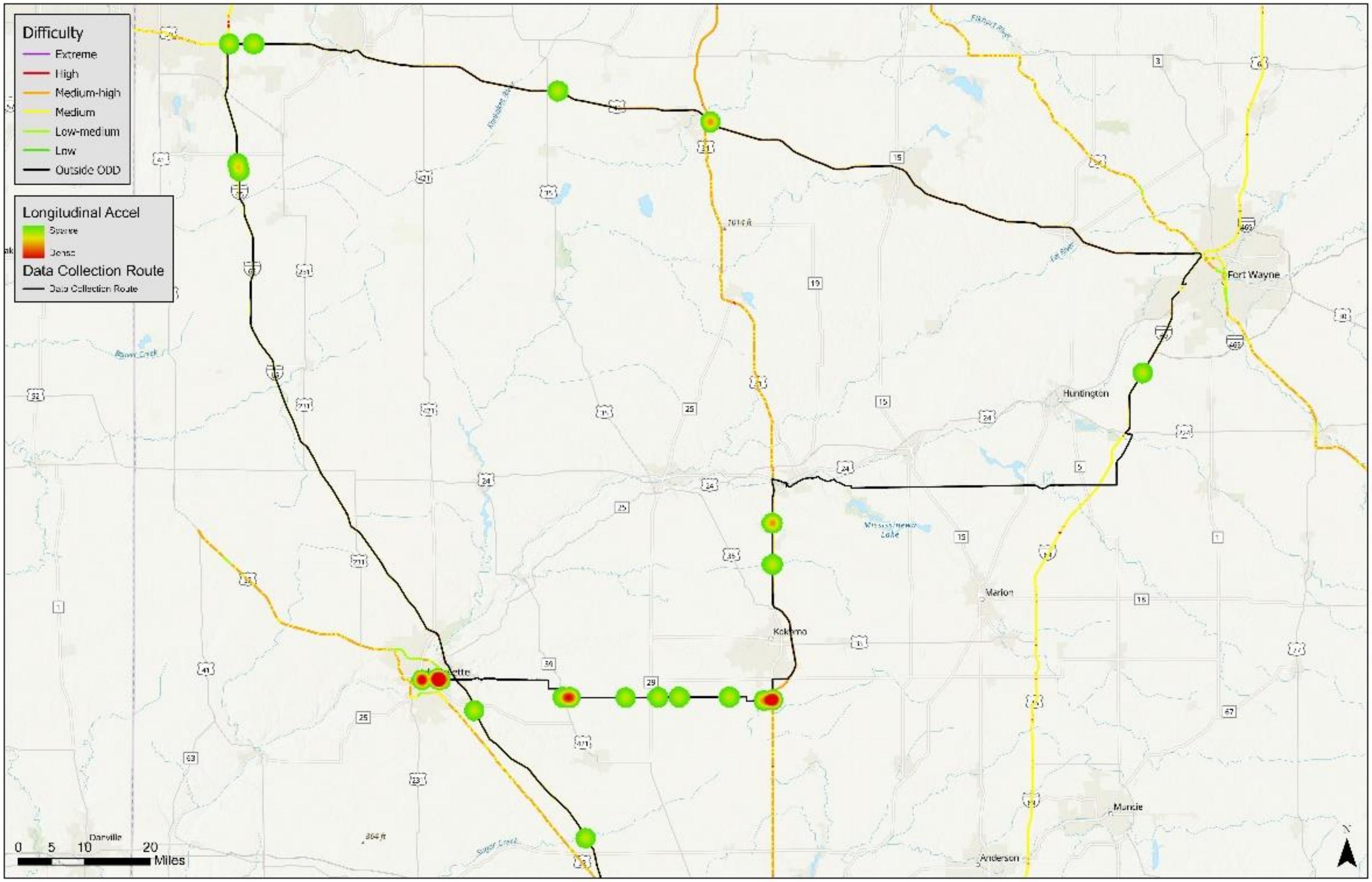

Figure 44: Data Collection Route with High Longitudinal Acceleration Heatmap

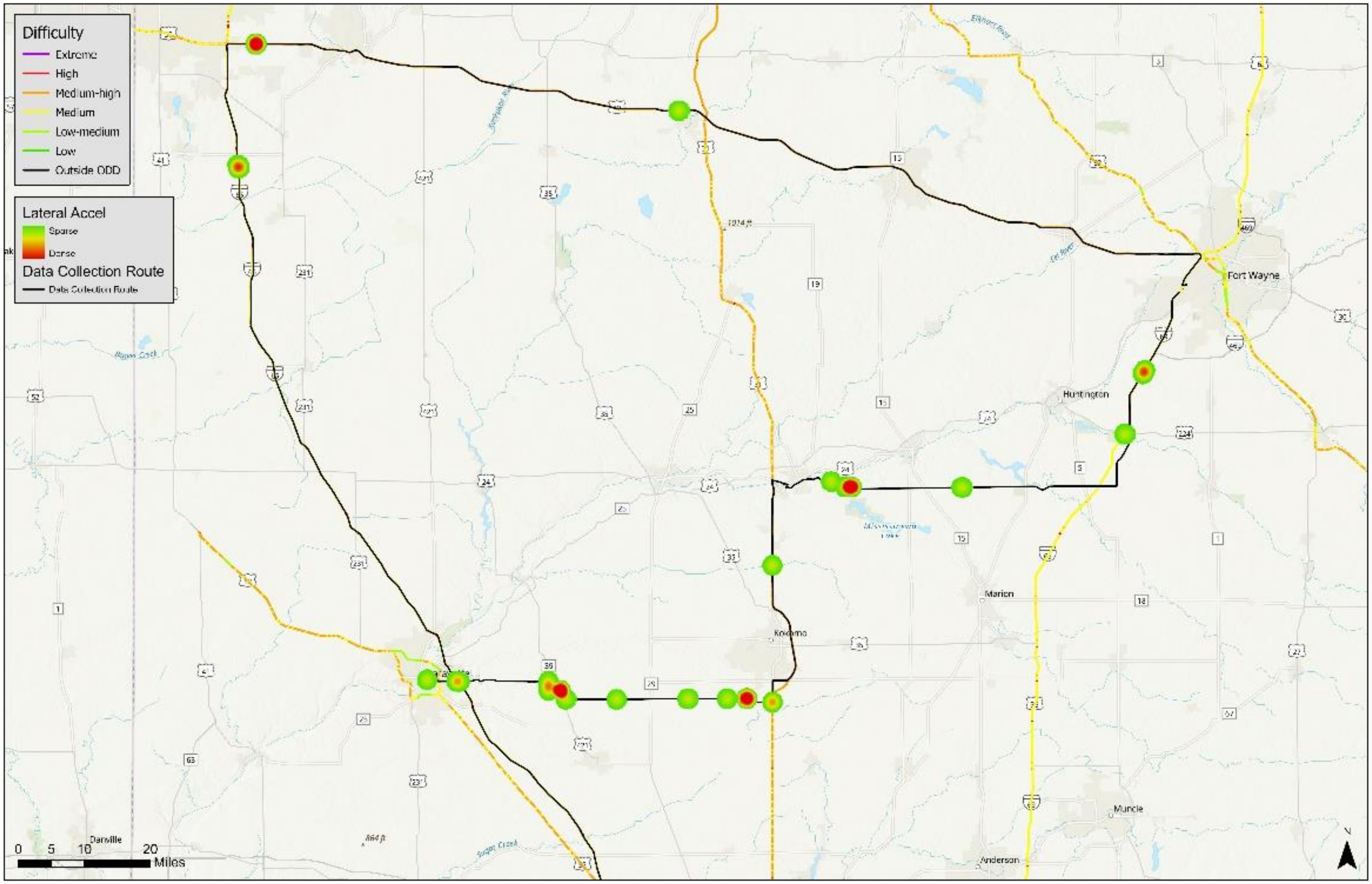

Figure 45: Data Collection Route with High Lateral Acceleration Heatmap