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INDIANA DEPARTMENT OF TRANSPORTATION
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Best Practices for Implementing Driving Simulators in INDOT Driver Training



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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract This study supports the Indiana Department of Transportation's (INDOT) initiative to enhance driver training through the strategic use of driving simulators. Traditional driving training methods are limited by seasonal variability and safety concerns. To address this, this project evaluated the role of simulators in improving driver preparedness, safety, and training efficiency. A comprehensive mixed-methods approach was used, including literature review, surveys, focus groups, performance data analysis, and case studies. Findings indicate that simulators are well-received, especially by novice drivers, enhancing confidence, decision-making, and situational awareness, particularly for snowplow operations. Realistic scenarios and structured debriefs using simulator-generated data were key to engagement and learning. Performance metrics revealed behavioral differences by skill level, age, and years of experience, while also validating the simulators' capacity to deliver targeted feedback. Long-term assessments confirmed sustained training benefits, though logistical barriers such as access and scenario refinement remain. In addition, operational analyses of INDOT's snow operations and national case studies demonstrated that simulators improve training efficiency and workforce allocation. Recommendations include expanding simulator access, developing a tiered training curriculum, integrating simulator data into performance evaluations, and establishing inter-district resource-sharing frameworks. Implementation of these practices, alongside robust evaluation and inter-agency collaboration, can support INDOT's long-term goals of cost-effective, scalable, and high-impact driver training.			
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EXECUTIVE SUMMARY

Introduction

The Indiana Department of Transportation (INDOT) oversees a workforce of more than 2,000 drivers who require annual training to ensure safe and efficient maintenance of Indiana's roads, alongside hundreds of new hires each year who need specialized instruction to obtain their Commercial Driver's License (CDL). Traditional training, comprising lectures and behind-the-wheel (BTW) components, often faces challenges in addressing the diverse needs of trainees, particularly novices who may find large vehicles intimidating. Seasonal conditions, such as snow or reduced visibility, further complicate BTW training, as these cannot be consistently replicated. Driving simulators offer a promising solution by providing customizable scenarios, safe training environments, performance data collection, and opportunities for postsession debriefs. Widely adopted in industries such as aviation and the military since the 1970s, simulators reduce costs and enable complex skill rehearsal, with research emphasizing the importance of aligning simulator tasks with training objectives over graphical fidelity. In the context of driver training, studies have demonstrated simulators' benefits in enhancing safety awareness, risk perception, and confidence across various vehicle types, including trucks, where simulator-based learning can match or outperform traditional methods with proper planning. State departments of transportation (DOTs), including INDOT, have explored simulators for snowplow training since the early 2000s with reports indicating positive trainee reception and potential fuel and cost savings, though long-term skill transfer remains challenging to quantify. INDOT's prior work (Debs et al., 2023) highlighted growing interest in simulator technology among state DOTs, setting the stage for this study. This report addresses the gap in comprehensive best practices for simulator use in state DOT driver training, focusing on INDOT's needs for CDL and winter operations training. The research team performed a literature review, short- and long-term surveys, focus groups, performance data analysis, historical data analysis, case studies of simulator programs, and synergy assessments with Indiana agencies. These efforts, guided by research questions on simulator utilization and resource sharing, aimed to identify best practices; recommend simulator-based training content; and evaluate effectiveness through driver feedback, performance metrics, and INDOT winter operation records.

Findings

The investigation revealed that driving simulators are highly effective in addressing INDOT's training needs, particularly for new and less experienced drivers. Drivers' feedback underscored the simulators' positive reception, with novices reporting increased confidence and comfort, particularly in snowplow operations where the gains in Year 2 were significant despite lower baseline ratings. Realistic scenarios, such as navigating Indiana's

highways or winter conditions, drove higher engagement, while less realistic ones highlighted the need for scenario refinement. Simulators proved invaluable for bridging the gap between theory and practice, enabling novices to develop decision-making and situational awareness before BTW training. CDL training showed broad improvements, though minor feedback issues warrant further review. These findings suggest simulators enhance training outcomes but require careful scenario design and evaluation to maximize impact. Performance data analysis further validated the simulators' value, while discovering distinct driving patterns across skill levels, age groups, and years of experience in five modules, including snowplowing and low-visibility scenarios. Novice drivers exhibited erratic speed control, abrupt acceleration, and frequent braking compared to experienced drivers who maintained stable, controlled patterns. A structured feedback pipeline integrated real-time data with video and performance summaries to identify anomalies such as collisions or unsafe distancing and to generate personalized feedback, such as warnings for sidewalk collisions or turning exercises for spatial awareness. This data-driven approach, though experimental, supports targeted training interventions and highlights the need for integrated analysis to contextualize performance metrics by offering insights into driver behavior and training effectiveness.

Long-term assessments, conducted 4 to 6 months post-training via surveys, focus groups, and historical data analysis, confirmed sustained confidence gains in CDL (mean scores of 6.62 in Year 1 and 6.28 in Year 2) and snowplow driving, though Year 2 snowplow confidence was lower (mean 5.59 vs. 6.39 in Year 1). Year 2 also had a higher proportion of novice drivers. Surveys indicated strong endorsement of simulator training's ease of use and job relevance, with Year 2 respondents (53.3% young drivers) rating benefits such as task efficiency highly, though access and skill mastery scored lower due to centralized simulator locations. Focus groups at Greenfield and Winamac praised simulators for novice training and efficiency but noted limitations in graphical realism, haptic feedback, and value for experienced drivers, suggesting more diverse scenarios (e.g., real-world plow routes, equipment malfunctions) and data-driven debriefs. Historical snow operation data was collected and analyzed to examine how INDOT can leverage these insights to inform labor allocation, training needs, and incident management, as well as to evaluate the effectiveness of the snowplow driving simulator. The analysis showed a dependency on transferred and temporary drivers across INDOT's North, Central, and South regions during snow operations. Incident rates were higher during holidays (0.29%) and severe weather events (0.25%) compared to normal conditions (0.13%), with regional differences and relatively higher rates in the North region. While the South region effectively managed severe weather through high deployment and resource use, the North region exhibited high individual workload despite increased staffing, and the Central region under-deployed, indicating limited responsiveness. Simulator training reduced working hours, particularly for novice and middle-aged drivers, suggesting improved efficiency.

Case studies of existing simulator programs demonstrated operational flexibility, with one program training 35–40 drivers per session using fixed and mobile simulators for CDL and

maintenance training, and another training 1,666 operators over two years across 14 divisions using a mobile trailer deployed. These programs highlighted the simulators' ability to accommodate large trainee volumes, adapt to varying skill levels, and deliver training in diverse locations, informing strategies for usage rates and equipment placement. Analysis of synergies with Indiana agencies identified municipalities, via the Local Technical Assistance Program (LTAP), as ideal partners due to aligned training goals. However, due to the high demand for simulator seat time (6,224 hours annually) driven by Greenfield and LaPorte's large driver and CDL trainee populations (364 and 352 drivers, 125 and 77 trainees, respectively) by INDOT, further exploration of how to effectively share resources between agencies and districts is recommended. Fall training peaks, especially in November, exceed capacity in most districts, necessitating additional simulators and strategic scheduling to ensure timely snowplow training.

Challenges include the difficulty of measuring long-term skill transfer due to complex variables and the need for strategic resource allocation to ensure broad access across INDOT's six districts. Data from simulator sessions offer opportunities for personalized debriefs, but robust evaluation frameworks are needed to track performance and justify investments. This study also identified potential for interagency collaboration to share simulator resources to enhance cost efficiency and training reach.

Implementation

To integrate driving simulators into INDOT's training programs, several strategic actions are recommended. INDOT should develop a tiered curriculum, including annual core training for all drivers and advanced modules for experienced operators, leveraging the simulators' extensive module library to address diverse needs. Acquiring an additional simulator for the Greenfield district will increase capacity, while a district-sharing framework will optimize resource use, particularly for time-sensitive snowplow training in areas like LaPorte, where scheduling should align with winter demands. Clear communication is essential to position simulators as supplementary tools and emphasize learning objectives over visual realism. INDOT should harness simulator data to enhance debriefs, using performance metrics to tailor feedback and identify skill gaps. A comprehensive evaluation framework, maintained by INDOT, should track trainee outcomes, retention, and on-road performance to assess effectiveness and guide refinements. Exploring partnerships with other Indiana agencies or simulator manufacturers could further reduce costs and enhance scenario development. These steps will ensure simulators are deployed efficiently and support INDOT's goals of improving driver preparedness, safety, and operational resilience while addressing logistical and economic considerations for sustainable implementation.

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1. INTRODUCTION

The Indiana Department of Transportation (INDOT) currently has more than 2,000 drivers who need yearly training to safely maintain its operations and the yearlong maintenance of Indiana roads. Moreover, every year INDOT hires hundreds of new employees who are given specific training to obtain their Commercial Driver's License (CDL) to operate INDOT's vehicles. Often, the training includes a lecture and a behind-the-wheel (BTW) portion. And, while some trainees may be seasoned drivers, others have never operated larger vehicles and may be overwhelmed. Furthermore, some BTW training lacks seasonal features that are key for learning safety of operations, such as training for changing visibility and pavement conditions.

To this point, simulators have been historically used to mitigate some of the shortcomings of hands-on training with actual equipment by drawing on four main advantages: (1) simulators can be customized to training needs; (2) data collection on training engagement and performance can be easily gathered and analyzed; (3) drivers train in a safe environment; and (4) the equipment can provide a chance for trainees to review the sessions and discuss points of weaknesses (de Winter et al., 2012). For example, digital simulators have been used in the flight, space, and military industries since the 1970s and are now widely accepted as training practice because it reduces cost, allows for a safe training environment, and the rehearsal of complex operations (Allerton, 2010; Page, 2000). In fact, simulator training is a routine part of airline pilot annual training, during which pilots usually "...spend two days every six months undertaking recurrent training and checking in a flight simulator" (Allerton, 2010, p. 748). Moreover, despite much focus on improved graphics in the last decades, previous research has indicated that high fidelity is not as important as carefully matching the simulator technology to the tasks the equipment is being used to replicate (Allerton, 2010).

Specific to driver training, most of the previous research on the use of driving simulator equipment has explored specialized training situations. Results from these studies have suggested improved safety awareness, perception of risk and confidence levels for drivers trained using simulators for different vehicles, such as ambulances (Prohn & Herbig, 2020), tractors (Ojados Gonzalez et al., 2017), and passenger cars (Yahoodik & Yamani, 2021). More interestingly, previous research with truck drivers indicated a comparable or smaller amount of time to apply certain in-truck driving skills in a simulator when compared to traditional, BTW learning (Hirsch et al., 2017). This can be achieved with careful planning for the equipment and training to avoid over or underload and maximize the effectiveness of training (Hirsch et al., 2017).

State departments of transportation (DOTs) have carefully explored the use of driving simulator equipment for snowplow driver training since the early 2000s, with eight reports being publicly available. The methods used in the reports varied, with some having a literature review focus (Debs et al., 2023; Masciocchi et al., 2006), others utilized case studies (Kihl et al., 2006), software development (Ash et al., 2022), and experiments to analyze training effectiveness (Debs et al., 2023; Masciocchi

et al., 2007; O'Rourke, 2011; Strayer et al., 2004) and potential fuel and maintenance efficiencies (Kihl et al., 2007; Strayer et al., 2004). Our previous work (Debs et al., 2023) is the latest of those commissioned reports and included a literature review, interviews with snowplow drivers and supervisors, and a survey of other state DOTs and of drivers undergoing a pilot training, suggesting an increase in interest by state DOTs on driving simulator technology for training.

Furthermore, findings from those previous state DOT reports suggested that the use of driving simulators in training for snowplow drivers is well received by trainees (Debs et al., 2023; Kihl et al., 2006; Masciocchi et al., 2007; Strayer et al., 2004), but measuring long-term effectiveness of the use of driving simulators for training and skill transfer is difficult due to the complexity of factors involved (Kihl et al., 2006; O'Rourke, 2011; Strayer et al., 2004). Improved driver performance was suggested in the comparison of pre- and post-training simulated drivers in Masciocchi et al. (2007), and improved confidence and comfort level in snowplowing for INDOT was also suggested in Debs et al. (2023) when comparing pre- and post-training driver feedback. However, sustained learning gains and statistical significance were not demonstrated due to the piloting nature of studies and state DOT reports focused mainly on snowplow driver training. Previous research also indicated a reduction in fuel consumption and cost related to accidents (Kihl et al., 2007; Strayer et al., 2004), but issues with data reporting, and the complexity of factors involved in an accident, make generalization difficult.

To summarize, many previous technical reports and academic papers indicate the benefits of driving simulators for training in different contexts, the need for careful planning for its use and evaluation, and the increasing number of state DOTs utilizing this technology for training. However, little recent research has been conducted to evaluate holistically best practices in the use of driving simulators in the training of state DOTs' drivers, considering the logistical and economical challenges of implementation beyond drivers' perceptions and performance changes. The present research addresses this gap, taking into consideration the needs of INDOT for training its new employees to obtain their CDL and yearly training for winter operations. Our research is guided by the following research questions:

- How to utilize driving simulators for INDOT's driver training programs (new hire CDL and yearly winter operations training)?
- How to effectively share resources with other Indiana state and local agencies to maximize impact of driving simulators for training?

To address these research questions, this report presents useful information to allow INDOT to make an informed decision by expanding on the findings from the technical report for SPR 4651 ("Synthesis Study on Employing Snowplow Driving Simulators in Training," from Debs et al., 2023). Specific objectives of this study included:

1. To determine best practices for the utilization of driving simulators in INDOT driver training, including synergies between other local or state agencies.

2. To recommend course content to be included in a driving simulator course by training type, experience type and driver type (transfer vs. regular) based on driver feedback, current training materials and previous research findings.
3. To measure training effectiveness utilizing drivers' perceptions and performance in training and INDOT historical data.

1.1 Background Literature

The literature review section covers previous academic and state DOT-sponsored research, starting with the use of driving simulators for training purposes, followed by its use in snowplow driver training and for CDL training.

1.1.1 Use of Simulators in Training

Constantly driven by technological innovation and increasing awareness for occupational safety, over the past decades, various forms of simulator have emerged and been adopted in different industries to promote safer and more effective occupational safety training. For example, the training of aircraft operations in a real-world environment could be a very risky situations, especially in the early stages of training (Saastamoinen & Maunula, 2021). Therefore, as early as in the 1910s, the first rudimentary flight simulator was invented to provide a low-risk training environment (Page, 2000). In the past forty years, the wider adoption of flight simulation contributed significantly not only to enhancing flight safety but also reducing the training costs in terms of fuel and aircraft maintenance savings. Nowadays, flight simulators have become an essential part of operations for both civil airplanes and military organizations (Vidakovic et al., 2021), from which the Federal Aviation Administration (FAA) allows a portion of flight time requirement to be substituted by the simulator training (Flight Simulation Training Device Initial and Continuing Qualification and Use, 2016).

Apart from flight simulators, other forms of simulator, such as driving simulators, have also gained popularity in the past decades. Starting in the early 1970s, Volkswagen built its first driving simulator based on a 3 degree of freedom (DOF), motion-based platform. This simulator was equipped with a screen installed in front of the windshield (Bouchner, 2016). Since then, more complex-designed and novel driving simulator systems have been developed. For example, to simulate a more realistic driving experience, 6 DOF motion-platforms, often enabled by hydraulic, electric, or pneumatic actuators, were developed to allow certain range of motion in all three axes (heave, surge, sway) and tilting in all three angles (yaw, pitch, roll; Bouchner, 2016). Furthermore, other motion cues, such as vibrations, can also be included for enhanced realism. Some simulators provide ultra-realistic experiences, such as the NADS-1 at the University of Iowa (Figure 1.1), which is mounted on a rotating platform in an immersive, multisensorial experience.

Perceiving its advantages in providing a low-risk and controlled testing environment, in the recent decade, extensive studies have been conducted to investigate the effectiveness of using driving simulators for training. For example, recent studies have explored the adoption of driving simulators in various training scenarios, including specialty vehicle training (Hirsch

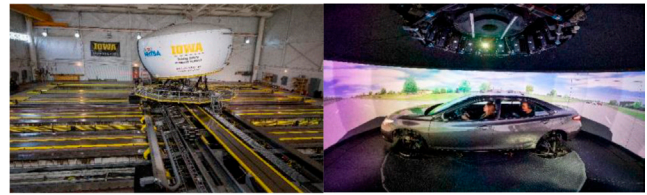


Figure 1.1 NADS-1 Driving Simulator Exterior (left) and Interior View (right). Photo Credit: University of Iowa, Reproduced With Permission.

et al., 2017; Prohn & Herbig, 2020), risk awareness assessment (Thorslund et al., 2024), drivers' decision-making (Calvi et al., 2020). Results from these studies indicate potentially beneficial outcomes of driving simulator adoptions in training such as potential skills transfer, safer driving behavior, and improved decision making.

In addition, some researchers have also investigated the integration of different technologies into driving simulators to increase effectiveness and comfort training. For example, through improvement of simulator hardware such as the addition of certain vibrations to the driver seat, symptoms of cybersickness could be mitigated (Lucas et al., 2020). From the software perspective, on the other hand, the inclusion of features such as high-fidelity graphics and physics, real-world accident-based simulator scenarios design also have positive contribution to simulator training experience and effectiveness (Bobermin & Feirerra, 2021; Ojados Gonzalez et al., 2017).

1.1.2 State DOTs Use of Driving Simulators for Snowplow Driver Training

Beyond academic researchers' interest in driving simulators, many of its uses can also be found in vocational training. Based on a synthesis report by Debs et al. (2023), eight reports from six state DOTs, including the state of Indiana, have conducted studies regarding driving simulator adoptions in snowplow driver training. For example, previous studies conducted by various state DOTs (Ash et al., 2022; Debs et al., 2023; Kihl et al., 2006, 2007; Masciocchi et al., 2006, 2007; O'Rourke, 2011; Strayer et al., 2004) have consistently highlighted the potential benefits and challenges of snowplow driving simulators. Specifically, the simulator training could improve operators' preparation for adverse winter conditions, build confidence in navigating complex snowplow environments, and may lead to reduced crash rates and lower fuel consumption (Debs et al., 2023; Kihl et al., 2006, 2007; Masciocchi et al., 2006, 2007; O'Rourke, 2011; Strayer et al., 2004). Furthermore, user feedback has generally been positive, along with some physiological measures (e.g., eye-tracking data) indicating that experienced drivers find simulated scenarios less cognitively taxing than novices (Masciocchi et al., 2007).

Despite promising findings, several limitations still exist. Short experiment durations and limited long-term follow-up results have caused difficulties in validating long-term performance improvements, while the diversity of environmental factors and driver experience levels also complicates the generalization of results (Kihl et al., 2006, 2007; Masciocchi et al.,

2006, 2007; O'Rourke, 2011; Strayer et al., 2004). Practical concerns such as simulator downtime and restricted access to training sessions could further limit wide implementation among the snowplow drivers.

More recent information for snowplow driving simulator adoption can be found in the reports commissioned by Ohio DOT (ODOT) and INDOT (Ash et al., 2022; Debs et al., 2023), each covering a different aspect of simulator training for snowplow drivers. Ash et al. (2022) focused on software perspectives in developing customized snowplow scenarios for future training. The study concluded with recommendations made to ODOT for implementation and training materials, yet it did not evaluate the training and use with driving simulators by ODOT drivers. Moreover, the report highlighted some difficulties in customizing scenarios for specialized driver training (Ash et al., 2022).

On the other hand, the technical report commissioned by INDOT conducted a more in-depth synthesis and a pilot study on snowplow driving simulator adoption (Debs et al., 2023). Focusing exclusively on the pilot results with 64 trainees presented in Debs et al. (2023), their results indicated generally favorable feedback from the drivers in terms of software and hardware features of the snowplow driving simulator, as well as different contents included in the simulator training. Moreover, most of the participants did not experience discomforts during the training, though some extreme cases were observed, suggesting trainers should still be cautious about participant's physical conditions during the training. In addition, this pilot study measured drivers' comfort and confidence level toward various snowplow-related activities, from which two activities "plowing near ditches and edges" and "plowing during whiteouts" saw large increases of more than 10% in terms of comfort level between the pre and post measurements. The overall confidence level also increased by 9.2%, suggesting potential effectiveness of simulator training in snowplow scenarios (Debs et al., 2023).

1.1.3 Use of Driving Simulator for CDL Training

In addition to applications in snowplow driver training, driving simulators were also extensively studied and deployed for commercial motor vehicle training. For example, two early studies from the University of Central Florida (Allen & Tarr, 2005; Tarr, 2005) investigated the human performance outcomes based on four levels of driving simulators, ranked by system fidelity. The increase in human performance was measured by the Virtual Check Ride System (VCRS), a virtual duplication of CDL test (Allen & Tarr, 2005). Conclusions from these studies revealed that the simulator with the highest fidelity yielded in highest human performance scores, though the authors noted simulators from other levels could also contribute significantly to improving human performance (Allen & Tarr, 2005).

Meanwhile during the 2000s, the U.S. Department of Transportation, in collaboration with Virginia Tech Transportation Institute, conducted a two-phase study to validate commercial vehicle driving simulators (Morgan et al., 2011; Robin et al., 2005). Specifically, the Phase I study focused on the development of simulator scenarios and lessons, pilot implementation

of instructional, testing, as well as all other activities that would be utilized in the full-scale implementation in Phase II (Robin et al., 2005). It is worth mentioning that the developed simulator training scenarios and curriculum structures in Phase I were made parallel to the BTW course, thereby making the measurement and evaluation more comparable. During the next phase of the study, from 2006 to 2010, the researchers then examined effectiveness of driving simulator adoption for entry-level commercial vehicle driver training, and the State Division of Motor Vehicle (DMV) driver tests (Morgan et al., 2011). Upon completion of the Phase II study, several highlighted insights were revealed by the authors. For example, Morgan et al. (2011) indicated that simulator training was a valid method for training entry-level commercial motor vehicle (CMV) drivers, given the evidence that no differences were found in real-world vehicle lateral control between simulator- and conventional-trained drivers. Moreover, the simulator training group demonstrated moderately significant correlations between simulated and actual road test scores. These two findings suggested the potential skill transfer from simulated environment to real-world practice, which well aligned with outcomes from Hirsch et al. (2017) validating transfer of basic truck control skills from simulator to real truck. Their results, conducted at the Canadian truck driver training centers, emphasized the transferability of basic vehicle control skills, such as gear shifting and backing maneuvers, from a high-fidelity simulator to actual vehicles. Key findings revealed that learners on simulators achieved skill competency at least as quickly as those trained conventionally, freeing valuable time for practicing safety-critical skills. The research highlighted the robustness of findings across varying experimental designs and stressed the integration of simulators within standard training curricula (Hirsch et al., 2017).

Other positive outcomes noted by Morgan et al. (2011) also implied small cost savings on simulator-based training over the conventional training method, as well as favorable opinions from drivers. Though multiple benefits were found from driving simulator adoption in commercial vehicle driver training, Morgan et al. (2011) still pointed out several key future research areas, which included the finding of "best practices" to ensure skill transfer of simulator training to BTW training, long-term safety implications of different training methods and modalities, as well as the need to standardizing novice-drivers training scenarios and equipment for both BTW and simulator training.

In conclusion, driving simulators have emerged as a valuable tool in CDL training, offering benefits such as skill transferability, cost savings, and enhanced safety outcomes. However, their effectiveness depends on factors like system fidelity, scenario design, and integration with BTW training. While simulators address several limitations of conventional training methods, challenges related to standardization and long-term safety outcomes still persist. Future research should prioritize developing best practices for simulator training, refining scenario validity, and examining the long-term implications of simulator-based instruction on driver performance and safety. By addressing these challenges, driving simulators can continue to play a pivotal role in advancing commercial driver training methodologies.

2. RESEARCH DESIGN

This research utilizes a mixed-methods approach through six different tasks to make recommendations to INDOT about the use of driving simulators for their driver training programs (see Figure 2.1). Most tasks, with the exception of Task 2 (long-term training assessment) and Task 6 (recommendations), were carried out in parallel. Tasks 1, 2, and 3 relate to the development and assessment of INDOT driving simulator-based training. Tasks 4 and 5 relate to evaluating considerations for a business case to the use of driving simulators in training, combining INDOT considerations with those of other state DOTs and public agencies. Finally, findings from previous tasks converge into Task 6 to make recommendations for the use of driving simulators in INDOT’s driver training programs.

Below we describe each task briefly:

- **Task 1 – Development of training modules:** This task includes the procurement of the two driving simulators installed in Greenfield and LaPorte districts, as well as module evaluation and selection. The research team and INDOT evaluated the modules available in the driving simulator. Following, the research team met with INDOT representatives in Fall 2023 to determine initial training modules from the driving simulator as well as other training considerations for the CDL and snowplow driver training programs. These modules and considerations were then revised based on findings presented by the research team and INDOT own experiences, and adjustments were made in a meeting in Fall 2024. Considering driver feedback and ongoing results from the project, an additional driving simulator was procured and installed at Crawfordsville during Spring 2025.
- **Task 2 – Short-term training assessment:** This task provides information related to data collected and analyzed by the research team before, during and immediately after the simulator-based

trainings. These trainings were conducted by INDOT employees and attended by INDOT-selected drivers at the two pilot locations (Greenfield and LaPorte districts) as part of their usual employment. This includes pre- and post-training surveys for CDL and snowplow driver training, and performance results captured by the driving simulators for select modules. Results were analyzed quantitatively and assist in evaluating training and equipment perceptions, as well as perceived improvement and driving patterns in the driving simulator.

- **Task 3 – Long-term training assessment:** This task evaluates the impact of driving simulator training on INDOT’s operations and drivers’ perceptions. A combination of survey and focus groups was utilized to gather feedback from trainees trained at least 4 months prior. This allowed trainees to reflect on their training and its impact on operations. In addition, historical winter operation and incident data were analyzed to understand INDOT’s historical winter operations and to investigate suitable training strategies. Furthermore, comparisons between pre-intervention and post-intervention INDOT data were conducted to assess the actual impact of training on operations.
- **Task 4 – Case studies:** During this project, the research team visited two other state DOTs that have implemented simulator-based driver training. This section outlines the findings from each of these case studies.
- **Task 5 – Synergies with other public agencies:** This task summarizes the analysis of expanding the driving simulator training program to other INDOT districts. This includes evaluating use and down time per district. Additionally, other public agencies were reviewed to determine potential synergies, with a special focus on local agencies.
- **Task 6 – Recommendations:** Task 6 utilizes previous tasks’ findings, as well as existing literatures to provide specific recommendations to INDOT about using driving simulators in their training programs.

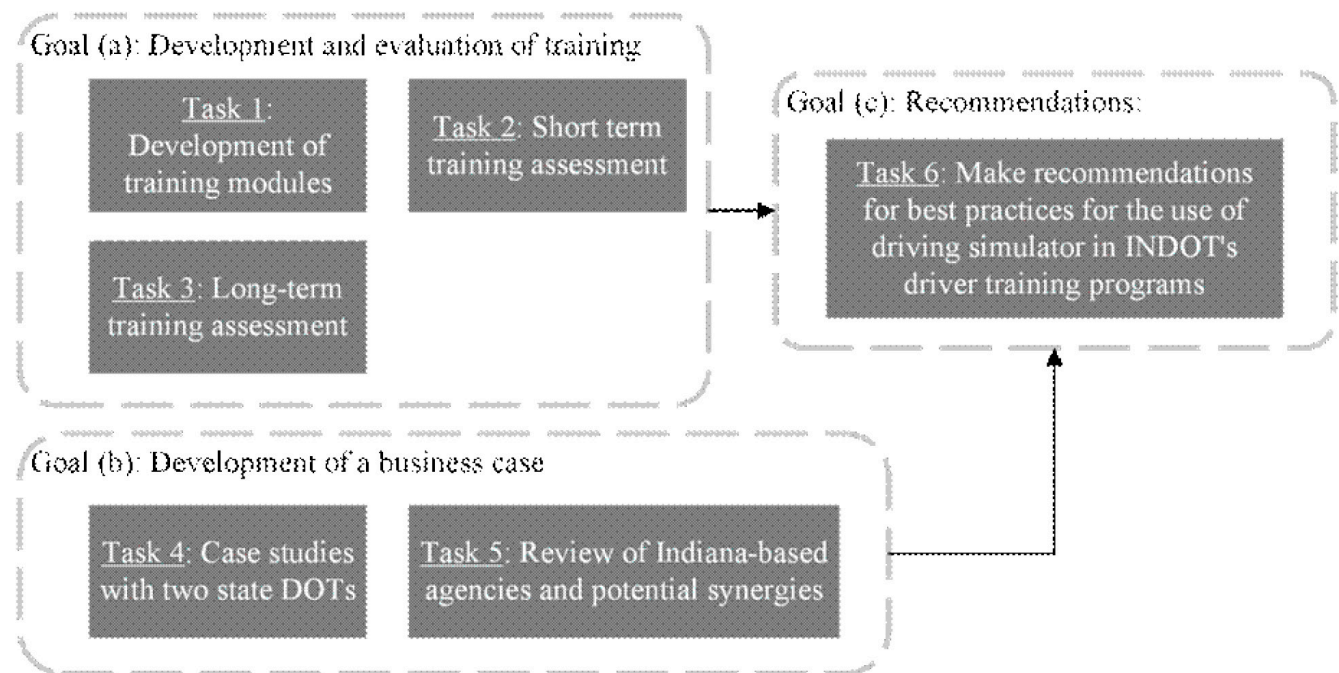


Figure 2.1 Overview of Research Activities and Deliverables.

3. WORK COMPLETED

All tasks for this research project have been completed. This section describes detailed findings per task, for Tasks 1 through 5.

3.1 Task 1: Development of Training Modules

For this project, the research team initially has procured two VS600M Simulators from Virage Simulation. Two simulators were delivered and installed at INDOT locations (Winamac and Greenfield, Indiana) during Fall 2023. One simulator was additionally delivered and installed at an INDOT location in Crawfordsville, Indiana, in June 2025.

In preparation for receiving the simulators, the research team reviewed the available modules to assess their suitability for research purposes and module summaries were prepared. In August 2023, a focus group with nine key INDOT and Local Technical Assistance Program (LTAP) stakeholders was held in West Lafayette, Indiana. During this meeting, the research team guided the stakeholders to propose training format and initial modules for the snowplow driver training and CDL trainings. However, due to the broad objectives of the CDL training, it was not possible for the stakeholders to finalize the module selections during this meeting and a subsequent meeting was held by INDOT with their trainers to provide the original module selection for CDL training. For snowplow driver training, ten modules were selected, and the initial format established included a 4-hr training for four trainees at one time, with approximately 1 hr of seat time in the simulator for each trainee. The main foci of the training were to reduce asset damage and accidents, improve performance under extreme weather, and better train drivers for different truck configurations. The driving simulator snowplow driver training should occur prior to the snow season, and ideally close to INDOT’s “snow schools,” which are a one-to two-day district-based winter operations training that occur yearly around October. For CDL training, INDOT trainers got together in early 2024 and suggested the use of minimum nine modules over a 10-hr training for two to three trainees at a time, aiming for several hours of seat time per trainee spread across many days. In both cases, four modules from the list of modules used in the training were selected by the research team to collect data through the driving simulator learning management system for further analysis. The main objectives for the simulator training for CDL learners were to increase behind the wheel training rotation, driver confidence (in driving and testing) and

improve drivers’ defensive driving skills. The simulator training proposed would be performed between CDL-trainees 40-hour theory-based training and their BTW training. The driving simulator would supplement the teaching of theory topics as well as used during the downtime of BTW training. The downtime currently occurs due to the number of trainees compared to the number of training vehicles and instructors available. Therefore, while some trainees are doing their BTW training, others could be using the driving simulator.

In 2024, a similar set of stakeholders were invited to participate in a second round of focus group. Five stakeholders participated in the session during which the research team presented updated results from the previous year. For the snowplow driving simulator no changes were made to the format, though it was acknowledged that the training duration varied between 3 and 4 hr. A note was made to time the training for after district snowplow training refresher, which happens yearly around October or November, depending on the district. Objectives for the training remained largely the same as the previous year, with the addition of improving drivers’ confidence levels.

Moreover, modules remained the same, except for adding tow-plow related modules for select drivers. For CDL training, the main change was removing two parking modules, because of changes in the testing regulations in August of 2024. Two other modules were included, also totaling a minimum of nine modules over a 10-hr training, aiming for the same amount of seat time per trainee over the course of 3 to 4 weeks that trainees remain for their theoretical and BTW training. Objectives remained similar, with the exception of adding the training for different truck configurations, especially for drivers that are moving from a Class B to a Class A type CDL license. Table 3.1 summarizes the information for the training.

3.1.1 Review of Equipment Functionalities

The adopted simulator platform is model VS600M from Virage, which is intended to provide realistic simulation of many heavy-duty vehicles on various applications (see Figure 3.1 for visual). The simulator hardware features real truck components mounted on a compact three-axis motion base, which is capable of delivering authentic haptic feedback through the seat, steering column, and pedals. Both automatic and manual gearboxes are modeled, including multiple speed nonsynchronized transmissions with force-feedback vibrations on the shifter. In terms of the visuals, a wrap-around LCD array provides a 180° forward

TABLE 3.1
Driving Simulator CDL and Snowplow Training Summaries.

Training Format	Snowplow		CDL	
	Fall 2023	Fall 2024/Spring 2025	March–August 2024	September 2024–May 2025
Minimum number of modules	8	10	9 (minimum)	13 (minimum)
Number of modules used for evaluation	4	4	4	4
Number of trainees per session	2–3	1	4	4
Total training time	10 hr	10 hr	4 hr	3–4 hr
Minimum seat time per trainee	undefined	1 hr	1 hr	45 min to 1 hr
Frequency of training	Once a year after snow schools		Once per driving license certification	



Figure 3.1 Driving Simulator Installed at INDOT Facility.

view plus rear-view mirrors for a full 360° visual envelope, complemented by spatial three-dimensional sound. Realistic steering torque, responsive clutch, brake and accelerator mapping, and an integrated training-and-evaluation suite were also included to complete the immersive experience.

When it comes to the software features, the simulator package also includes fully structured truck training programs with more than 200 modules covering topics such as basic truck controls, maneuvers, plow techniques, speed and distance control, urban and rural driving, highway and interstate driving, as well as emergency response, and more. In addition, several targeted practices such as shifting, backing, and parking were provided to drivers for advanced practice. After each training module, a detailed performance report consisting of trainees' driving behaviors (level of acceleration, deceleration, etc.) can be accessed by the instructors for further evaluation and debriefing.

3.1.2 Modules Recommendations for CDL and Winter Operations Pilot Training

Two focus groups with INDOT training experts and stakeholders were conducted in 2023 and 2024 to identify and structure core CDL and winter operations simulator training modules for implementation. The focus group carefully reviewed and discussed various driving scenarios to reflect real-world challenges. The focus group discussed: (1) learning outcomes to be addressed by the driving simulator training; (2) recommended modules; (3) recommended training structure including length of training, number of trainees per training session, seat time per trainee, and frequency of training; and (4) additional recommendations. Key learning outcomes identified for CDL training were to increase behind the wheel training rotation, to increase confidence in driving skills, and to prepare for drivers equipped with defensive driving skills. Learning outcomes identified for snowplow training were to reduce assets being hit, to reduce sliding or guardrail accidents, to prepare for drivers to be able to use different truck configurations and extreme weather, and to increase drivers' confidence. Initially, a minimum of eight modules were selected for winter operations training in 2023, which were revised to ten modules in 2024. Similarly, an initial list of nine minimum driving simulator modules selected for CDL operations training in 2023 and then revised to 13 modules in 2024 (Table 3.1). These modules were chosen to address both routine and real-world driving conditions to ensure the training program could cover a broad range of skill requirements and incident responses.

3.2 Task 2: Short-Term Training Assessment

During both snowplow and CDL training, drivers' perceptions of the driving simulator use in training were collected using a pre- and postsurvey approach. Survey participants were recruited through flyers with a direct link to the survey before they started their training and asked to complete a survey before they started the driving simulator training (preintervention survey) and another at the end of their training (postintervention survey). All surveys were hosted in Qualtrics, an online survey website.

For the preintervention parts, both the CDL and snowplow survey started with Likert-type questions regarding drivers' comfort levels toward a variety driving tasks, followed by their overall confidence level before the simulator training. In addition, drivers were asked if they had previous experience with simulators as well as interest level in simulator training. At the end of the preintervention survey, an open-ended question was included in case the driver has any additional input. As for the postintervention, the CDL and snowplow instruments both contained demographics information, Likert-type scale questions for post comfort and overall confidence level toward various driving tasks. Moreover, using a 5- point Likert-type questions, drivers were asked about their perceptions toward the simulator training, including simulator hardware and software features, different aspects of the simulator training, recommendations of the training, time allocations, and any experienced physical discomforts. Similarly, an open-ended question was placed at the end of the postintervention survey to capture any additional information from the drivers. Appendix A includes the CDL and snowplow driver pre- and postintervention surveys.

Then, the collected data were downloaded from Qualtrics website as .csv files. Results are presented in three main topics: (a) impacts on confidence and comfort level; (b) perceptions of training equipment; and (c) perceptions about the training session. Descriptive statistics are provided for all close-ended questions. Then, to further evaluate potential benefits of using a driving simulator for training, inferential statistical tests were applied to drivers' comfort and overall confidence level pre- and postintervention. For snowplow results, an additional inferential test was also adopted to investigate if driver's experience level could impact driver's comfort and confidence level. It is however worth noting that both CDL and snowplow training data were collected shortly before and after the simulator training, thus do not reflect implications from long-term perspective.

Additionally, the research team analyzed performance data captured through the driving simulator. More information about the driving simulator performance analysis methods and results are included in Section 3.2.4.

3.2.1 Survey Results From Snowplow Drivers (Year 1)

Year 1 for snowplow driver training in this project contains data collected in Fall 2023, during which 80 drivers were selected by INDOT to participate in the simulator-based training in both Winamac and Greenfield locations. From the responses collected (n = 80), participants ranged widely in age, spanning

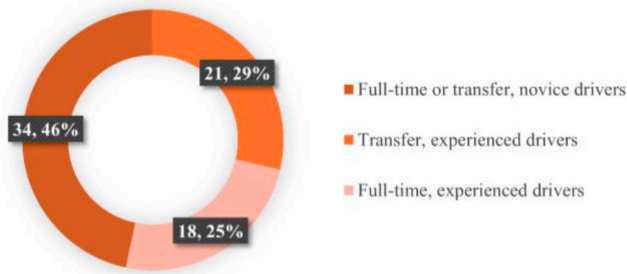


Figure 3.2 Snowplow Training Participants' Work Assignment and Experience Level (Year 1; n = 73).

from 18 to over 65 years, with the 35–39 (n = 12) and 45–49 (n = 12) age groups being the most represented. In terms of experience level, the participants' pool consisted of a slightly higher proportion of experienced drivers (n = 39, 53%), when compared to the novice drivers (n = 34, 47%), defined here as those who have three or less years of plowing experience.

When it comes to their main work assignment at INDOT, drivers could choose to identify themselves as working full time for the maintenance department, those that are transferred (here called “transfer drivers”) to the maintenance department on occasion, when additional snowplow drivers are needed during winter operations, or others. A significant portion of participants identified themselves as full-time drivers for INDOT (n = 45). Moreover, 32 participants identified themselves as transfer drivers, and three self-identified in other roles. Upon closer look, it was deemed all these three driver roles align with maintenance unit and, therefore, are treated as full-time drivers for the remainder of the analysis. In addition, Figure 3.2 summarizes experience and work assignment considered for analysis purposes: we had 18 full-time and experienced drivers, 21 transfer and experienced drivers, 34 novice drivers (who could be either full time or transfer), five full-time drivers who did not report years of experience, and two transfer drivers who did not report years of experience.

In addition, when asked if the participants had previous experience in using a driving simulator, most of the participants (n = 63) indicated that they did not have such experience, while a small portion (n = 14) indicated that they had used driving simulator previously either through their own devices or with INDOT.

3.2.1.1 Differences in Confidence and Comfort Levels.

The short-term pre- and post-training surveys assessed the comfort and confidence levels of snowplow drivers across a range of tasks, utilizing a scale from 1 to 7. A total of 16 items were used to measure comfort level and one item for confidence levels regarding various snowplow-related tasks. From an overall look, the comfort level remained fairly consistent between the preintervention (mean = 5.72, n = 77) and postintervention (mean = 5.70, n = 80) results. However, the research noted a small (+2.4%) increase was observed in confidence levels, rising from a preassessment mean of 5.75 (n = 77) to a postassessment mean of 5.89 (n = 80). Individual task

comfort level differences highlighted specific areas of improvement. For example, comfort with “plowing during whiteouts” showed the largest increase at 12.6%, while tasks like “overtaking other vehicles” saw a decline of 11.2%. However, it is worth noting that the items with declines were often associated with high preintervention ratings. For example, the tasks with highest declines in perception ratings, namely “overtaking other vehicles” and “judging stopping distances” both had relatively higher preintervention scores when compared to items with positive changes. Table 3.2 below summarizes detailed information regarding percentage changes in comfort across various tasks.

Next, to determine if there were statistically significant differences in snowplow drivers' comfort and confidence levels before and after training, inferential statistical tests were conducted on matched data from 64 participants, using $\alpha = 0.05$. Firstly, the Wilcoxon Signed-Rank test was conducted to compare pre- and post-training comfort levels among 64 matched responses across various tasks. This test was selected because of the nonparametric nature of the collected data set and suitability for comparing two sets of results from the same participants. It should be noted that the research team took a less conservative approach and did not adjust the significance level, despite running multiple tests. Given the exploratory nature of this research and the small sample size, adjustment of the significance level might result in loss of some relevant information. This analysis revealed a statistically significant increase in comfort for the task of “plowing during whiteouts” ($p < 0.001$), indicating

TABLE 3.2 Comfort and Confidence Level Differences for Snowplow Drivers (Year 1)*.

Items	Pre-Intervention		Post-Intervention		Difference (%)
	Average	SD	Average	SD	
Plowing during whiteouts**	4.58	1.7	5.24	1.49	12.6%
Utilizing a wing plow**	4.01	1.71	4.19	1.75	4.4%
Avoiding large objects when plowing	5.83	1.43	5.99	1.3	2.6%
Plowing near ditches and edges	5.74	1.36	5.83	1.29	1.5%
Driving in tandem	5.83	1.45	5.90	1.26	1.2%
Merging and exiting highway/interstates	5.77	1.33	5.84	1.34	1.1%
Multitasking to control equipment	5.73	1.32	5.78	1.33	0.8%
Avoiding small objects when plowing	5.75	1.38	5.77	1.29	0.4%
Backing	5.81	1.36	5.74	1.46	-1.3%
Changing traffic lanes	6.01	1.26	5.90	1.36	-2.0%
Reversing	5.77	1.37	5.65	1.56	-2.1%
Parking	6.27	1.17	6.06	1.38	-3.4%
Maintaining control of vehicle	6.16	1.27	5.93	1.3	-4.0%
Driving at appropriate speed for different road conditions	6.19	1.15	5.95	1.42	-4.0%
Judging stopping distances	6.19	1.18	5.85	1.42	-5.9%
Overtaking other vehicles	6.14	1.69	5.53	1.57	-11.2%

*Scale with 1 being extremely uncomfortable, 4 as neutral, and 7 being extremely comfortable

**Statistically significant difference at $\alpha = 0.05$

that participants could potentially feel more comfortable handling this challenging condition following the training. Another statistically significant finding was observed in the task “utilizing a wing plow,” with comfort levels showing a meaningful improvement ($p = 0.038$) from pre- to post-training. In addition, no significant change was found for other tasks that saw major declines in the descriptive tests, namely “overtaking other vehicles” ($p = 0.658$) and “judging stopping distances” ($p = 0.108$). Hence, these tasks might need more evidence to determine the effectiveness.

Moreover, to assess the effect of experience on comfort and confidence gains, the Kruskal-Wallis H test was employed to examine differences across driver groups (novice, experienced full-time, and experienced transfer drivers) from the snowplow survey data. The test results indicated no statistically significant differences across experience levels for any item at $\alpha = 0.05$, suggesting that the training’s impact on comfort and confidence was consistent regardless of experience. Nonetheless, near-significant trends emerged for tasks such as “avoiding small objects” ($p = 0.075$) and “multitasking to control equipment” ($p = 0.093$). These findings might imply that such tasks may resonate differently with varying experience levels, suggesting further exploration in future training sessions.

3.2.1.2 Drivers’ Perceptions and Attitudes Toward Simulator Equipment. The present and following paragraphs include more questions from the postintervention snowplow survey, using a similar Likert scale with five points. To begin with, the participants were asked about specific features of the simulator, from which the item “haptic inputs” that provides tactile feedback to mimic the feel of operating a snowplow, received the highest ratings for realism (mean = 3.88, median = 4, SD = 0.89). This was followed closely by “audio inputs” (mean = 3.80, median = 4, SD = 0.88), which help simulate the auditory cues associated with snowplowing tasks. Additionally, participants felt that the simulator replicated real-world driving conditions accurately, as indicated by a mean

realism score of 3.36 (median = 3, $n = 80$). Detailed rating of the simulator features is displayed in Figure 3.3.

When asked if experienced physical discomfort such as nausea, headache, or dizziness when receiving the simulator training, low rating of this item was recorded with a mean score of 1.83 and a median of 2 (SD = 0.88, $n = 80$). Most participants ($n = 66$) indicated they felt no or very little discomfort, while a small portion ($n = 14$) still experienced moderate to a great deal of discomfort. Hence, it is still suggested for trainers to closely monitor participants’ physical conditions. Figure 3.4 categorizes participants’ perceptions toward physical discomforts.

3.2.1.3 Drivers’ Perceptions and Attitudes Toward Simulator Training Session. The postintervention snowplow survey also asked participants regarding their perceptions on various aspects of the simulator training. Starting with the level of involvement when conducting the simulator training, drivers reported a strong sense of involvement in the training activities, as evidenced by a high average engagement score of 4.01 (median = 4, SD = 0.77, $n = 80$). In addition, the drivers generally found the training enjoyable, with a mean score of 3.80 (median = 4, $n = 80$), suggesting a positive reception to the new learning environment. Figure 3.5 summarizes drivers’ perceptions toward different aspects of the training.

When it comes to the adequacy of time allocated for simulator training, ratings received from the participants implied favorable feedback, with most drivers rated the duration as appropriate (mean = 4.21, median = 4, $n = 80$). This might suggest that the training schedule was generally well-aligned with drivers’ needs and expectations. Moreover, drivers also rated the usefulness of different training components, with “overall training” receiving the highest score (mean = 3.85, median = 4, SD = 0.87), reflecting its perceived value in preparing them for real-world scenarios. Among the individual content areas, the segment focused on communication skills received the highest score (mean = 3.58, median = 4, SD = 0.96).

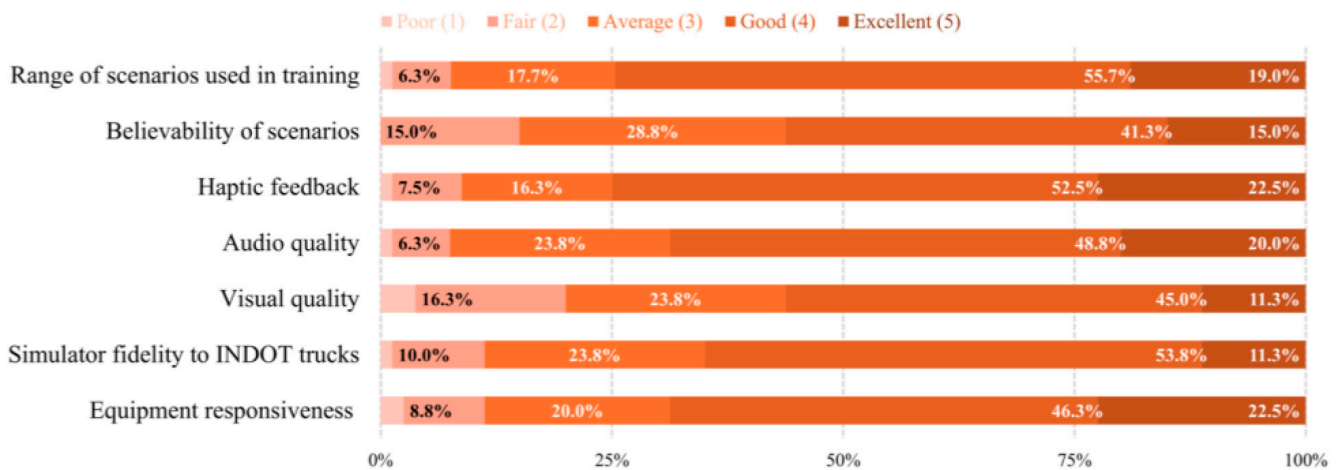


Figure 3.3 Participants’ Perceptions Toward Simulator Hardware and Software (Year 1).

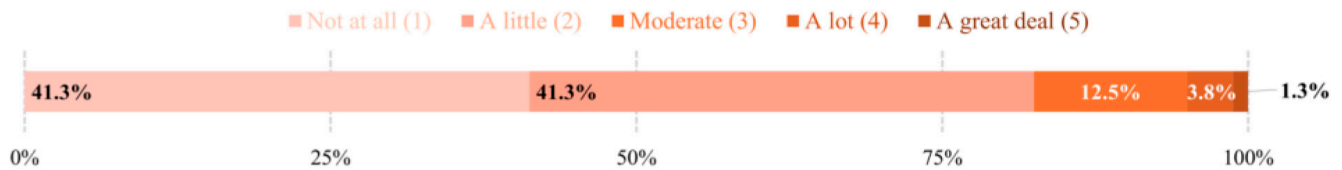


Figure 3.4 Participants' Perceptions Toward Physical Discomfort (Year 1, n = 80).

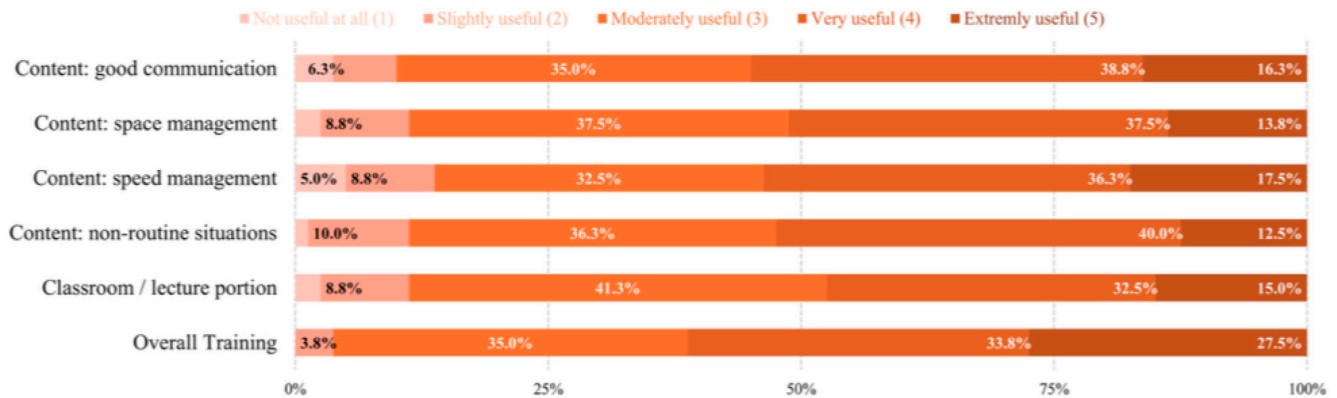


Figure 3.5 Participants' Perceptions Toward Different Simulator Training Aspects (Year 1).

Following, participants were asked if they would recommend the snowplow simulator training based on drivers' experience level (n = 80). From the feedback, the simulator training was highly recommended to novice drivers, with a high mean score of 4.41 and a median of 5. This was followed by experienced transfer drivers (mean = 3.71, median = 4.0, SD = 1.17), and experienced full-time drivers (mean = 3.30, median = 4.0, SD = 1.24). Moreover, it is worth noting that the simulator training was strongly recommended (mean = 3.81, median = 4, n = 80) for drivers across all experience levels, which may imply that the training offers relevant benefits for both new and experienced drivers.

Two open-ended questions were placed at the end of pre- and postintervention survey, respectively, to collect training-related information. For preintervention response, a majority of the drivers (n = 70) did not have comments, while a few drivers provided their perceptions the upcoming simulator experience such as the training should not be mandatory, and the training could be beneficial for new drivers. For postintervention results, responses are mixed with fewer drivers who had no further comments (n = 15). Some drivers (n = 8) indicated that they were satisfied with the simulator training and implied it should be beneficial for new drivers. On the other hand, few drivers (n = 7) pointed out the simulator could be improved in terms of reward system, realism, as well as training procedures. Overall, the postintervention responses suggested the simulator was seen as beneficial for preparing new operators, but some drivers had ideas for improving the realism and customization of the training.

3.2.2 Survey Results From Snowplow Drivers (Year 2)

Data collection for Year 2 was conducted between November 2024 and January 2025, during which a total of 84 trainees were selected for the driving simulator training

in Winamac and Greenfield INDOT training facilities. It is worth noting that three additional questions were added to the Year 2 snowplow simulator survey for more comprehensive evaluation: one question regarding drivers' confidence level when called by INDOT for snow emergency was included, one asking to provide additional information for whether they received debriefing session after the training, and one related to participants' top three takeaways for the simulator-integrated training experience.

Upon finalization of the data collection, 69 unique drivers answered the Fall 2024/Spring 2025 simulator training survey, specifically 69 responses collected for preintervention, and 56 for postintervention questions. These numbers were lower when compared to Year 1 snowplow training survey results. In terms of demographics information, participants' age varies from 18–65+ years old, with the age group 18–34 representing the largest number of drivers. Meanwhile, novice drivers (n = 36) with three or less years of experience took more than half (64.3%) of the participant samples based on postintervention responses, which was relatively higher when compared to those of the Year 1 results. Moreover, when asked for participants' main work assignment at INDOT, a majority of the drivers (n = 31) indicated that they work full-time at the maintenance department, followed by transfer drivers from other INDOT departments (n = 15). The remaining 10 participants indicated various positions, that upon further examination by the research team were deemed to be one full-time drivers and nine transfer drivers for the analysis. Figure 3.6 presents a full breakdown of the drivers experience and work assignments, which includes a total of 36 novice drivers, seven full-time experienced drivers, and 12 transfer experienced drivers. One full-time driver did not provide the information in terms of years of experience.



Figure 3.6 Snowplow Training Participants' Work Assignment and Experience Level (Year 2; n = 55).

TABLE 3.3
Comfort Level Differences for 2024–25 Snowplow Training.

Items	Pre-Intervention		Post-Intervention		Difference (%)
	Average	SD	Average	SD	
<i>Plowing during whiteouts**</i>	3.96	2.06	5.04	1.71	27.3%
<i>Utilizing a wing plow**</i>	3.62	2.02	4.60	1.68	27.0%
<i>Avoiding small objects when plowing**</i>	4.51	2.13	5.46	1.66	21.0%
<i>Plowing near ditches and edges**</i>	4.43	2.16	5.33	1.73	20.4%
<i>Multitasking to control equipment**</i>	4.57	2.08	5.49	1.61	20.1%
Avoiding large objects when plowing	4.69	2.14	5.47	1.68	16.7%
Reversing	4.59	2.27	5.33	1.88	16.1%
Changing traffic lanes	4.78	2.09	5.55	1.68	16.0%
Backing	4.57	2.27	5.25	1.86	14.9%
Driving in tandem	4.58	2.18	5.25	1.71	14.7%
Overtaking other vehicles	4.60	2.13	5.20	1.72	13.0%
Maintaining control of vehicle	4.91	1.98	5.53	1.61	12.6%
Judging stopping distances	4.82	2.18	5.41	1.75	12.2%
Parking	4.91	2.14	5.43	1.83	10.5%
Merging and exiting highway/interstates	4.93	2.09	5.40	1.76	9.6%
Driving at appropriate speed for different road conditions	4.96	2.05	5.35	1.83	7.9%

*Scale with 1 being extremely uncomfortable, 4 as neutral, and 7 being extremely comfortable

**Statistically significant difference at $\alpha = 0.05$

3.2.2.1 Differences in Comfort and Confidence Level (Year 2). Following, participants' perceptions of comfort and confidence toward 16 snowplow-related tasks were measured using a Likert-scale of 1–7, of which the results showed an overall increase in comfort level rating of 15.9% percent (pre = 4.59, post = 5.32). Specifically, the items “plowing during whiteouts” (+27.3%) and “utilizing a wing plow” (+27.0%) recorded the highest scores among the tested comfort-level items (see Table 3.3). On the other hand, a large increase of 22% in overall confidence level was also recorded from drivers' responses (pre = 4.44, post = 5.43). Although these changes are encouraging, it is important to note that confidence and comfort levels in the pretraining survey for Year 2 were somewhat lower than in Year 1. In 2024–2025 snowplow training, it is worth noting that an

additional question regarding confidence level was added to obtain more detailed drivers' perceptions, namely “if INDOT called you during a snow emergency, how confident would you feel about plowing snow in that situation.” Similarly, ratings received for this question indicated 13.4% increase in confidence level when called for a snowplow emergency.

Similar to the Year 1 snowplow driving simulator survey, inferential tests were applied to the Year 2 snowplow survey responses to determine whether the differences between pre- and postcomfort and confidence level items remain statistically significant. The tested dataset consisted of 48 matched participants. Since the distribution of the data deviates from normal distribution, two non-parametric inferential tests that were used in the Year 1 were also adapted in the Year 2's snowplow survey. To begin with, the researchers team ran the Wilcoxon Signed-Rank test to determine which comfort and confidence level items' differences are statistically significant, using $\alpha = 0.05$. Based on the results, 5 out of 17 tested comfort level items remains statistically significant, which are “utilizing wing plow” ($p = 0.002$), “plowing during the whiteouts” ($p = 0.005$), “multitasking to control equipment” ($p = 0.006$), “plowing near ditches and edges”, ($p = 0.037$) and “avoiding small objects” ($p = 0.04$). In addition, the difference in confidence level regarding driving a regular plow also tested statically significant ($p = 0.001$).

Apart from these, items such as “changing traffic lanes” ($p = 0.073$) and “confidence when called for snow emergency” ($p = 0.081$) could be considered near statistically significant. In addition to the Wilcoxon Sign-Rank test, the research team further conducted a Kruskal Wallis H test to determine if there are any differences between driver groups (novice, experienced full-time, experienced transfer) in terms of comfort and confidence level items. The results indicated that no items were tested statistically significant, suggesting the simulator training had consistent effect on drivers regardless of their experience level and work assignment.

3.2.2.2 Snowplow Drivers' Perceptions and Attitudes Toward Simulator Equipment.

Similar to instruments used in the Year 1 snowplow training, participants were then asked about their thoughts on simulator equipment given a Likert-scale of 1–5 during the postintervention survey. Firstly, participants found out that the overall simulator equipment could moderately simulate real-world scenarios (mean = 3.07, med = 3, n = 56) and indicated above-average ratings for all simulator hardware and software features. Among which the item “audio input” (mean = 3.62, med = 4, n = 55), and “range of scenarios used in training” (mean = 3.56, med = 4, n = 54) received the top ratings. The ratings for each simulator hardware and software features are shown in Figure 3.7.

In addition, the research team noted low level of overall physical discomforts among the driver (mean = 1.95, med = 2, n = 56). Yet, like pointed out by other short-term surveys results, a relatively small portion (14.3%, n = 8) of drivers still reported a lot to a great deal of discomforts during the training. Figure 3.8 summarizes drivers' perceptions toward physical discomforts during the simulator training.

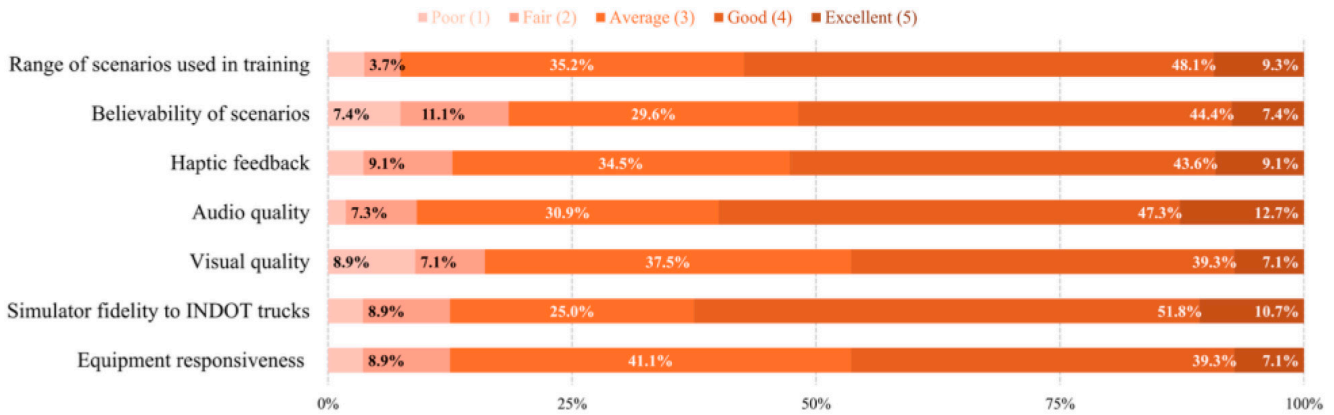


Figure 3.7 Participants' Perceptions Toward Simulator Equipment (Year 2).

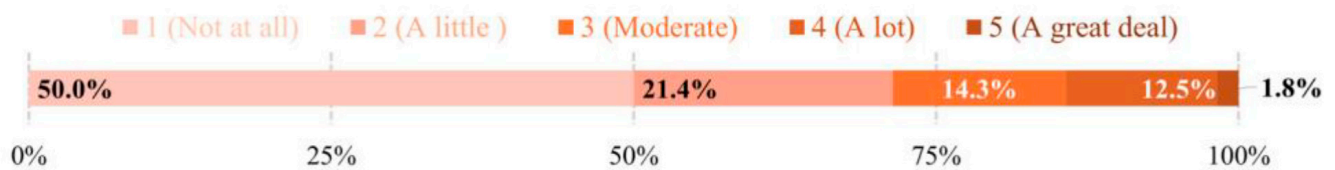


Figure 3.8 Snowplow Participants' Perceptions Toward Physical Discomfort (Year 2, n = 56).

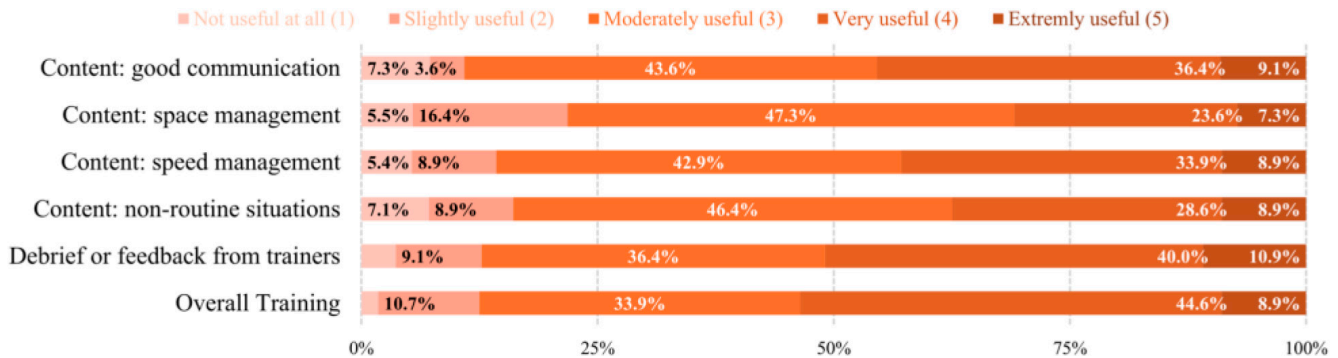


Figure 3.9 Participants' Perceptions Toward Usefulness of Simulator Training (Year 2).

3.2.2.3 Snowplow Drivers' Perceptions and Attitudes Toward Simulator Training.

Next, participants were asked to provide their perceptions toward various aspects of the simulator training. To begin with, participants indicated high level of involvement (mean = 3.61, med = 4, n = 56) when training with the simulator and that the training was a fairly enjoyable experience for them (mean = 3.50, med = 3, n = 56). Furthermore, the participants mentioned that the allocated training time was very adequate (mean = 4.21, med = 4, n = 56) and that most of them (n = 49) received either individual and/or collective debrief after the training. Moving on to training recommendations, participants mentioned that they would mostly recommend the novice drivers to receive the simulator training (mean = 4.11, med = 4, n = 56), followed by transfer drivers (mean = 3.48, med = 3, n = 56), and then experienced drivers (mean = 3.11, med = 3, n = 56).

Following, participants were asked to rate their perceptions regarding usefulness for simulator training based on five items, of which the “overall training” (mean = 3.48, med = 4, n = 56) and “debrief/feedback received from trainer during the simulator driving sessions” (mean = 3.45, med = 4, n = 55) were perceived as most useful aspects of the training. Besides, all other items also received above average ratings. Figure 3.9 showcases detailed ratings for items measured for useful aspects of the simulator training.

Upon finalization of both pre-and postintervention survey, open-ended questions were placed for collecting additional training information from the participants. For the preintervention survey, most participants (n = 67) indicated no further comments. Two trainees included comments, with one citing concerns for disability when participating in the simulator

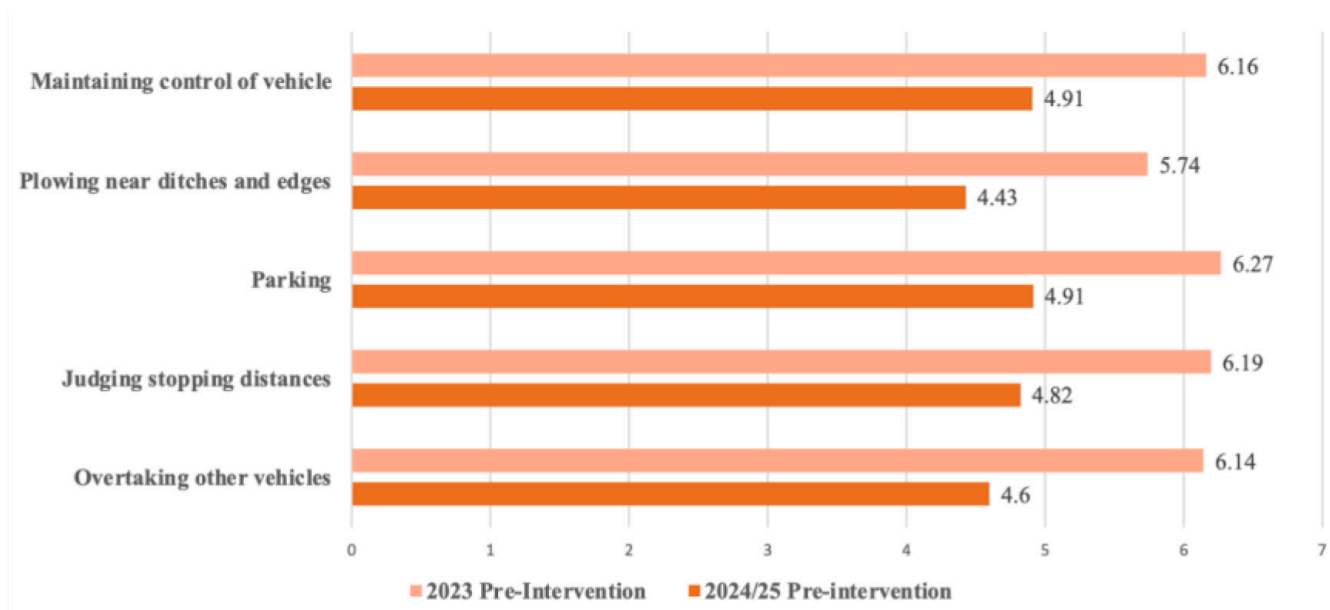


Figure 3.10 Partial Comparison of Comfort Level Items Between Year 1 and Year 2 Snowplow.

training, and the other one recommended extensive training for wing-plow drivers. During the postintervention survey, additional open-ended questions were provided to participants. Firstly, participants provided various input when asked about their thoughts on most effective parts of the training and reasons. Based on 33 collected responses, the top responses included 18 participants who implied that simulator training provided good opportunities for learning many techniques in snowplow operation, snow/ice skid controls, as well as general driving skills; six participants praised the realism of the simulator, citing accurate road conditions and the ability to provide new drivers and perspective before actual BTW driving; and, five participants implied that all the simulator training parts are effective. Following, participants were asked about their takeaways from the training, from which the top three named takeaways were situational awareness/perspectives for new drivers ($n = 7$), controls of the vehicle ($n = 5$), and realism of the simulator ($n = 4$).

3.2.2.4 Comparative Analysis for Snowplow Driving Years 1 and 2. In summary, while larger increase across all comfort level and confidence level items were recorded in the 2024–2025 snowplow simulator training, the research team noted that ratings in many preintervention items were lower than their counter parts recorded during the 2023 snowplow training (Year 1). For example, the measured task “judging stopping distances” recorded an average preintervention mean of 6.19 in Year 2, while such number was lower in the Year 2 results, with an average of 4.82. One possible explanation could be attributed to the higher percentage of novice drivers participated in the 2024–2025 training, where 64% of the participants were classified as novice drivers, compared to 47% of novice drivers in the 2023 snowplow training. A partial comparison of pre- and postcomfort level items results between Year 1 and Year 2 can be found in Figure 3.10.

On the other hand, several consistencies were also observed by the research team for the difference between pre- and post-training comfort and confidence levels. For example, the comfort level items “plowing during the whiteouts” and “utilizing a wing-plow” were the top two gained tasks in both 2023 and 2024 snowplow simulator survey and were both tested statistically significant. Other similar items that received consistent gains also included “avoiding small/large objects,” “plowing near ditches and edges,” as well as driver’s confidence overall confidence level, suggesting that the snowplow simulator might be particularly helpful in improving training effectiveness for these tasks. Table 3.4 showcases the breakdown of the top five gained comfort level items for Year 1 and Year 2 snowplow simulator training.

Similar consistent results were also found for perceptions of simulator equipment features and training. For example, both participants in Year 1 and Year 2 surveys indicated all items related hardware features and software features, along

TABLE 3.4
Comparison of Five Top Gained Comfort Items for Year 1 and Year 2 Snowplow Training.

Items	Gains Between Pre- and Post-Training Survey	
	Year 1 (Rank)	Year 2 (Rank)
Plowing during whiteouts*	12.6% (1)	27.3% (1)
Utilizing a wing plow*	4.4% (2)	27.0% (2)
Avoiding large objects when plowing	2.6% (3)	
Avoiding small objects when plowing**		21.0% (3)
Plowing near ditches and edges**	1.5% (4)	20.4% (4)
Driving in tandem	1.2% (5)	
Multitasking to control equipment**		20.1% (5)

*Statistically significant difference at $\alpha = 0.05$ at Years 1 and 2

**Statistically significant difference at $\alpha = 0.05$ at Year 2, but not Year 1

with usefulness of simulator training had at least above average ratings. Also, simulator training was highly recommended to new drivers, followed by transfer and full-time experienced drivers in both years' results. Open-ended questions highlighted benefits including realistic virtual practice environment for plow tasks and to gain perspectives of driving also in both years. These findings paired well with results from the CDL training and previous DOT technical reports (Masciocchi et al., 2007; O'Rourke, 2011), indicating that the adopted simulator platform and curriculum could be scalable and effective for developing targeted driving skills and tasks.

Meanwhile, although a majority of the participants in Year 1 (82.5%) and Year 2 (71.4%) simulator training implied low effect of motion sickness, there was still a relatively smaller portion of drivers mentioned that they experienced a higher level of discomfort that impacted their training. Considering that similar observations related to simulator discomfort were also noted by previous research in snowplow simulator training (Kihl et al., 2007; Masciocchi et al., 2007; O'Rourke, 2011), cautions for trainers to closely monitor drivers' conditions during training are strongly advised.

3.2.3 Survey Results From CDL Drivers (2024–2025)

Results for CDL driving simulator training consist of continuous training data from March 2024 to May 2025, from which a total of 72 unique drivers participated in the preintervention and 57 participated in postintervention perception survey. Starting from demographics information, based on the responses collected (n = 57), participants' age ranges from 18–65 years old, with a majority of groups fall into 18–34 years old (n = 35), which were considered young drivers. Next, participants were asked to provide their information regarding their current CDL license status and intended type of CDL license to obtain with the simulator training. Based on the results, many drivers (n = 40, 70%) indicated that this was their first time applying for a CDL license, followed by restricted Class A holders (n = 6, 10.5%), and restricted Class B holders (n = 6, 10.5%). In addition, most of the drivers (n = 53, 73.6%) did not have previous experience in using a simulator.

3.2.3.1 Differences in Confidence and Comfort Levels for CDL Participants. Driver's perception ratings toward comfort and confidence level in various CDL-related driving tasks were collected through pre- and postsimulator training surveys. From the surveys, using a Likert-scale survey of 1–7, a total of 16 items related to comfort level were provided to the participants, along with one item for confidence level. Based on an overall look, the research team noted positive increase across 14 out of 16 measured comfort level items when comparing the preintervention and postintervention results, with an overall increase of 3.4%. Among which, the researcher team identified that “overtaking other vehicles” (+15.7%) and “driving in low visibility conditions” (+7.3%) were among the top two tasks with highest gains. On contrast, comfort level for “parking” (-0.9%) and “maintaining control of vehicles” (-0.5%) were found to be slightly decreased at the postintervention survey.

TABLE 3.5
Individual Comfort Level Differences for CDL Drivers.

Items	Pre- Intervention		Post- Intervention		Difference (%)
	Average*	SD	Average*	SD	
<i>Overtaking other vehicles**</i>	4.79	1.78	5.54	1.57	15.7%
<i>Driving in low visibility conditions**</i>	4.96	1.48	5.32	1.49	7.3%
<i>Turning right**</i>	5.38	1.61	5.75	1.42	7.0%
<i>Judging stopping distances**</i>	5.36	1.45	5.68	1.53	6.0%
Multitasking to control additional truck elements	4.94	1.28	5.18	1.66	4.8%
Merging and exiting highway/interstates	5.35	1.58	5.55	1.64	3.9%
Driving at night	5.41	1.30	5.56	1.49	2.8%
Avoiding small objects when driving	5.44	1.37	5.60	1.50	2.8%
Reversing	5.18	1.55	5.30	1.65	2.3%
Avoiding large objects when driving	5.46	1.42	5.59	1.50	2.3%
Crossing railroad tracks	5.65	1.31	5.76	1.53	2.0%
Backing	5.27	1.42	5.35	1.59	1.4%
Changing gears	4.86	1.71	4.91	1.73	1.0%
Driving at appropriate speed for different road conditions	5.59	1.37	5.59	1.65	1.0%
Maintaining control of vehicle	5.66	1.28	5.63	1.57	-0.5%
Parking	5.50	1.36	5.45	1.57	-0.9%

*Scale with 1 being extremely uncomfortable, 4 as neutral, and 7 being extremely comfortable

** Statistically significant differences between pre- and post-test scores at p = 0.05

In addition, CDL driver's perceptions towards confidence level increased by 9.7% (preintervention mean = 4.64; postintervention means = 5.09). Table 3.5 provides a summary of the detailed results toward 16 CDL activities.

To investigate whether the large increase of driver's comfort and confidence level between the pre- and postintervention remains statistically significant, inferential tests were applied to the collected dataset consisting of 47 matched drivers. Firstly, using a $\alpha = 0.05$, the research team conducted a normality test to determine whether the collected pre- and post-Likert-scale data were normally distributed. Based on the results, none of the measured items fit the criteria. Hence, the research team proceeded to conduct a nonparametric inferential test, namely Wilcoxon Signed Ranked test, to determine if the increase in postintervention survey is statistically significant, using a similar $\alpha = 0.05$. The results revealed that 4 out of 16 items were tested statistically significant, which are “overtaking other vehicles” (p < 0.001), “turning right” (p = 0.003), “judging stopping distance” (p = 0.049), “driving in low visibility conditions” (p = 0.047). In addition to these four tasks, two items “avoiding small objects when driving” (p = 0.062), and the “confidence level” (p = 0.09) were near statistically significance.

3.2.3.2 CDL Drivers' Perceptions and Attitudes Toward Simulator Equipment. This and the following subsection present results from post-training CDL survey instruments

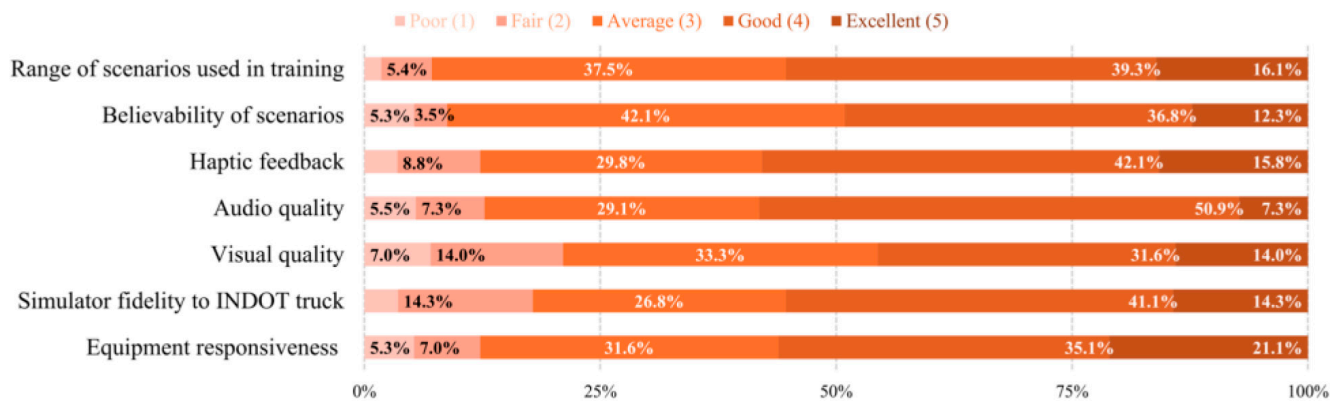


Figure 3.11 CDL Perceptions Rating Towards Simulator Hardware and Software Features.

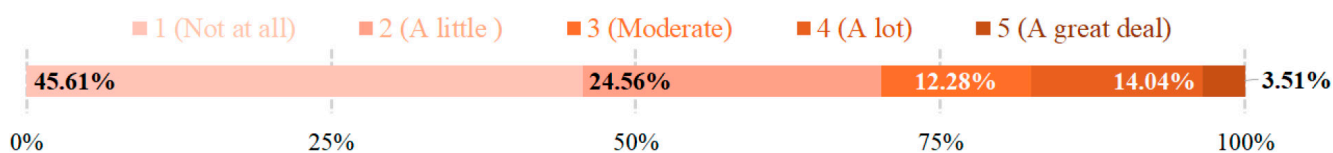


Figure 3.12 CDL Participants' Perceptions Toward Physical Discomforts (n = 57).

using a Likert-scale of 1–5. Starting with perceptions towards simulator’s capabilities in replicating the real-world scenarios, participants suggested that the simulator could moderately simulate real-world conditions (mean = 2.86, med = 3, n = 57). Following, the survey asked participants for perceptions toward specific hardware and software features of the simulator equipment. Based on the results, simulator equipment was generally found favorable by the participants as all items received above average ratings. Among which, the item “range of scenarios used in training” and received the highest perception rating from the drivers (mean = 3.63, med = 4, n = 56), followed by “equipment responsiveness” (mean = 3.6, med = 4, n = 57) and “haptic input” (mean = 3.58, med = 4, n = 57). Specific rating of each simulator equipment feature can be found in Figure 3.11.

Then, participants also indicated if they experienced any physical discomforts such as nausea or headache when interacting with the simulator. Based on the responses, while the research team noticed that majority of the participants only experienced little to none discomfort (n = 40, 70%), however it should be cautious that nearly 30% of the CDL drivers still experienced moderate to a great deal of physical discomforts. Therefore, CDL trainers should still extra attention to drivers’ conditions when conducting the simulator training. Figure 3.12 presents summarized information for drivers’ perceptions of physical discomfort during CDL simulator training.

3.2.3.3 CDL Drivers’ Perceptions and Attitudes Toward Simulator Training. In terms of perceptions toward the simulator training itself, collected responses indicated that participants were well involved (mean = 3.61, med = 4, n = 57) when training with the simulator, and the simulator training was perceived as a somewhat enjoyable experience (mean = 3.30, med = 4, n = 57).

Specifically related to aspects of the simulator training, participants found the simulator training course was moderately useful (mean = 3.41, med = 3, n = 56). We also note two items received top ratings in terms of usefulness, specifically the “classroom/lecture” (mean = 3.80, med = 4, n = 56) and “good communication” (mean = 3.63, med = 4, n = 56). After the training, participants were asked to indicate whether the allocated CDL simulator training time was adequate, from which their responses revealed that the duration of training was very adequate (mean = 4.13, med = 4, n = 54). Detailed ratings for items under simulator training usefulness can be found in Figure 3.13.

Following, participants were asked to rate their recommendations for using the driving simulators per type of INDOT driver. Respondents highly recommended the simulator training to novice drivers (mean = 3.84, med = 4, n = 56), followed by transfer drivers (mean = 3.36, med = 3, n = 56), and full-time experience drivers (mean = 3.07, med = 3, n = 55). This was consistent with the findings from the snowplow driver training survey.

Upon finalization of both pre- and post-CDL surveys, several open-ended questions were placed to collect any additional information from the drivers. In the preintervention CDL survey, participants provided their feedback on any additional thoughts toward CDL driver training or training with simulator. The collected feedback indicated that most participants had no further comments prior to the simulator training, except two drivers expressed concerns over realism and simulator sickness. When it comes to the open-ended question in postintervention survey, participants were first asked for a question regarding the most effective parts of the simulator training and reasons. Among 33 collected responses, 20 participants indicated that the provided training scenarios were effective, including those related to snow/icy conditions, basic skill training, time management/

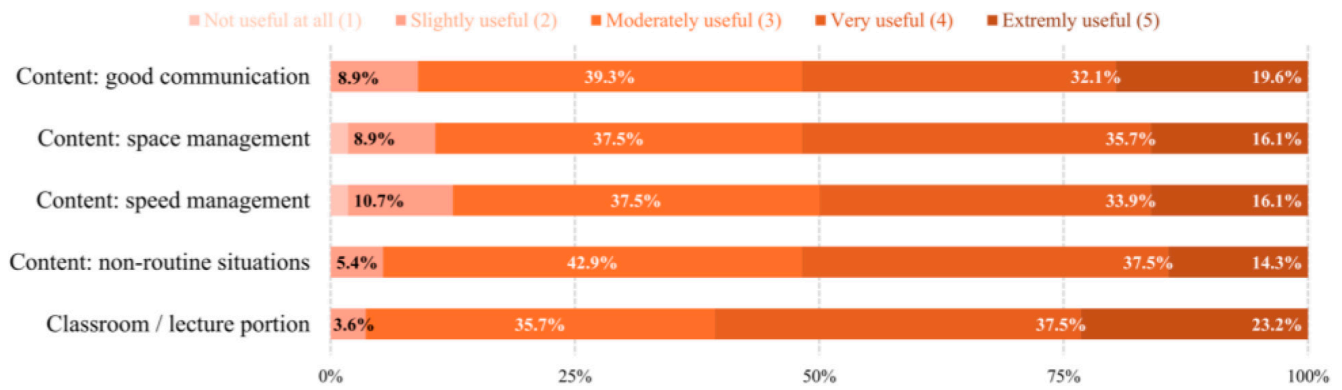


Figure 3.13 CDL Perceptions Rating Towards CDL Simulator Training Aspects.

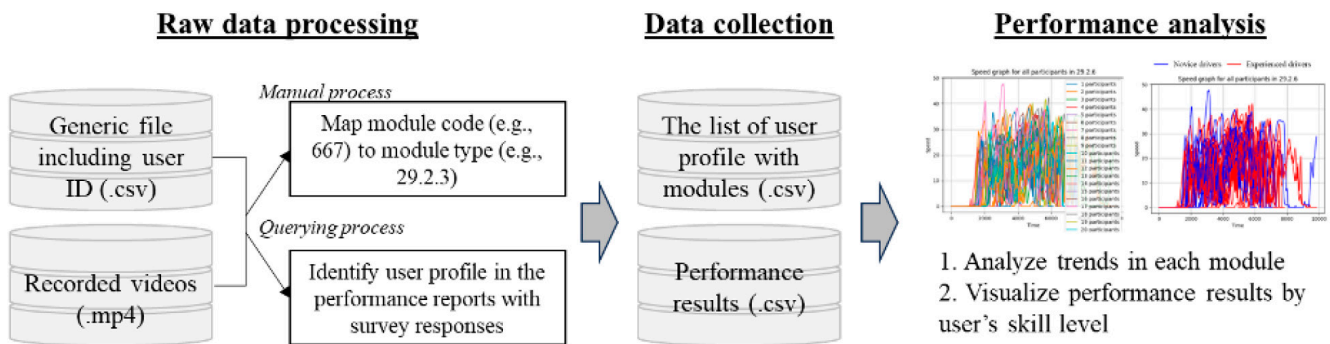


Figure 3.14 Performance Report Analysis Workflow.

delivery, and snowplow techniques; four participants suggested that all training parts were effective, and four other participants pointed out that some haptic and sensory feedback felt realistic. The remaining participants implied various information including benefits to cost efficiency, performance feedback, and more. Lastly, participants were asked to give any additional feedback regarding the simulator training (n = 20). From the results, 11 respondents did not have further comments; four participants provided comments related to improvements for technical aspects, including adding nose graphics to the truck, ability to manually set gears on the transmission, as well as laser features to the plow. The remaining responses included praise for simulator realism/immersions, as well as critiques to simulator software features such as parallel parking and steering sensitivity being too high.

Based on both quantitative and qualitative results from the pre- and post-CDL training intervention surveys, it can be inferred that the simulator training was most effective in helping to train new CDL drivers. Moreover, the research team noted similar results for measured items under perceptions towards simulator equipment and training when compared with early snowplow simulator training surveys. Such findings suggest that the positive perceptions toward simulator hardware and software features, as well as training usefulness could be generalizable to broader training context, such as CDL training.

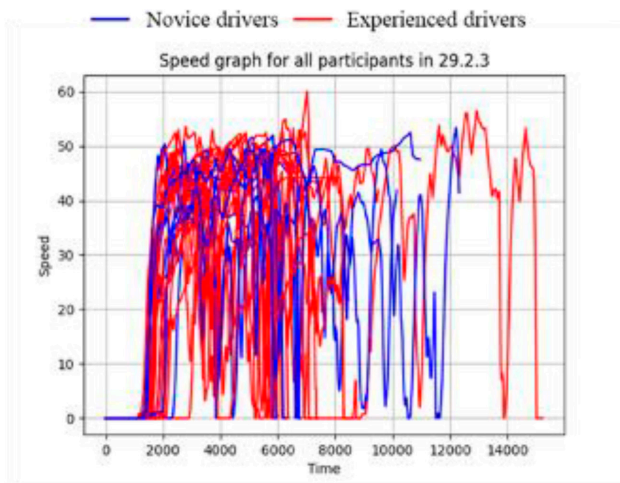
Moreover, our results are similar to Morgan et al. (2011), who also evaluated simulator driver training in commercial

vehicle training for the Federal Motor Carrier Safety Association (FMCSA). Participants in Morgan et al. (2011) cited benefits such as a safer training environment and the opportunities to be trained for hazardous conditions when utilizing driving simulator training. Additionally, drivers from the FMCSA study believed that simulator training would be most beneficial to entry-level drivers, with some degree of skill transfer to real-world driving occurred (Morgan et al., 2011). These findings well matched the short- and long-term results mentioned in the present study with similar benefits found. Taken together, the converging results from Morgan et al. (2011) and this research suggest that the inclusion of simulator component can be potentially effective in improving CDL driver training experience and outcomes.

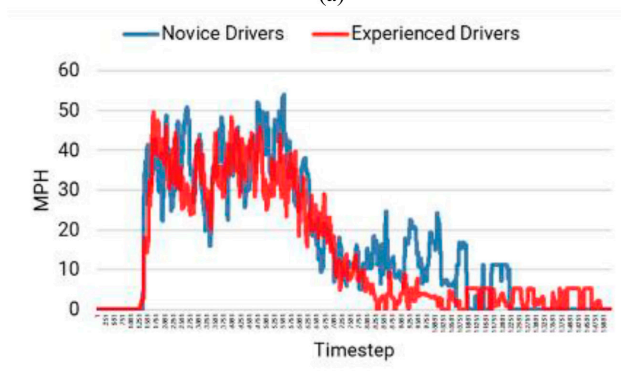
3.2.4 Simulator Performance Results

The research team conducted a study on the simulator's performance results, exporting the data in a time series format from the simulator. The data were categorized into three types: (1) generic files, (2) time series-based raw driving records in CSV format, and (3) recorded videos in MP4 format, as shown in Figure 3.14.

The generic file includes user ID, such as trainer and trainee information, and module code. It is utilized to match the raw data and survey for the analysis of identical trainee. Through the user metadata and module code from the generic file and survey,



(a)



(b)

Figure 3.15 Speed Behavior Comparisons Between Novice and Experiences Drivers in Module 29.2.3: (a) Raw Datasets; (b) Average Speed Graphs.

the research team specified the performance result, which involves speed, and braking and acceleration pedal, to analyze the driving patterns in each module. The research team categorized the set of users into age (18–29, 30–39, 40–49, 50–59, 60+), skill levels (experienced, novice), and years of experience (0–2, 3–5, 6–8, 8+ years). Data analysis had been promoted in the three phases: (1) Essential raw data patterns for two categories’ driver users, (2) further performance results of essential driving parameters (speed, and acceleration and braking pedal) in metainformation (age, skill levels), and (3) online-based performance results with generic feedback. Furthermore, the research team focused on data analysis for the five modules, such as two-way traffic with obstacles in city (Module 29.2.3), advanced exercise low visibility in city (29.2.6), introduction in snowplowing rural (29.3.1), bridges and railway crossings in freeway (29.4.3b), and snowplowing freeway ramps (29.4.6).

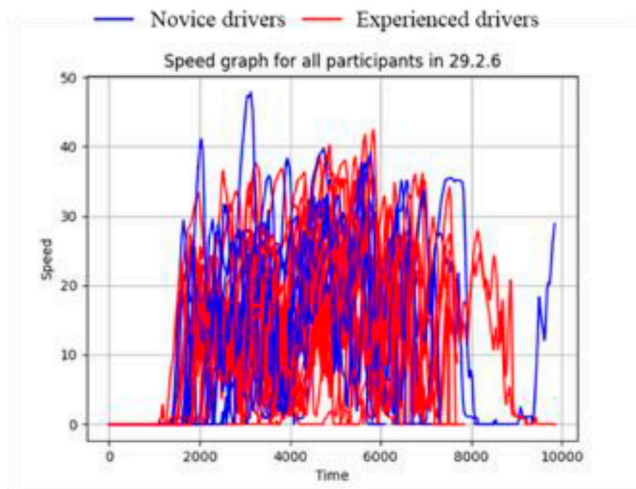
3.2.4.1 Raw Data Patterns for Two Categories’ Driver Users. In the initial phase of the project, the research team aimed to identify distinct driving patterns from raw performance

data. Speed was selected as the primary parameter to examine differences in driving behavior between novice and experienced users across three modules (29.2.3, 29.2.6, 29.4.6), as shown in Figure 3.17, 3.18, and 3.19. Overall novice drivers demonstrated more abrupt and irregular changes in speed compared to their experienced counterparts throughout all modules. Figure 3.15a, which represents all individual speed graph, clear distinctions were not visually apparent due to the overlapping and noisy nature of the data. To tackle this issue, drivers were grouped by skill level (novice vs. experienced) and their speed data were averaged, resulting in Figure 3.15b, which reveals more pronounced differences. In Module 29.2.3 (Two-Way Traffic With Obstacles), novice drivers accelerated more quickly at the beginning but showed steeper deceleration and greater fluctuation toward the end of the module. Experienced drivers, on the other hand, maintained a steadier pace and demonstrated more controlled deceleration. This contrast suggests that novice drivers may lack consistent speed control and task pacing.

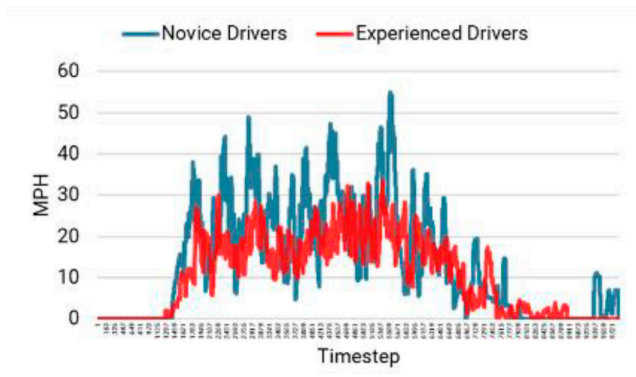
In Module 29.2.6 (Advanced Exercise Low Visibility), the individual speed graphs (Figure 3.16a) reveal that novice drivers displayed frequent and abrupt speed changes, with greater variability compared to experienced drivers. Meanwhile, experienced drivers maintained more stable and consistent speed patterns. The average speed graph (Figure 3.16b) further highlights this distinction: novice drivers tended to drive at higher speeds, but with sharp fluctuations and irregular peaks, indicating potential issues with speed control and pacing. Experienced drivers, on the other hand, demonstrated smoother acceleration and deceleration, maintaining a steady and predictable pace throughout the simulation. It implies that novice drivers are more likely to exhibit aggressive or inconsistent driving behavior in Module 29.2.6. This supports the use of simulator-based training to improve speed management skills, particularly for less experienced drivers.

Figure 3.17a illustrates the individual speed profiles of novice and experienced drivers in Module 29.4.6 (Snowplowing Freeway Ramps), while Figure 3.17b shows their corresponding average speed trends. The individual traces indicate that novice drivers frequently operated at higher speed compared to experienced drivers. The average speed graph reinforces this observation: novice drivers reached higher peak speeds in the middle phase of the task but exhibited a steep decline and unstable behavior in the latter half. On the other hand, experienced drivers maintained more moderate and consistent speeds throughout the simulation, with smoother acceleration and deceleration transitions.

Overall, the results showed that novice drivers are more prone to over-acceleration and inconsistent speed control, especially during longer or more complex driving scenarios. On the other hand, experienced drivers demonstrate more stable and controlled driving behavior, reflecting greater proficiency in task pacing and speed regulation across three modules. However, this method has been challenged that early stages of data processing lacked accurate calibration, which leads to inconsistent and latency results between datasets. Additionally, reliance on a single parameter such as speed limits the scalability of the analysis, underscoring the need for multidimensional data integration to fully capture driver behavior.



(a)

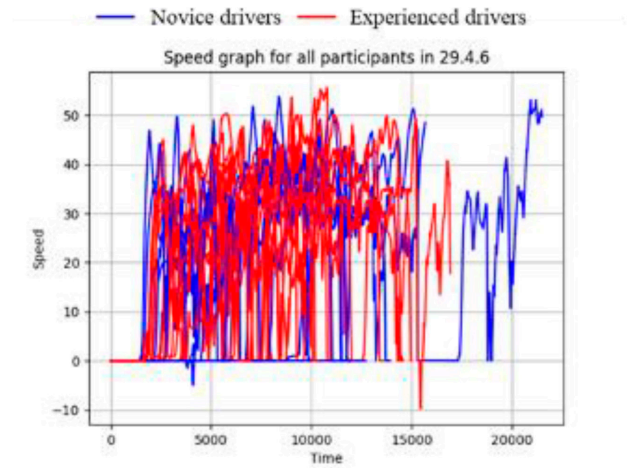


(b)

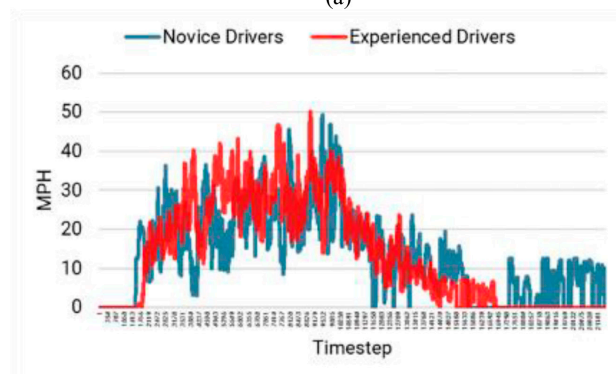
Figure 3.16 Speed Behavior Comparisons Between Novice and Experiences Drivers in Module 29.2.6: (a) Raw Datasets; (b) Average Speed Graphs.

3.2.4.2 Advanced Performance Results of Essential Driving Parameters in Meta Information Classes. To address the data calibration issue in the initial phase of data analysis, the second phase improved preprocessing accuracy and expanded the scope of analysis to include five simulation modules. In this phase, the research team extracted and analyzed three key parameters, speed, acceleration, and brake pedal pressure, across three metainformation categories: driving skill level, age, and years of experience group. The dataset did not include participants in the 30–39 and 60–64 age groups, not by design, but because no data from individuals in these age ranges were available. Speed and acceleration served as indicator of overall vehicle control and responsiveness, while brake pedal pressure provided insight into each driver’s control strategy and braking behavior under simulated conditions.

Figures 3.18–3.26 present a comparative analysis of speed, acceleration, and brake pedal usage by skill level, age, and years of experience group in Module 29.3.1 (Introduction to Snowplowing Rural), which is to practice maneuvering the



(a)



(b)

Figure 3.17 Average Speed Behavior Comparisons Between Novice and Experiences Drivers in Module 29.4.6: (a) Raw Datasets; (b) Average Speed Graphs.

vehicle while operating the plows and spreader. The findings show that experienced drivers consistently maintained stable speeds, smoother acceleration, and controlled braking patterns, reflecting greater driving proficiency (Figures 3.18–3.20). In contrast, novice drivers exhibited more erratic acceleration and abrupt braking, particularly in the early stages of the module, suggesting lower control precision. Age-based results showed that drivers in their 40s and 50s demonstrated the most stable speed and braking control (Figures 3.21–3.23), while those in their 20s showed more aggressive acceleration patterns (Figure 3.23). Overall, the experienced drivers in 50–59 age group showed superior control across all three parameters, supporting the notion that these factors correlate with more stable and confident driving performance in simulation settings. Furthermore, driving experience appears to influence pedal control consistency positively (Figures 3.24–3.26). Drivers with more than 8 years of experience exhibit smoother braking, steadier acceleration, and more consistent speeds, reflecting more controlled driving behavior. In contrast, novice to intermediate drivers show signs of erratic pedal use, which may impact vehicle stability and safety.

Skill level (Speed) 29.3.1

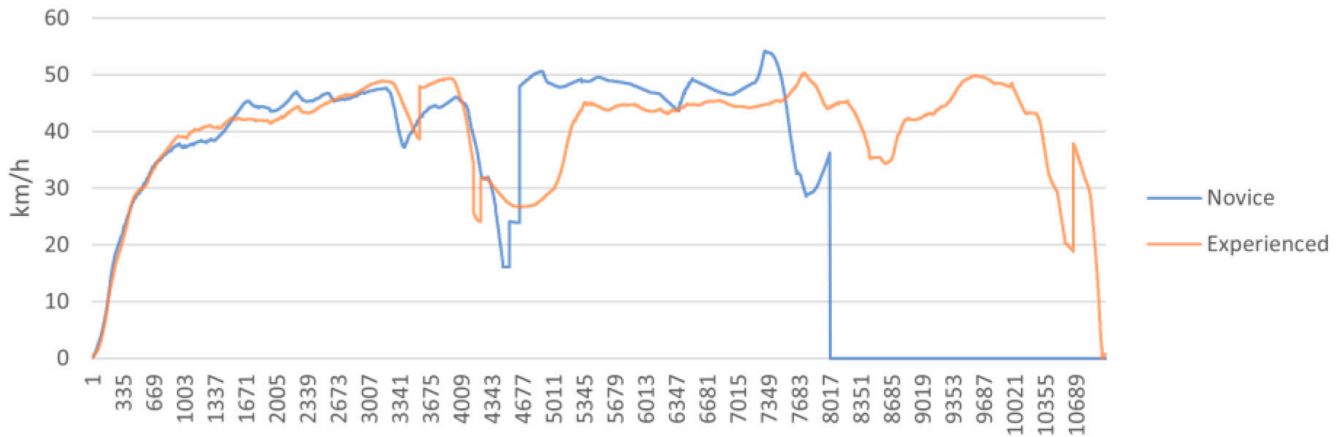


Figure 3.18 Analysis of Speed by Skill Level Group in Module 29.3.1.

Skill level (Acceleration) 29.3.1

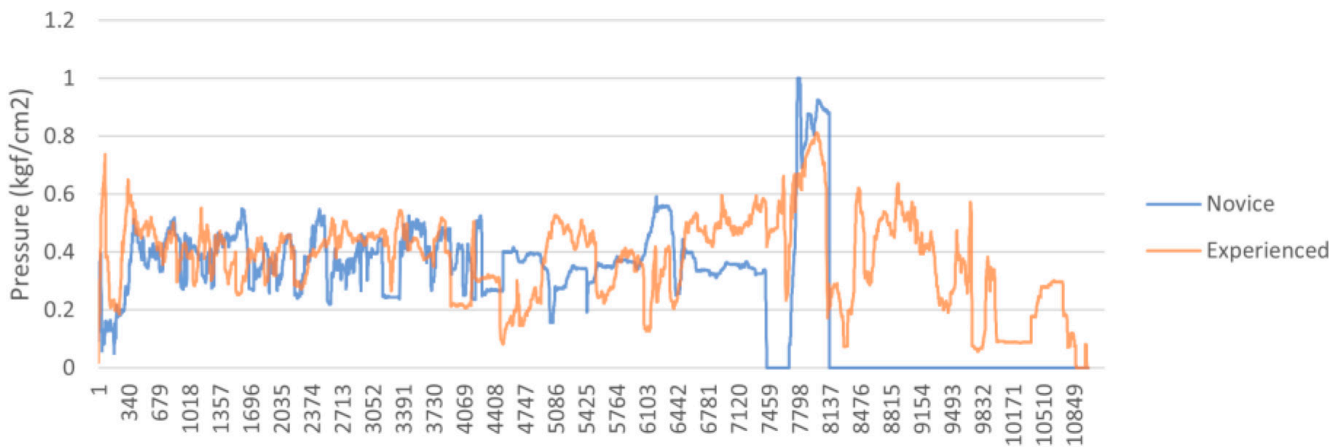


Figure 3.19 Analysis of Acceleration Pedal Usage by Skill Level Group in Module 29.3.1.

Skill level (Brake Pedal) 29.3.1



Figure 3.20 Analysis of Brake Pedal Usage by Skill Level Group in Module 29.3.1.

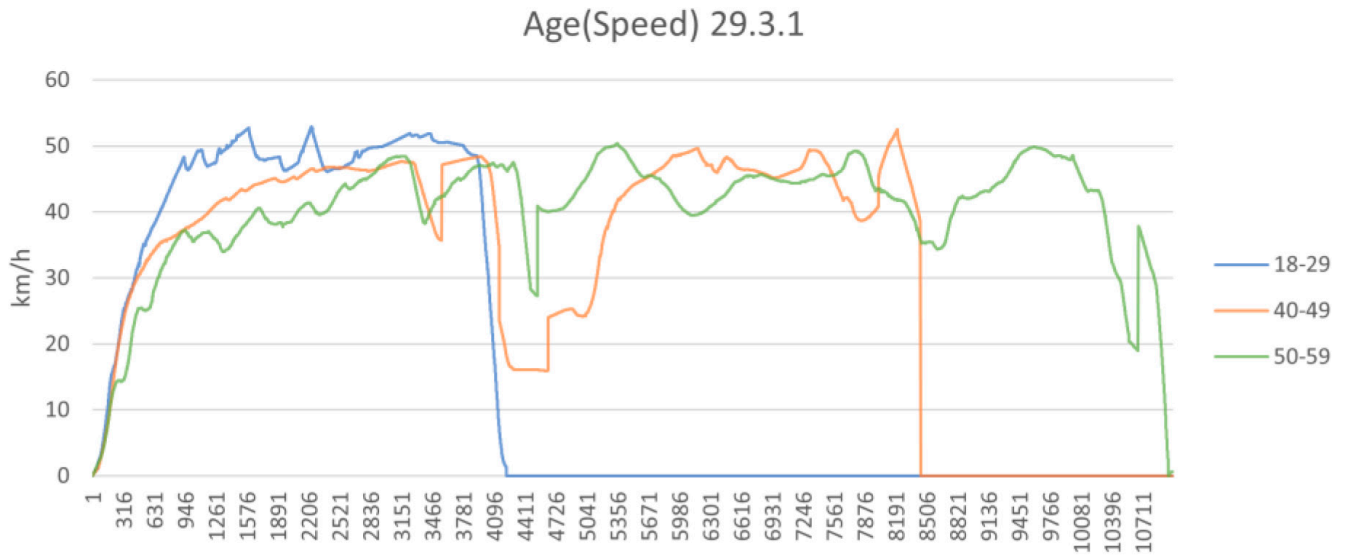


Figure 3.21 Analysis of Speed by Age Group in Module 29.3.1.

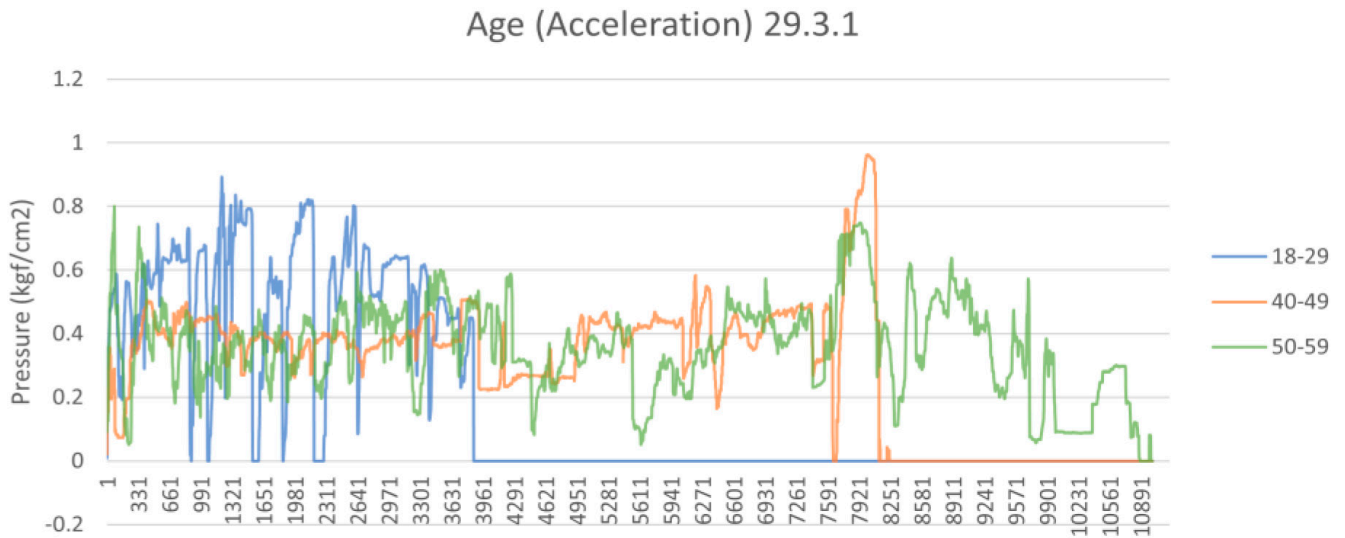


Figure 3.22 Analysis of Acceleration Pedal Usage by Age Group in Module 29.3.1.

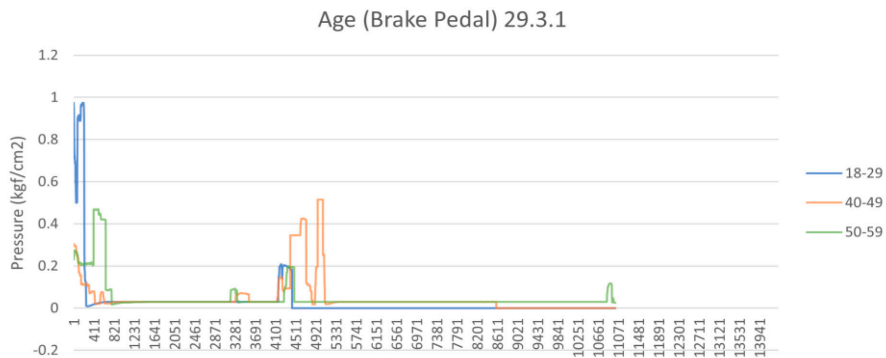


Figure 3.23 Analysis of Brake Pedal Usage by Age Group in Module 29.3.1.

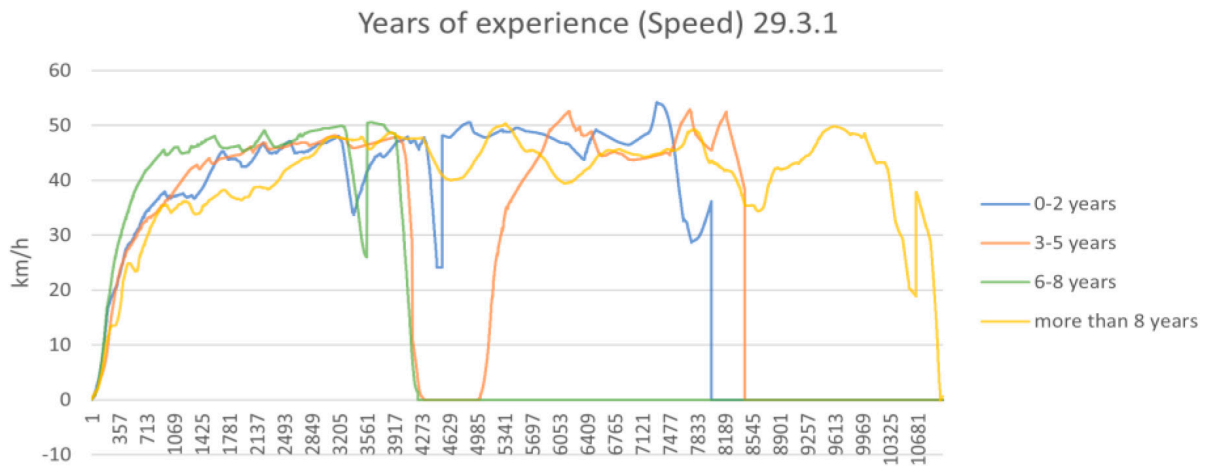


Figure 3.24 Analysis of Speed by Years of Experience Group in Module 29.3.1.

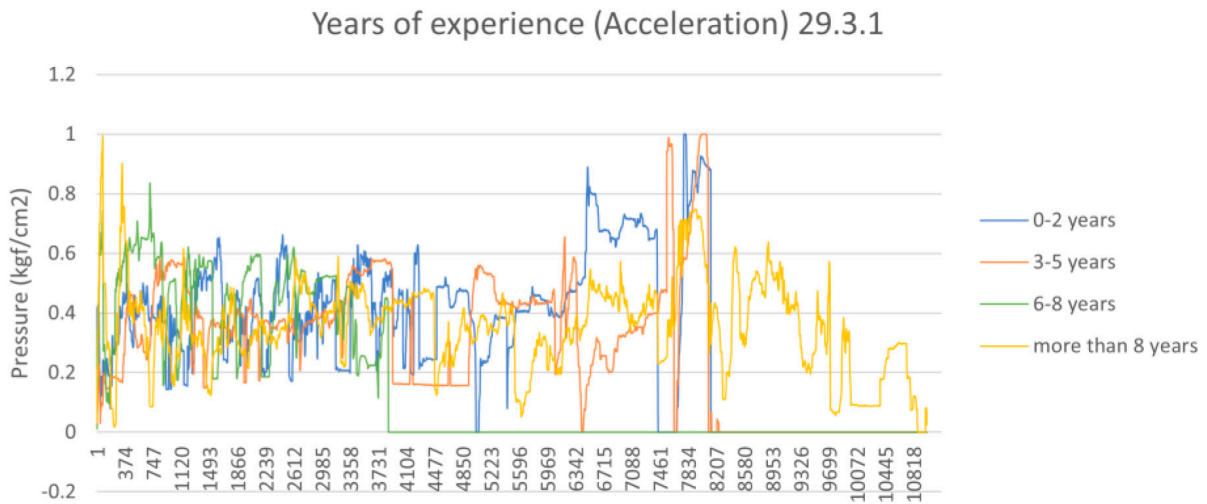


Figure 3.25 Analysis of Acceleration Pedal Usage by Years of Experience Group in Module 29.3.1.

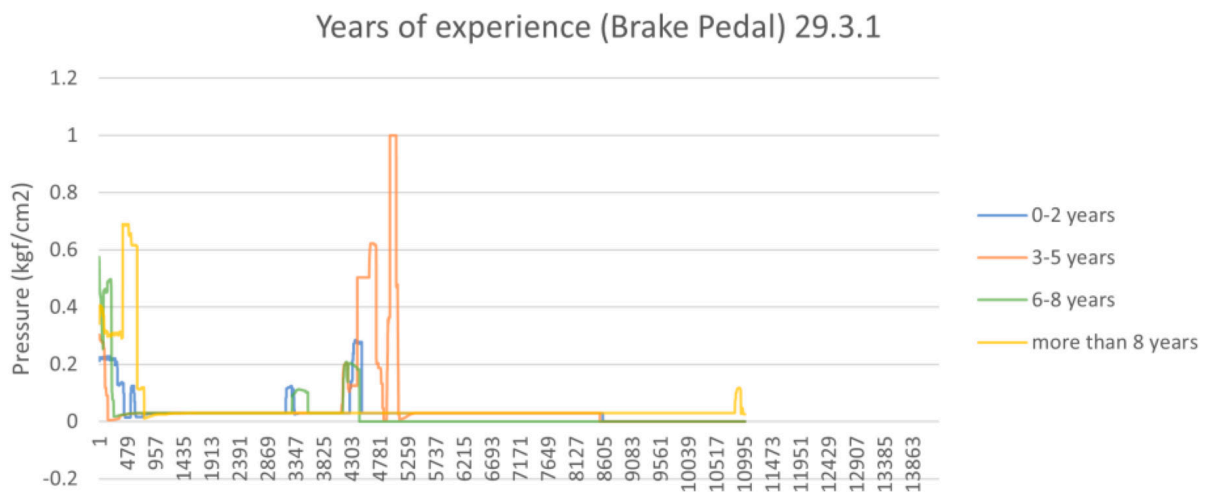


Figure 3.26 Analysis of Brake Pedal Usage by Years of Experience Group in Module 29.3.1.

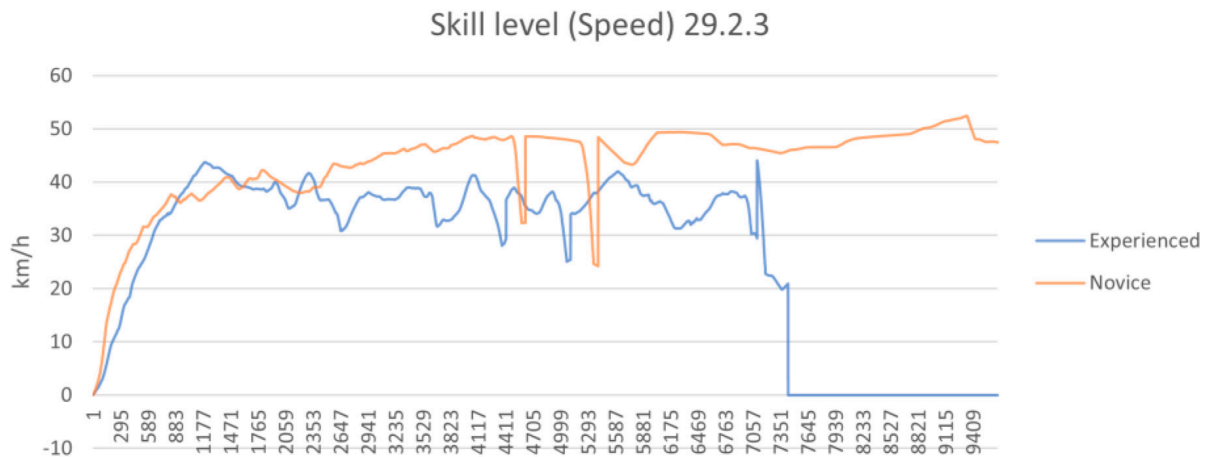


Figure 3.27 Analysis of Speed by Skill Level Group in Module 29.2.3.

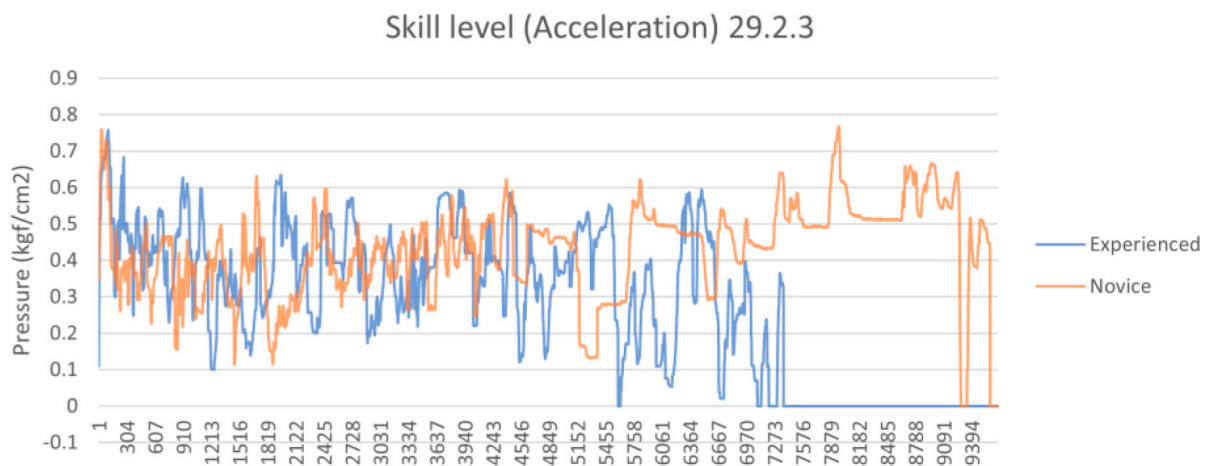


Figure 3.28 Analysis of Acceleration Pedal Usage by Skill Level Group in Module 29.2.3.

In Module 29.2.3 (Two-Way Traffic With Obstacles), which is to practice steering around road site obstacles, parked vehicles and operate the plows and spreader while driving across intersections and railways, Figures 3.27–3.35 illustrates driving behavior across three key parameters, such as speed, acceleration, and brake pedal pressure, with skill level, age and years of experience group. In terms of skill level, experienced drivers demonstrated more stable speed control, while novice drivers showed greater fluctuations in both speed and acceleration, especially when encountering roadside obstacles during the middle stage of the simulation (Figures 3.27–3.29). As driving experience increases, drivers tend to exhibit more dynamic and adaptive control of both acceleration and brake pedals and speed. For instance, they show frequent and scattered brake usage, but generally within a lower pressure range (below 0.5 kgf/cm²), indicating light and anticipatory braking. In contrast, novice drivers appear to rely on more rigid and less adaptive patterns, such as a sharp, high-pressure peak with relatively high speeds over time (Figures 3.33–3.35).

In Module 29.2.6 (Advanced Exercise Low Visibility), which is to demonstrate proficiency by plowing city streets

under adverse weather conditions, speed profiles revealed moderate variations among the different categories, as shown in Figures 3.36–3.44. Novice and drivers in their 20s showed more fluctuation in speed compared to experienced drivers, indicating less consistency in speed control (Figure 3.36 and Figure 3.39). However, acceleration data failed to indicate distinct driving patterns in all categories, due to high scattered and inconsistent patterns. The most distinctive patterns were observed in the brake pedal parameter (Figure 3.37, 3.38, 3.40, 3.41). Novice drivers consistently applied stronger and more frequent braking than their experienced counterpart, especially during the middle of training session (Figure 3.38). Less experienced drivers (0–2 years) showed more aggressive and unstable control behavior, while drivers with more than two years of experience demonstrated passive and overly conservative control (Figures 3.42–3.44). For instance, less experienced drivers applied relatively high speeds (~35 km/h) with aggressive and late-phase pedal control (up to 1.0 kgf/cm² of acceleration pedal pressure for 0–2 years, 0.3–0.7 kgf/cm² of acceleration pedal pressure for more than three years).

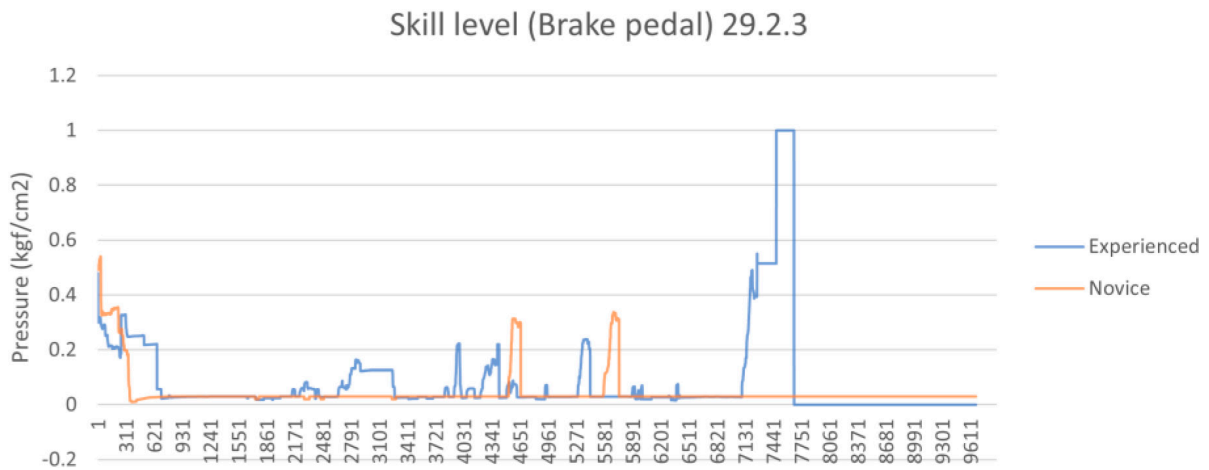


Figure 3.29 Analysis of Brake Pedal Usage by Skill Level Group in Module 29.2.3.

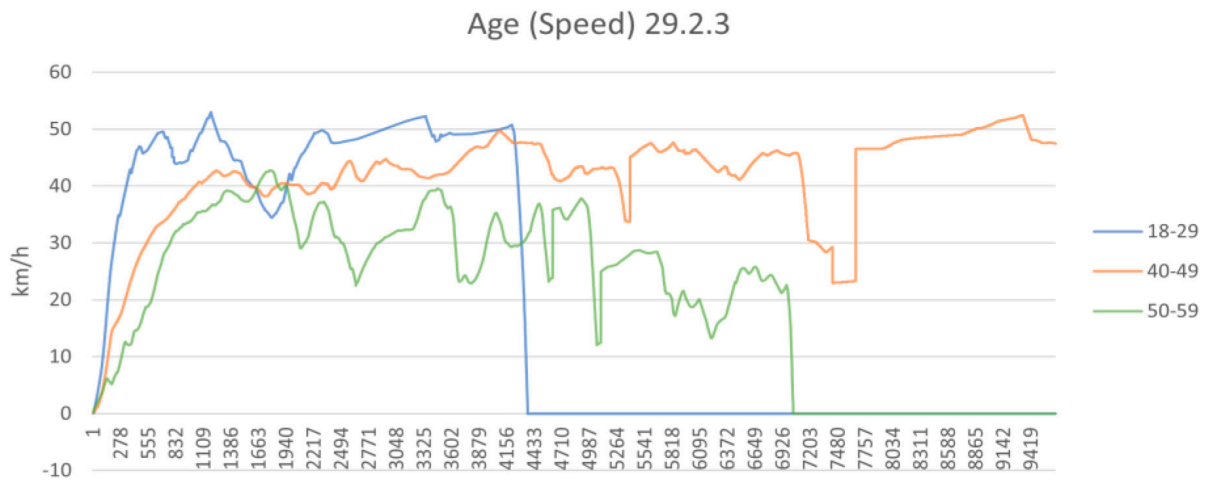


Figure 3.30 Analysis of Speed by Age Group in Module 29.2.3.

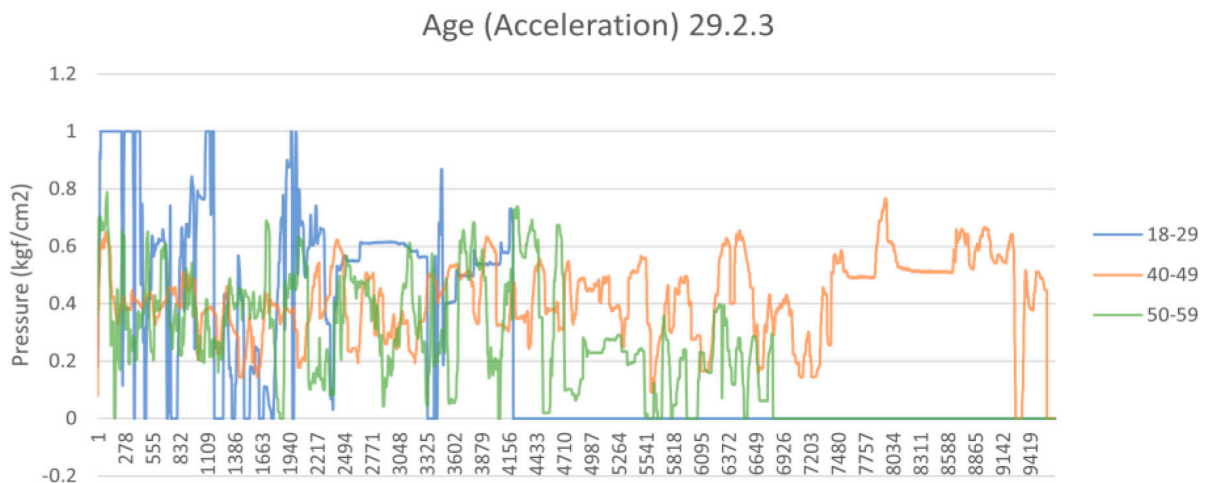


Figure 3.31 Analysis of Acceleration Pedal Usage by Age Group in Module 29.2.3.

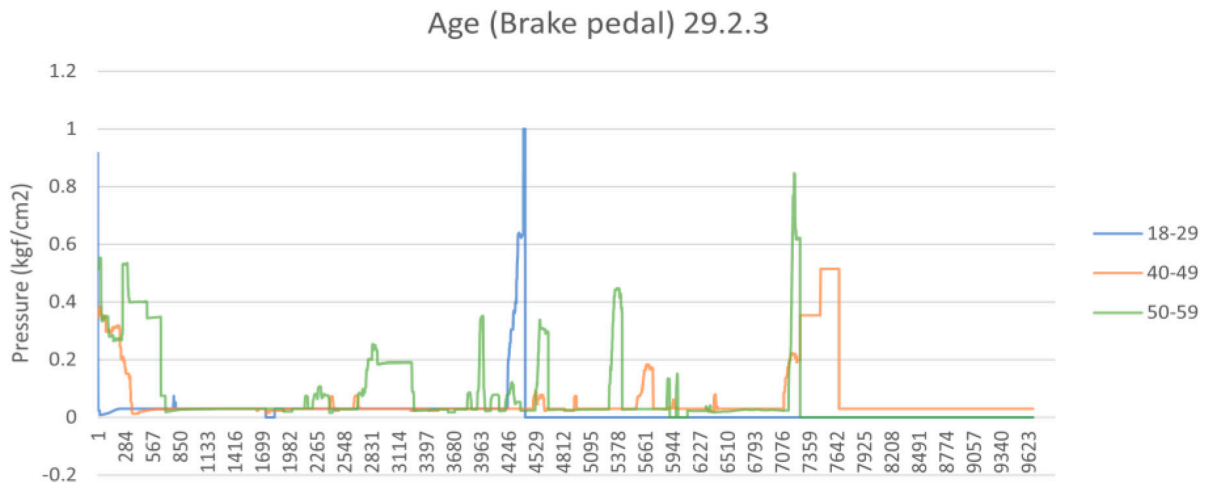


Figure 3.32 Analysis of Brake Pedal Usage by Age Group in Module 29.2.3.

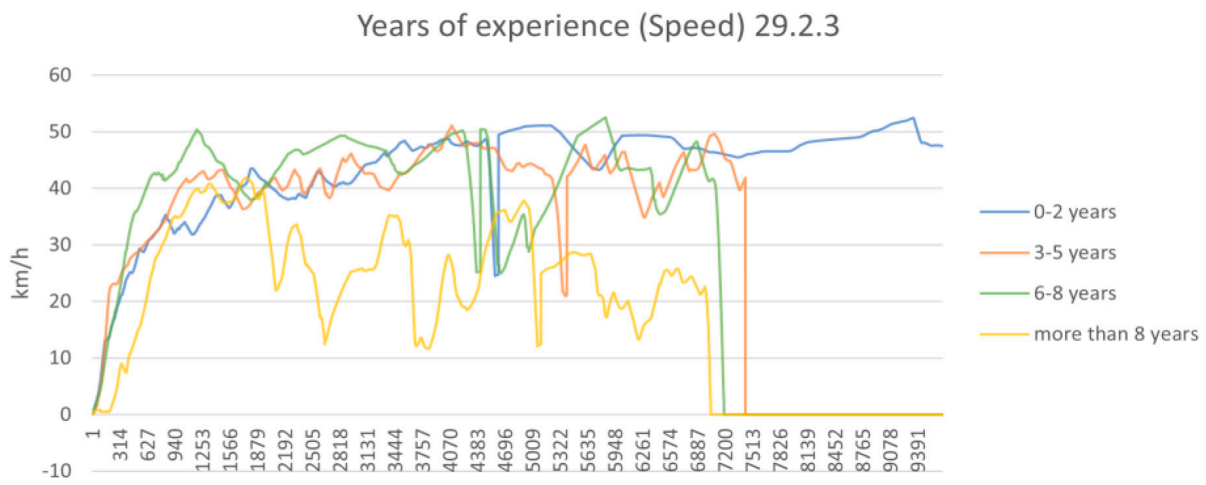


Figure 3.33 Analysis of Speed by Years of Experience Group in Module 29.2.3.

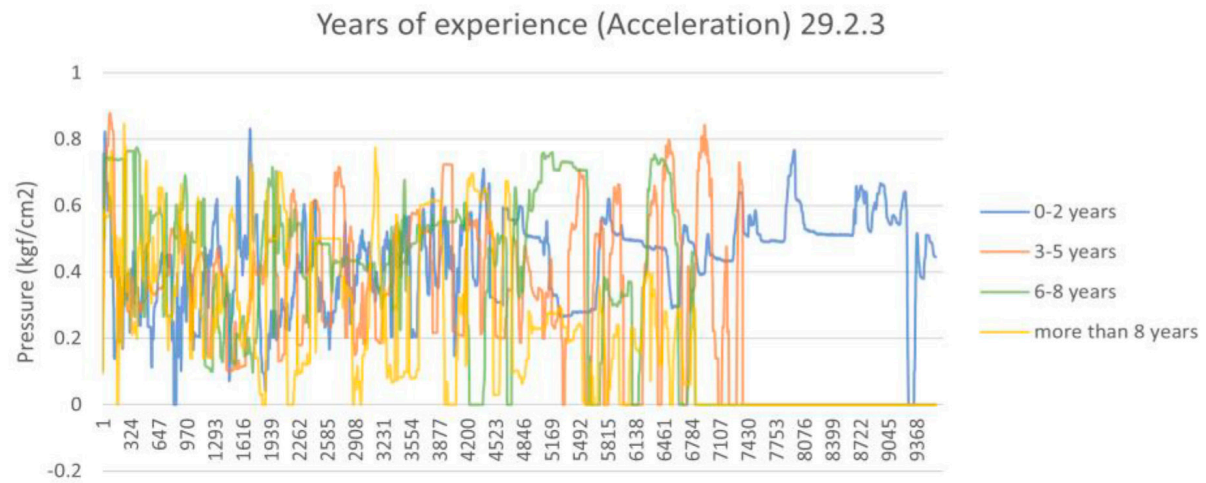


Figure 3.34 Analysis of Acceleration Pedal Usage by Years of Experience Group in Module 29.2.3.

Years of experience (Brake Pedal) 29.2.3

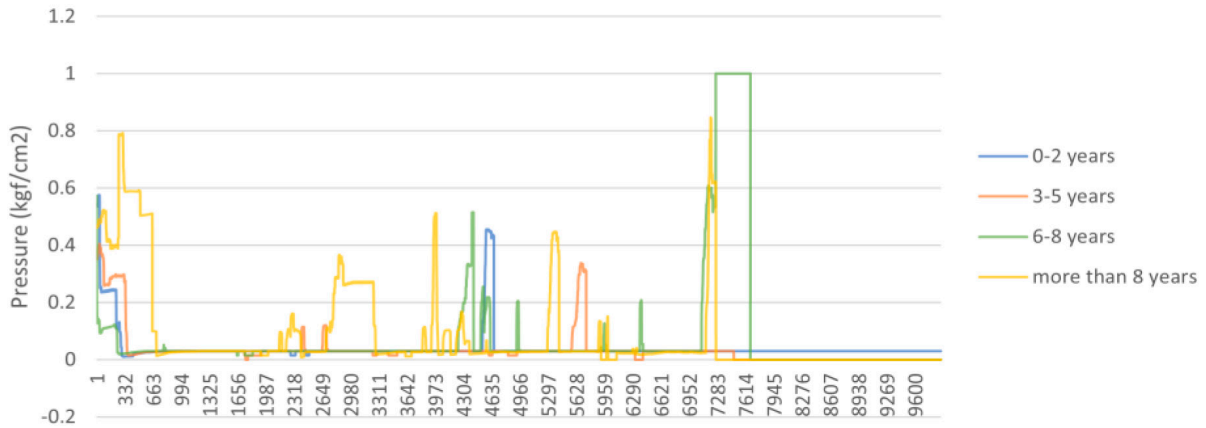


Figure 3.35 Analysis of Brake Pedal Usage by Years of Experience Group in Module 29.2.3.

Skill level (Speed) 29.2.6

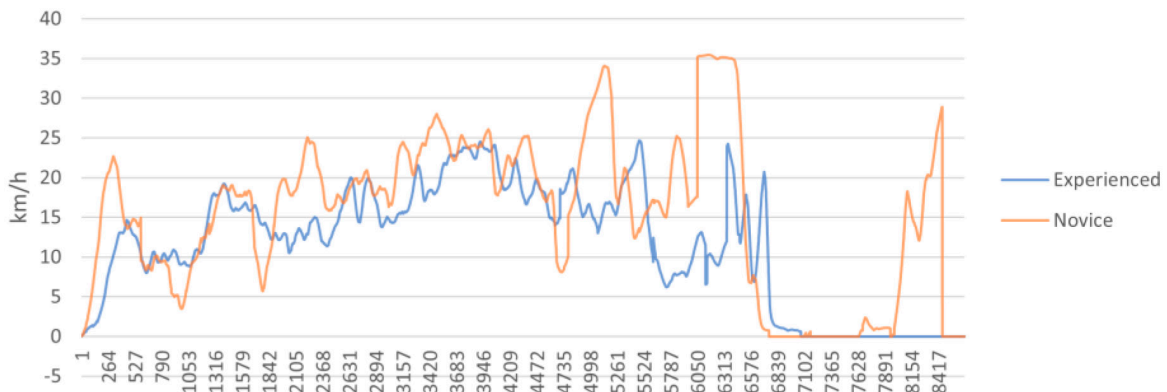


Figure 3.36 Analysis of Speed by Skill Level Group in Module 29.2.6.

Skill level (Acceleration) 29.2.6

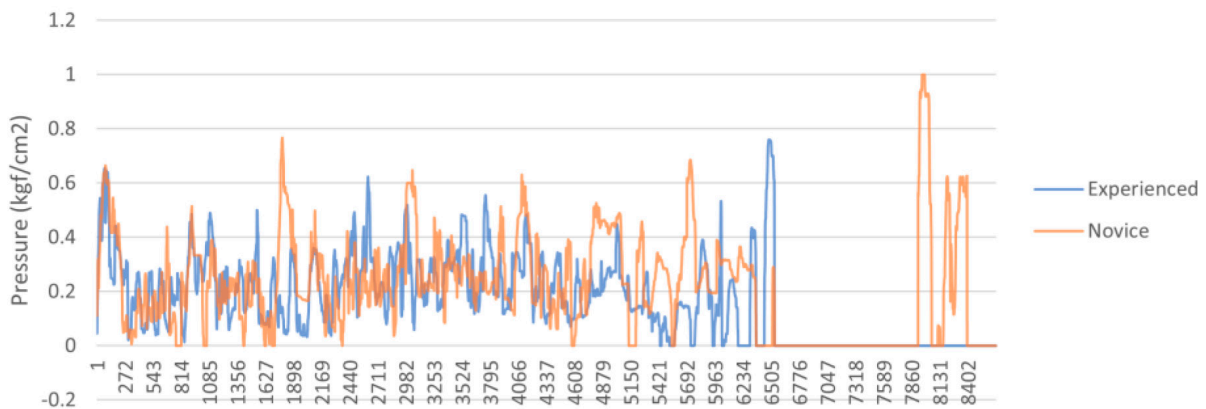


Figure 3.37 Analysis of Acceleration Pedal Usage by Skill Level Group in Module 29.2.6.

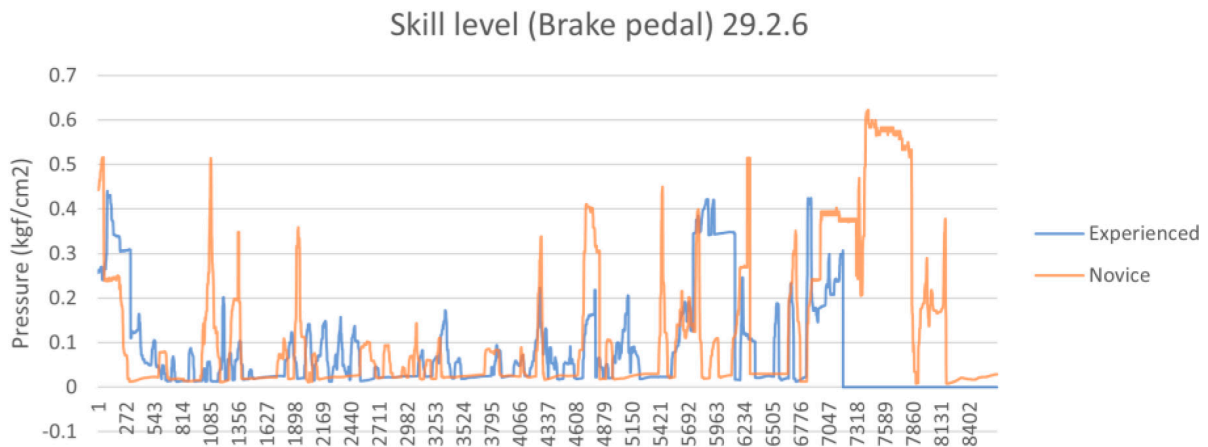


Figure 3.38 Analysis of Brake Pedal Usage by Skill Level Group in Module 29.2.6.

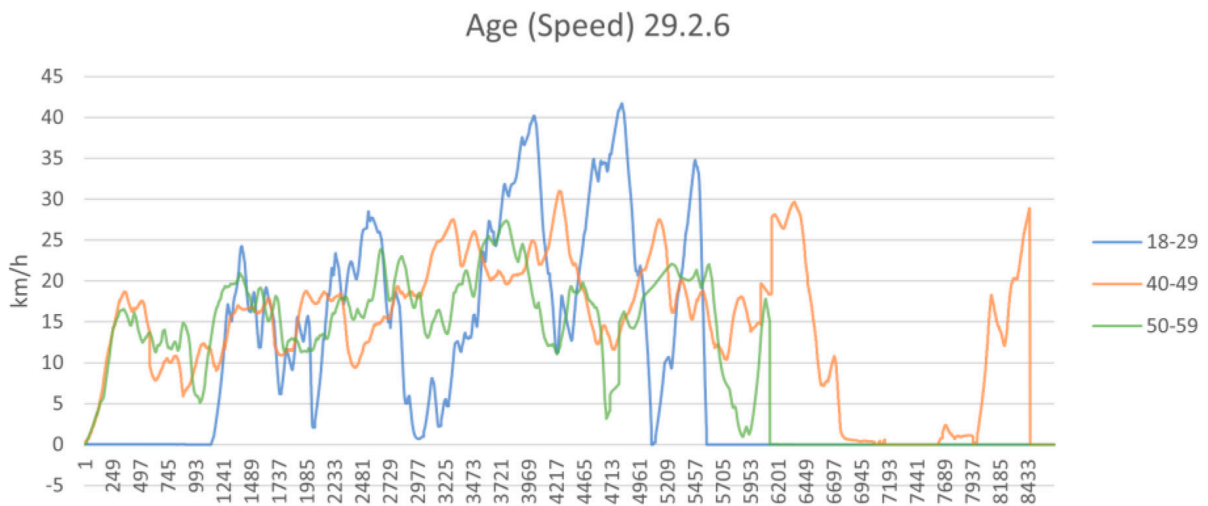


Figure 3.39 Analysis of Speed by Age Group in Module 29.2.6.

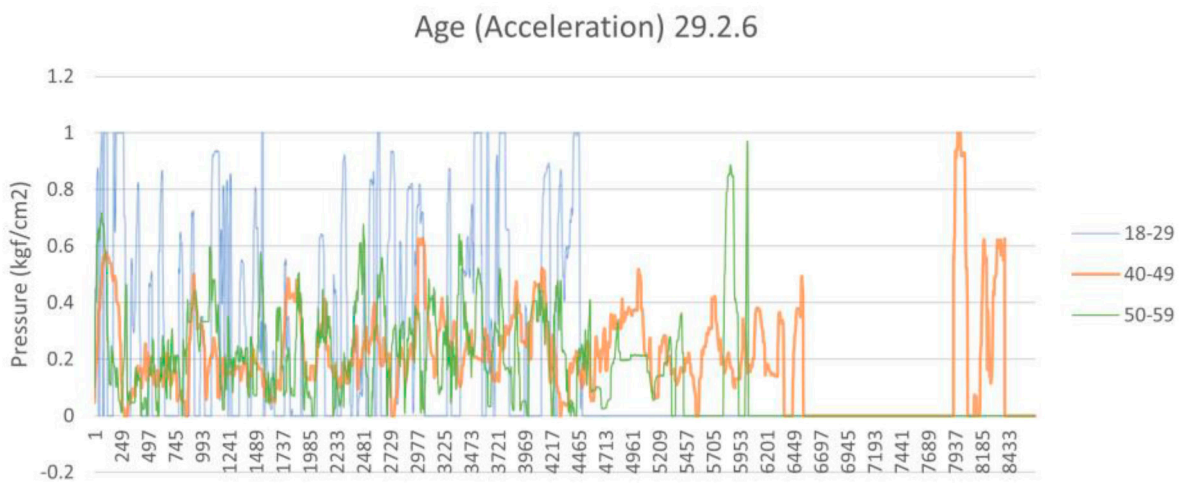


Figure 3.40 Analysis of Acceleration Pedal Usage by Age Group in Module 29.2.6.

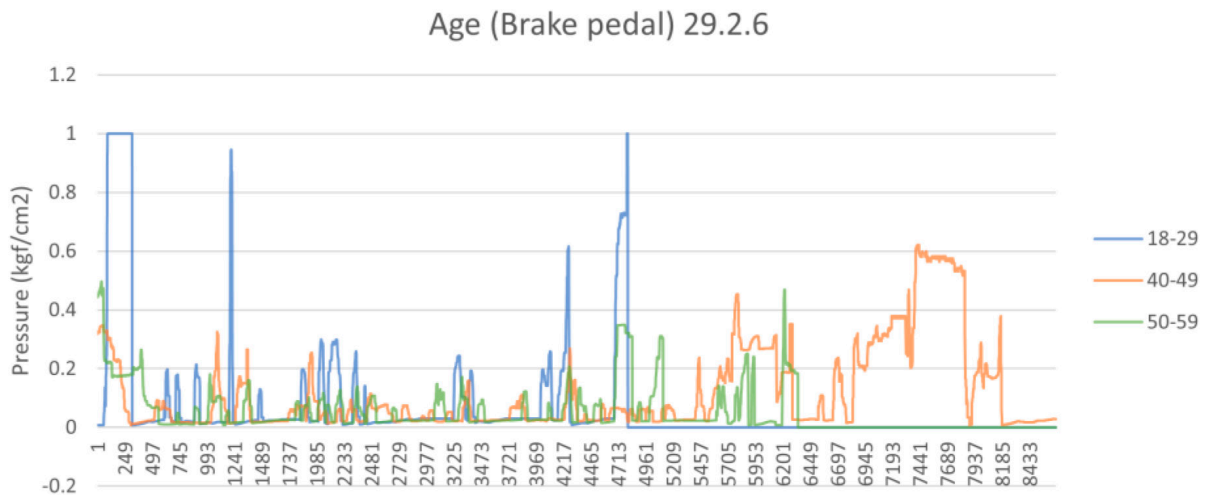


Figure 3.41 Analysis of Brake Pedal Usage by Age Group in Module 29.2.6.

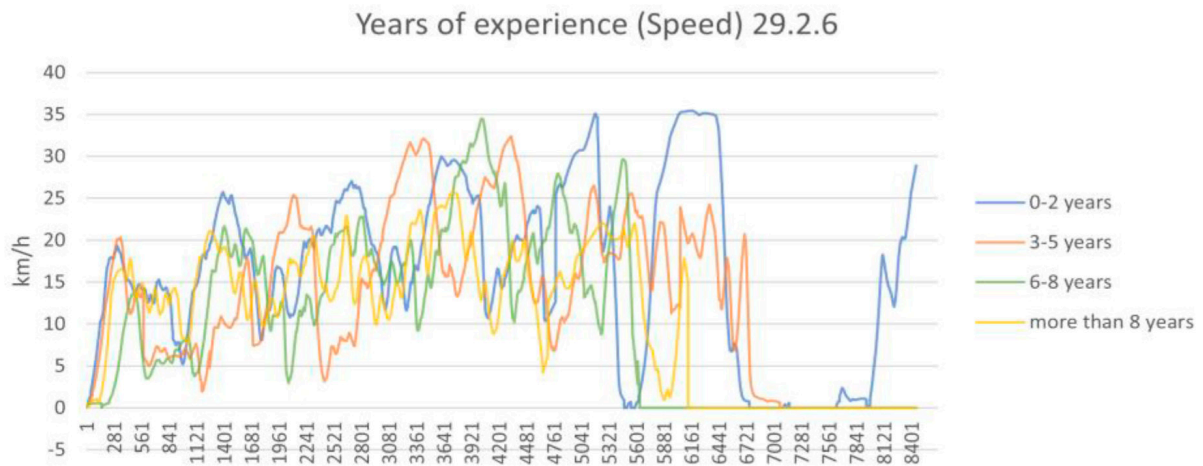


Figure 3.42 Analysis of Speed by Years of Experience Group in Module 29.2.6.

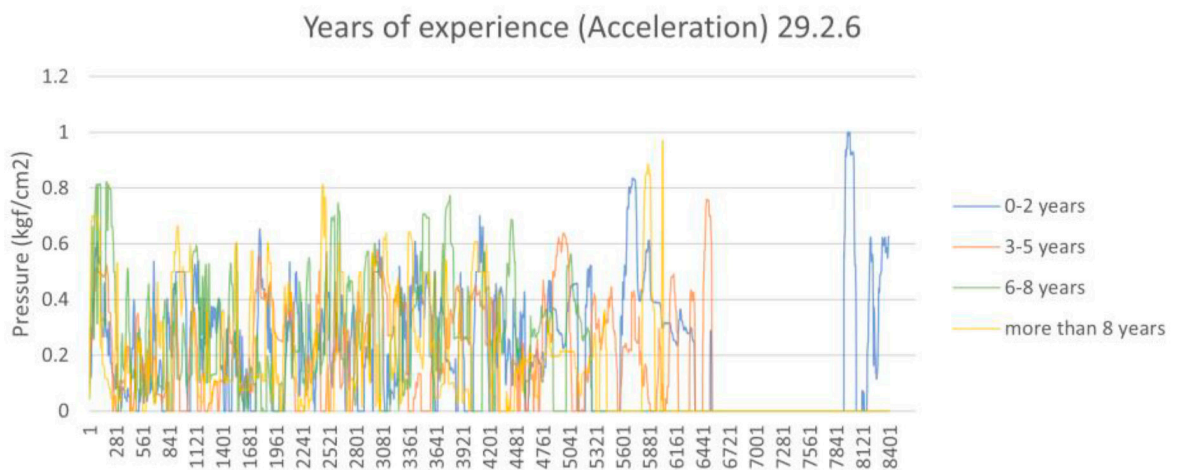


Figure 3.43 Analysis of Acceleration Pedal Usage by Years of Experience Group in Module 29.2.6.

Years of experience (Brake pedal) 29.2.6

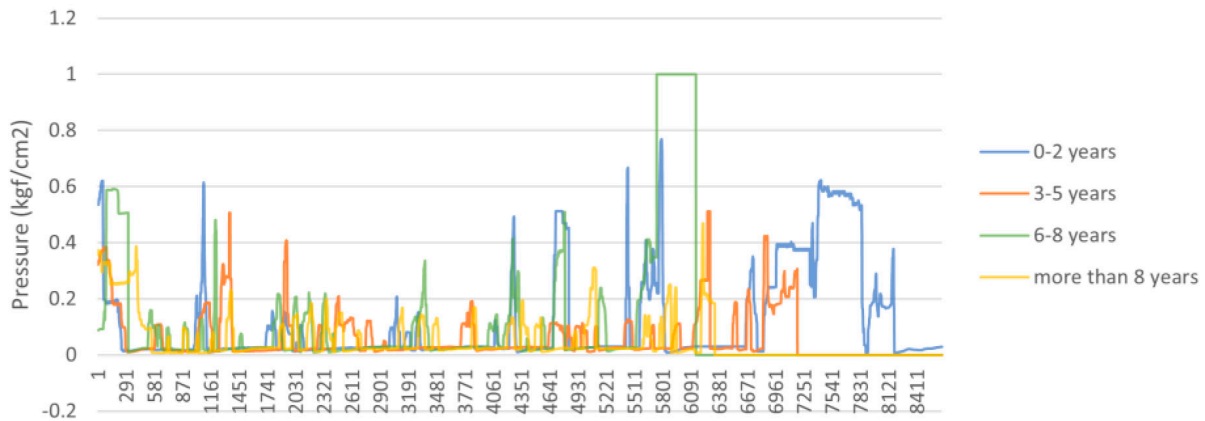


Figure 3.44 Analysis of Brake Pedal Usage by Years of Experience Group in Module 29.2.6.



Figure 3.45 A Snapshot of the Simulation for Novice and Experienced Drivers in Module 29.2.6.

A snapshot from the simulation shows both a novice and an experienced driver making a right turn into a narrow alley at the same location. As shown in Figure 3.45, although the event occurs at the same position within the same module, the elapsed time differs, and the experienced driver executes the turn much more smoothly than the novice driver. This illustrates that in modules with longer durations and more embedded events, such as Module 29.2.3, driver response can vary significantly. Therefore, data analysis for such modules can be further enhanced by incorporating raw performance data and additional sources, such as recorded video and individual performance results, exported from the simulator, to more accurately interpret driver behavior and training effects.

In Module 29.4.3b (Bridge and Railroad Freeway), which is to practice plowing bridges and railway crossings on a freeway and avoiding roadside obstacles, the speed profile revealed moderate variability among the driver groups, as shown in Figures 3.46–3.54. Both experienced and novice drivers maintained comparable peak speeds; however, novice drivers showed higher inconsistency in maintaining stable speeds. It indicates a tendency towards more abrupt transitions or reactive speed control (Figures 3.46–3.48). Age-based speed differences were

subtle; all groups accelerated rapidly early in the session and stabilized thereafter (Figures 3.49–3.51). Specifically, the 50–59 age group maintained a relatively stable and conservative speed throughout the session. However, acceleration patterns were characterized by high variability within all demographic groups. In other words, no clear trend emerges to differentiate between the groups. Previous studies have investigated age-related differences in driving behaviors. Doroudgar et al. (2016), Robertsen et al. (2022), and Depestele et al. (2020) results showed that older drivers exhibited slower reaction, less speed deviation, and reduced ability to maintain a constant following distance with more variable and less consistent driving performance. In contrast to these prior findings, the present simulator data did not reveal age-based differences in speed or acceleration patterns. The module was too monotonous in design to adequately capture age-related effects in driving behavior. This implies that future training may need to provide drivers with more challenging modules to improve the performance of all trainees. The brake pedal pressure result showed the most distinct insights. Novice drivers showed a notably higher frequency and magnitude of brake application compared to experienced drivers in the initial course. It implies that a more cautious or

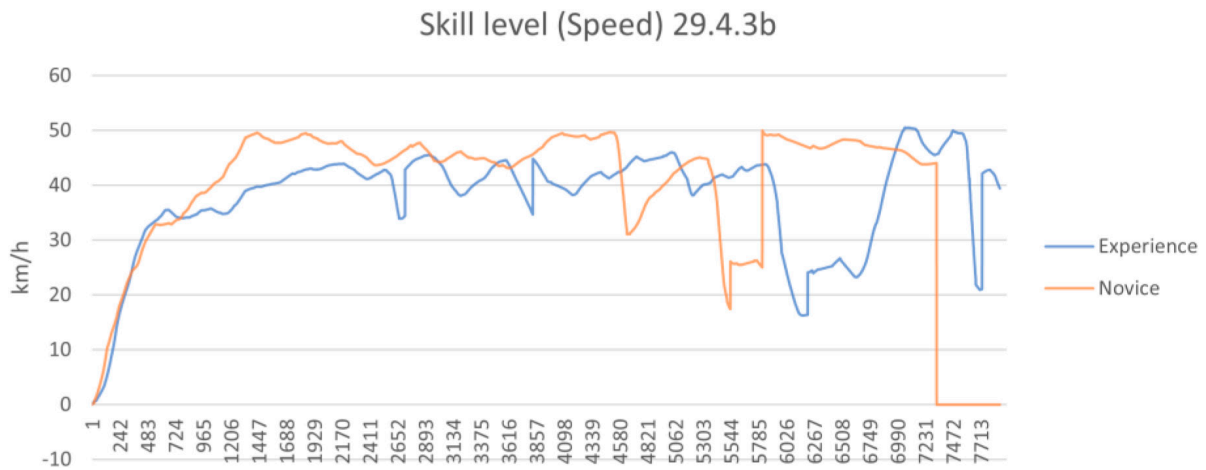


Figure 3.46 Analysis of Speed by Skill Level Group in Module 29.4.3b.

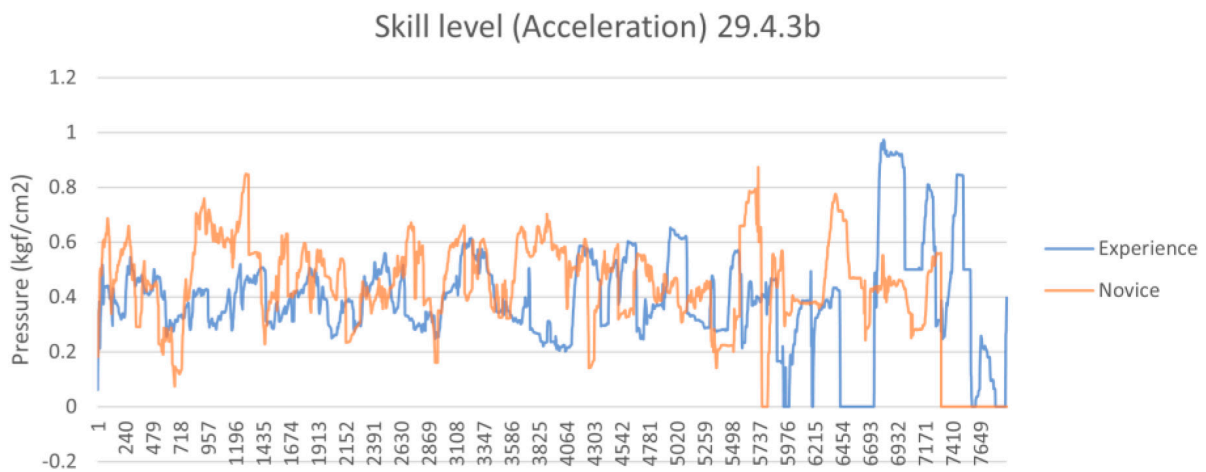


Figure 3.47 Analysis of Acceleration Pedal Usage by Skill Level Group in Module 29.4.3b.

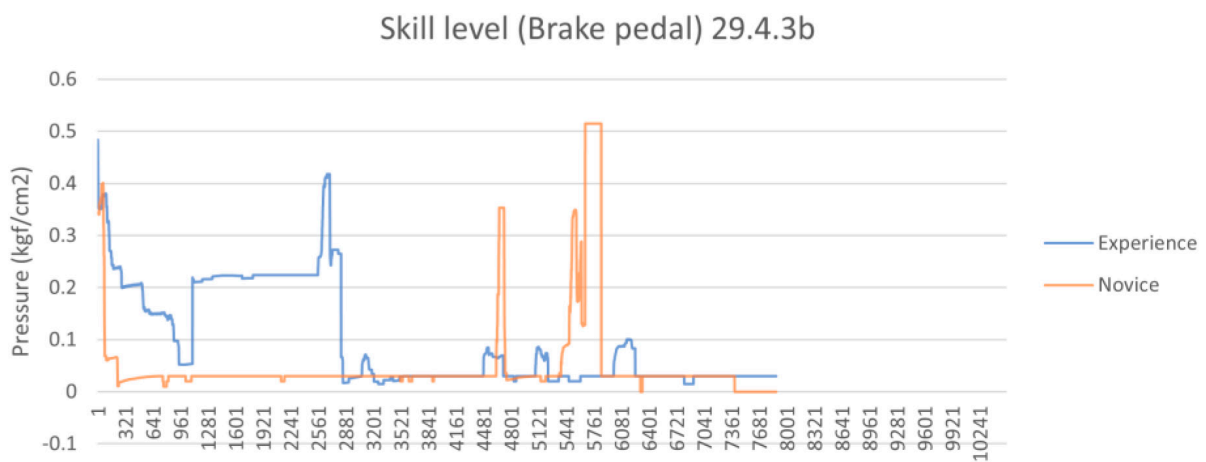


Figure 3.48 Analysis of Brake Pedal Usage by Skill Level Group in Module 29.4.3b.

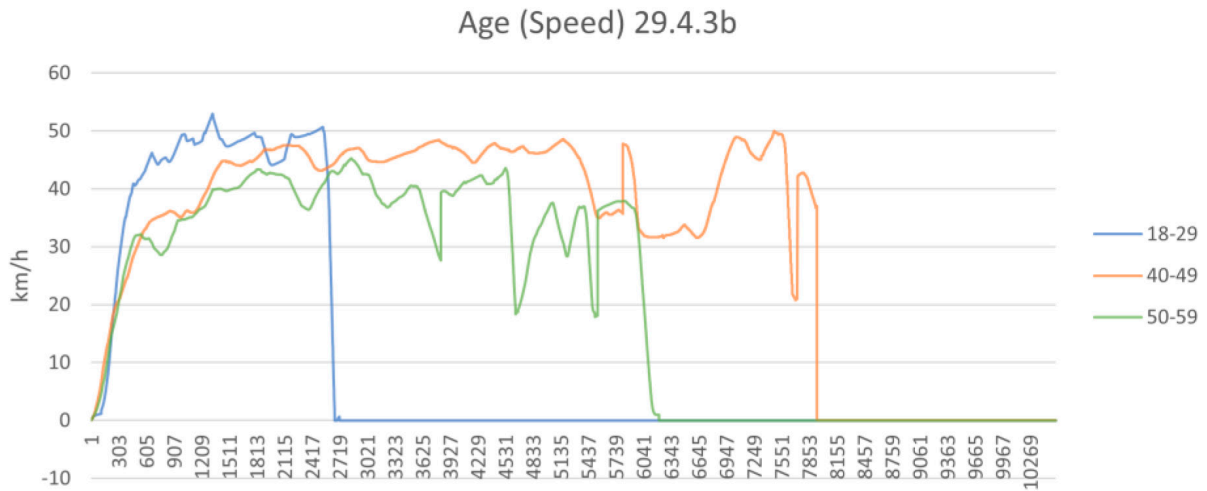


Figure 3.49 Analysis of Speed by Age Group in Module 29.4.3b.

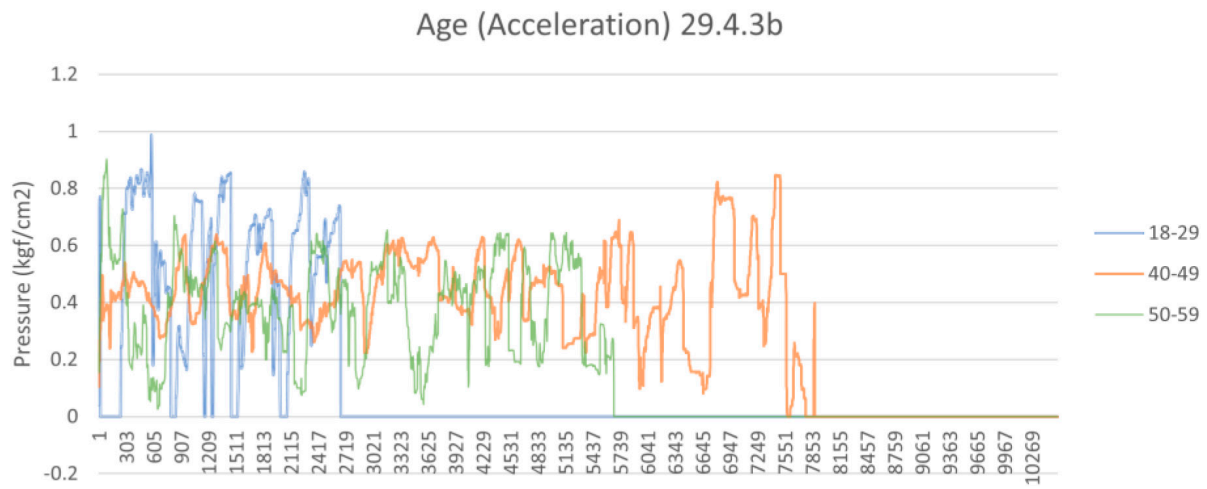


Figure 3.50 Analysis of Acceleration Pedal Usage by Age Group in Module 29.4.3b.

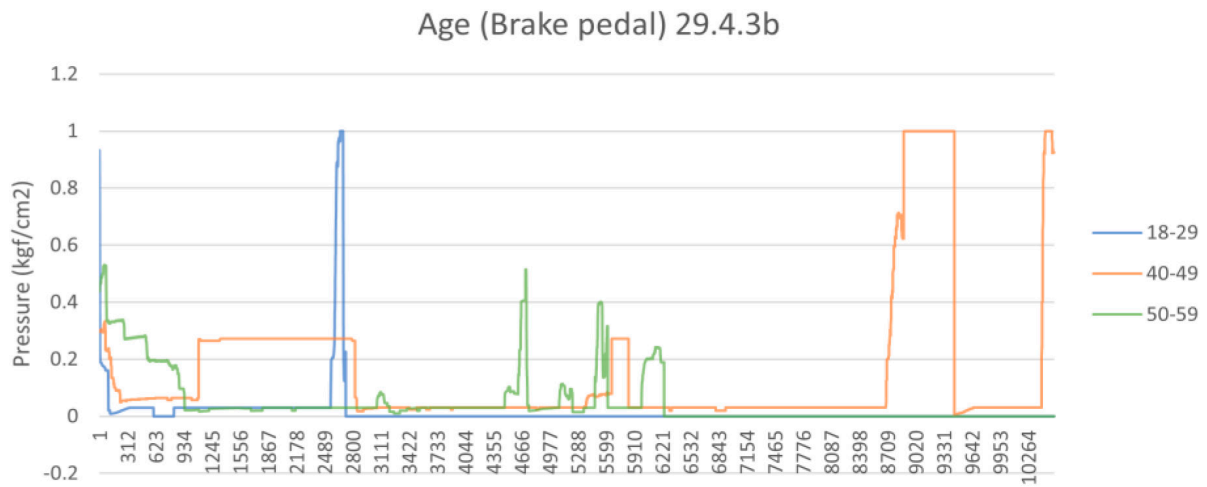


Figure 3.51 Analysis of Brake Pedal Usage by Age Group in Module 29.4.3b.

abrupt braking style is potentially associated with lower anticipatory control. Age-based comparison showed that the 50–59 age group showed a smoother pattern with fewer and less intense brake applications. Drivers with 6–8 years of experience showed the strongest and most frequent pedal input, while highly experienced drivers (8+ years) appeared more conservative (Figures 3.52–3.54). In contrast, less experienced drivers (0–5 years) showed late but sharp engagement in vehicle speed regulation, especially with the brake and accelerator pedal control, occurring during the mid driving intervals (4,500 ~ 7,000 simulation timesteps = 1'40" ~ 2'35").

In Module 29.4.6 (Snowplowing Freeway Ramps), which is to practice plowing operations on different freeway ramp configurations, novice drivers exhibited greater variability and higher peaks in velocity compared to experienced drivers, as shown in Figures 3.55–3.63. The inconsistency in their speed maintenance may suggest a lack of steady control, potentially

driven by inexperience (Figures 3.55–3.57). Age-group comparisons showed that the 18–29 group exhibited the most dynamic changes in speed, with sharp rises and falls (Figures 3.58–3.60). In contrast, the 50–59 and 60+ groups maintained more conservative and stable speeds, with the oldest group showing delayed but steady acceleration, possibly reflecting cautious driving behavior. The brake pedal pressure analysis provided that novice and 60+/18–29 age groups showed the most reactive and abrupt stopping maneuvers, potentially due to limited familiarity with the route or vehicle handling. Midlevel experienced drivers (3–8 years) demonstrated the most balanced and adaptive control, while novice and highly experienced drivers showed more inconsistent control behaviors (Figures 3.61–3.63).

Overall, the second phase of data analysis successfully identified distinct driving patterns across different groups within the five modules. However, the analysis faced limitations in contextualizing the data with the specific tasks required in each

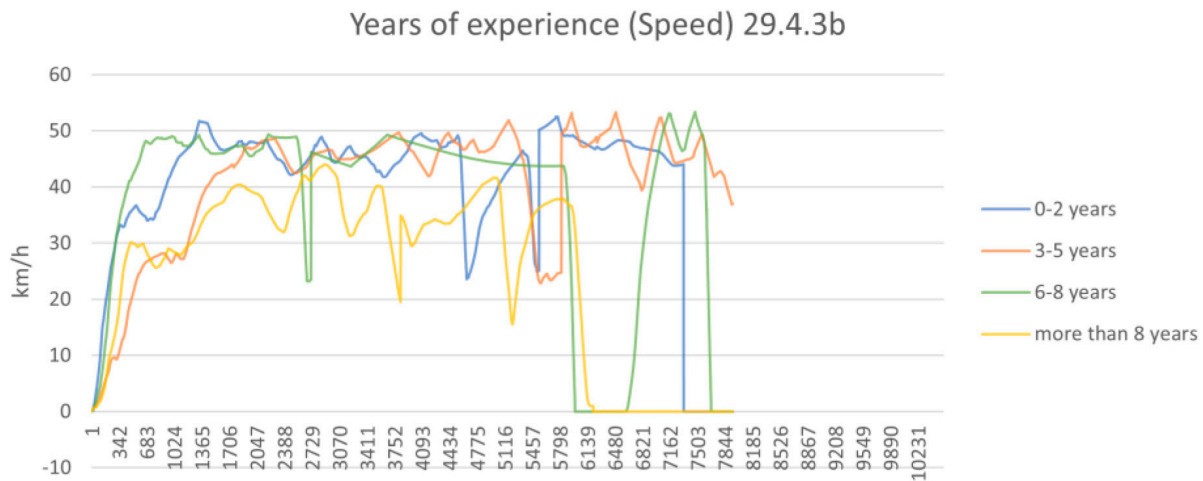


Figure 3.52 Analysis of Speed by Years of Experience Group in Module 29.4.3b.

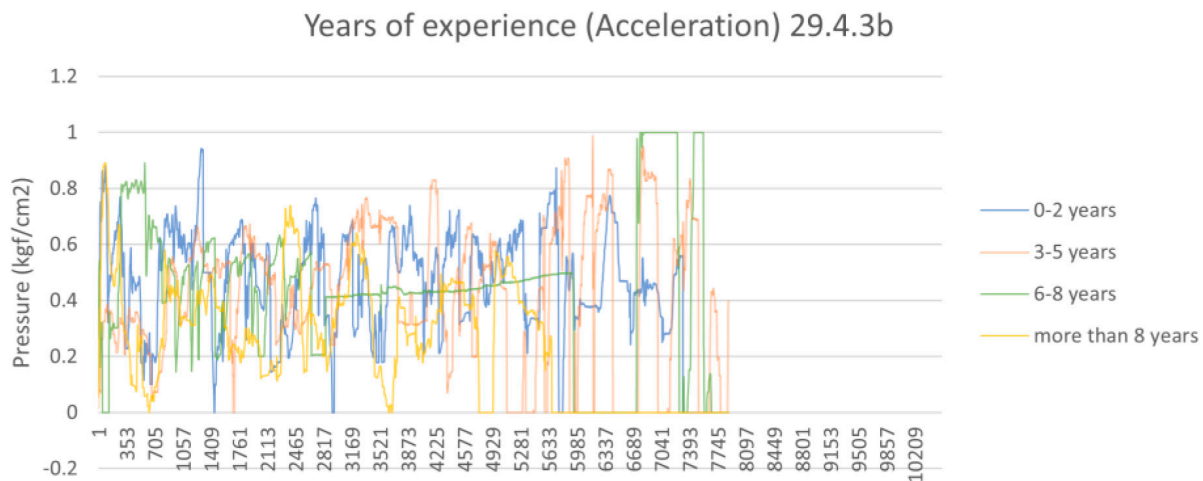


Figure 3.53 Analysis of Acceleration Pedal Usage by Years of Experience Group in Module 29.4.3b.

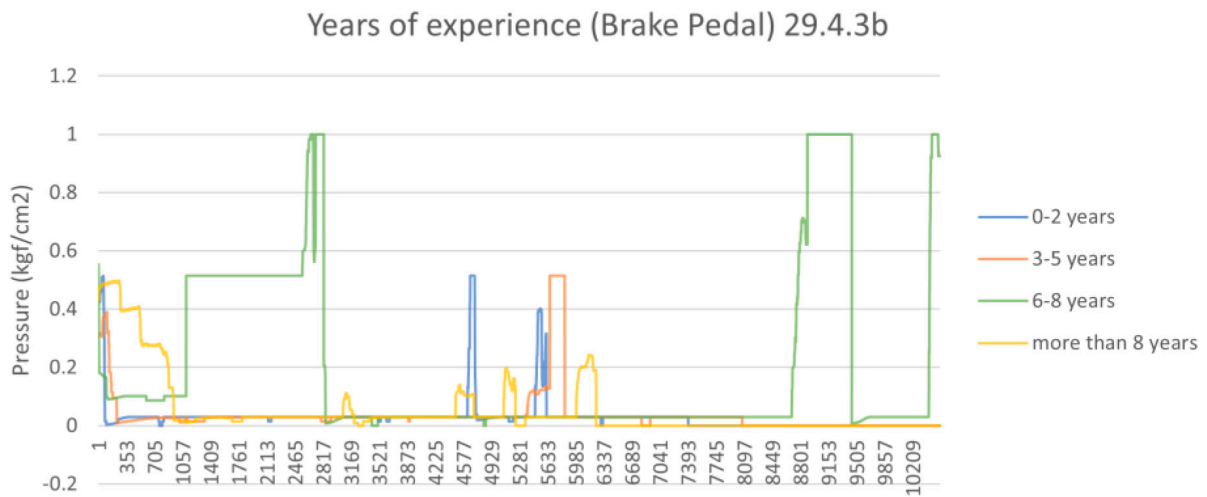


Figure 3.54 Analysis of Brake Pedal Usage by Years of Experience Group in Module 29.4.3b.

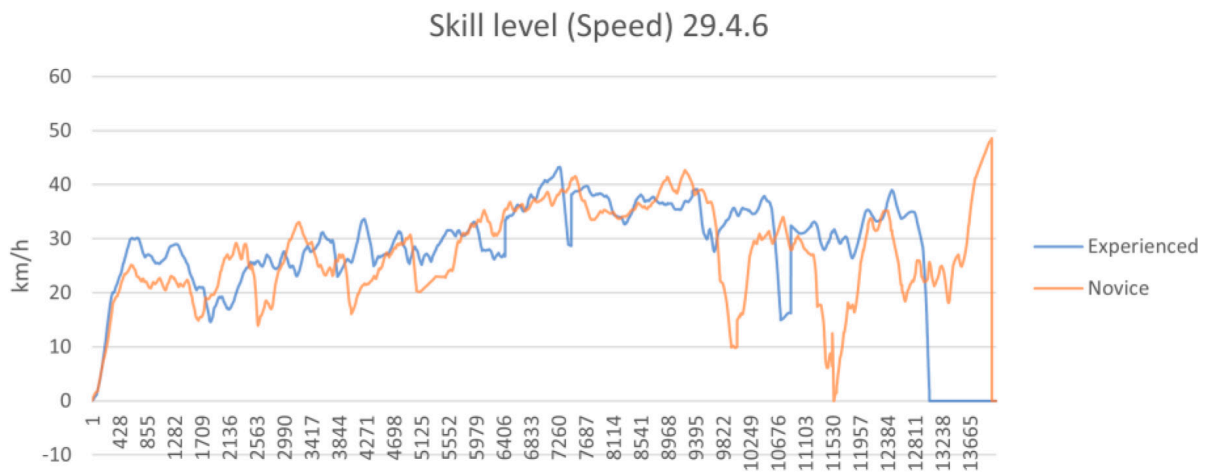


Figure 3.55 Analysis of Speed by Skill Level Group in Module 29.4.6.

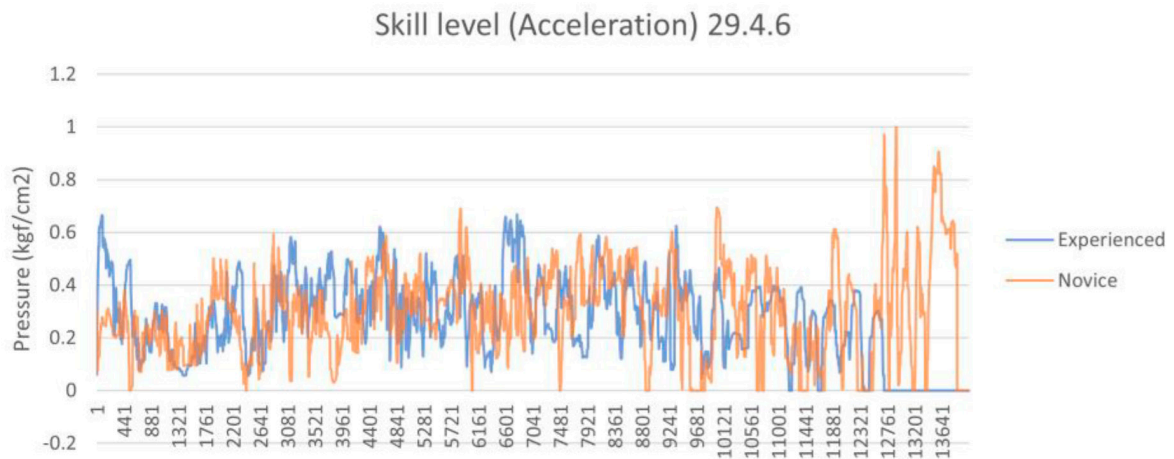


Figure 3.56 Analysis of Acceleration Pedal Usage by Skill Level Group in Module 29.4.6.

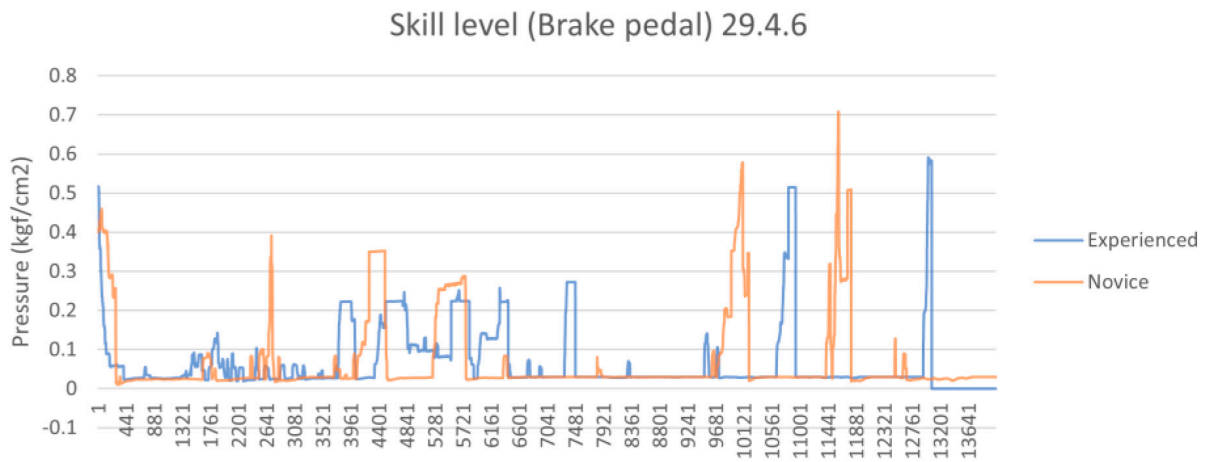


Figure 3.57 Analysis of Brake Pedal Usage by Skill Level Group in Module 29.4.6.

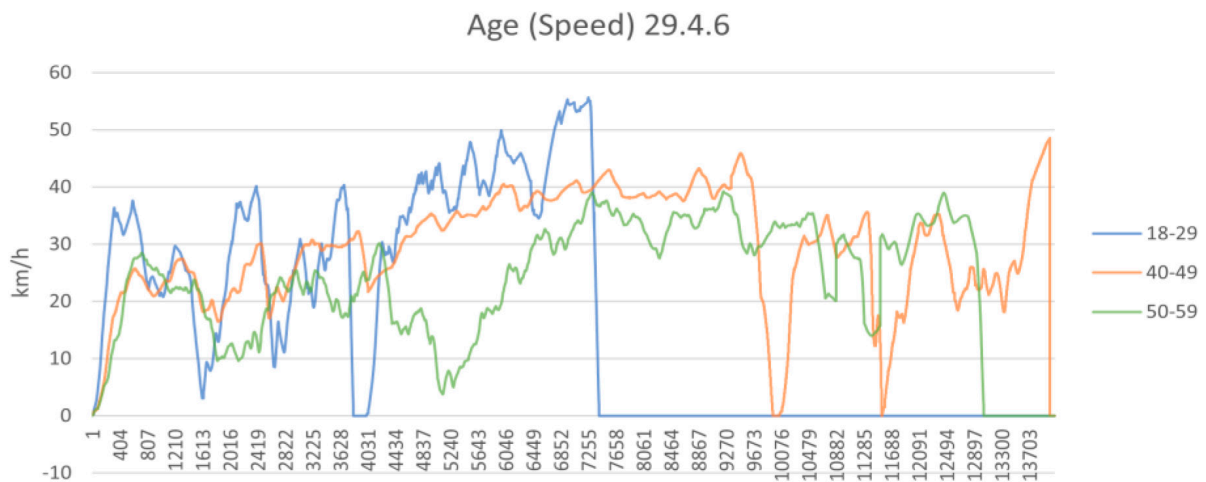


Figure 3.58 Analysis of Speed by Age Group in Module 29.4.6.

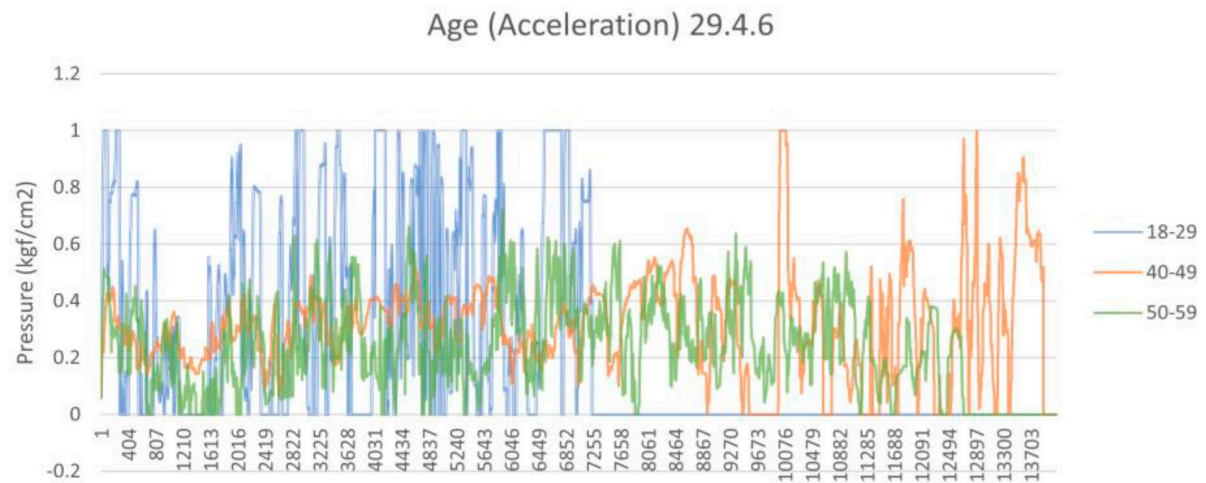


Figure 3.59 Analysis of Acceleration Pedal Usage by Age Group in Module 29.4.6.

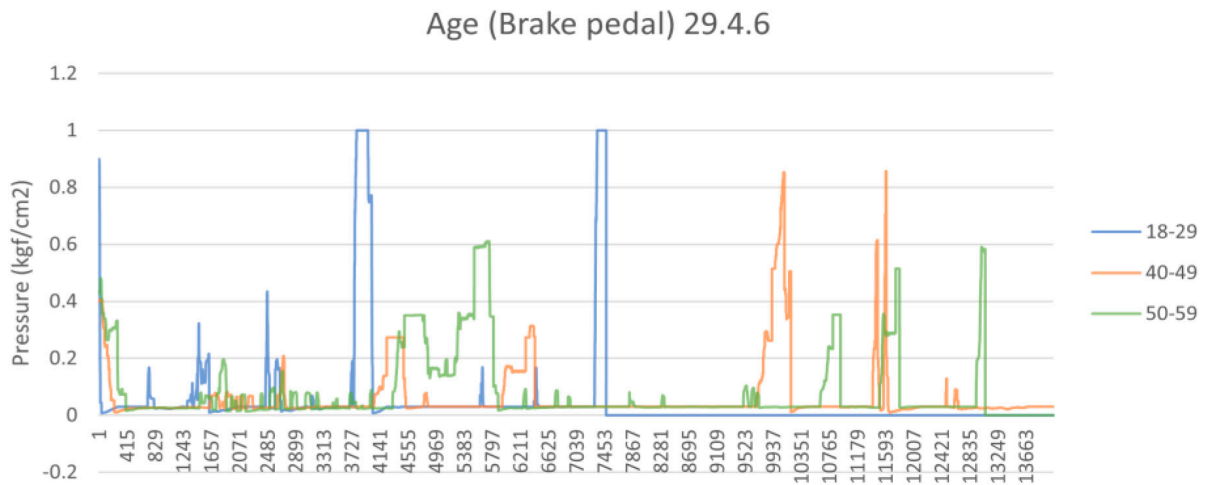


Figure 3.60 Analysis of Brake Pedal Usage by Age Group in Module 29.4.6.

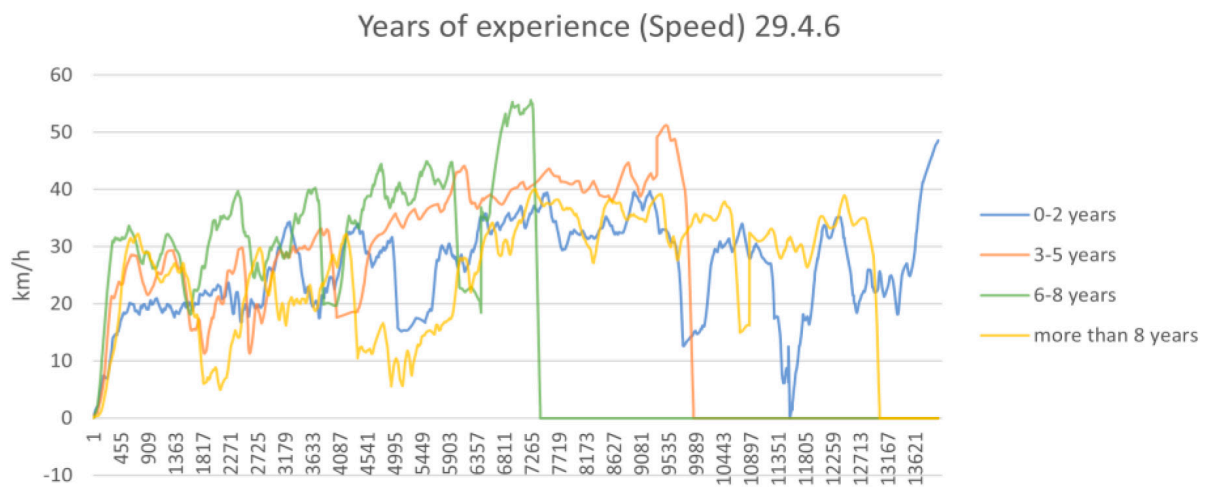


Figure 3.61 Analysis of Speed by Years of Experience Group in Module 29.4.6.

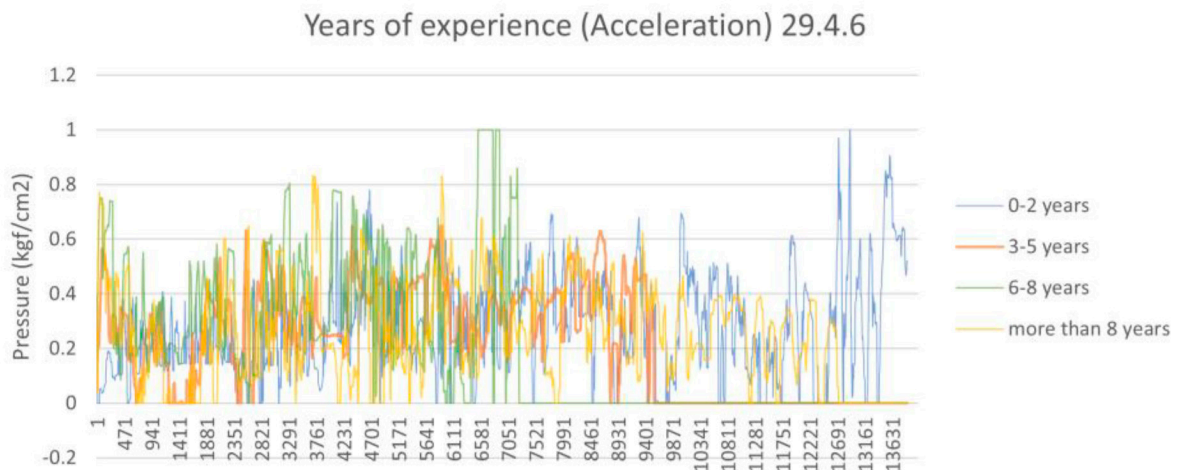


Figure 3.62 Analysis of Acceleration Pedal Usage by Years of Experience Group in Module 29.4.6.

Years of experience (Brake Pedal) 29.4.6

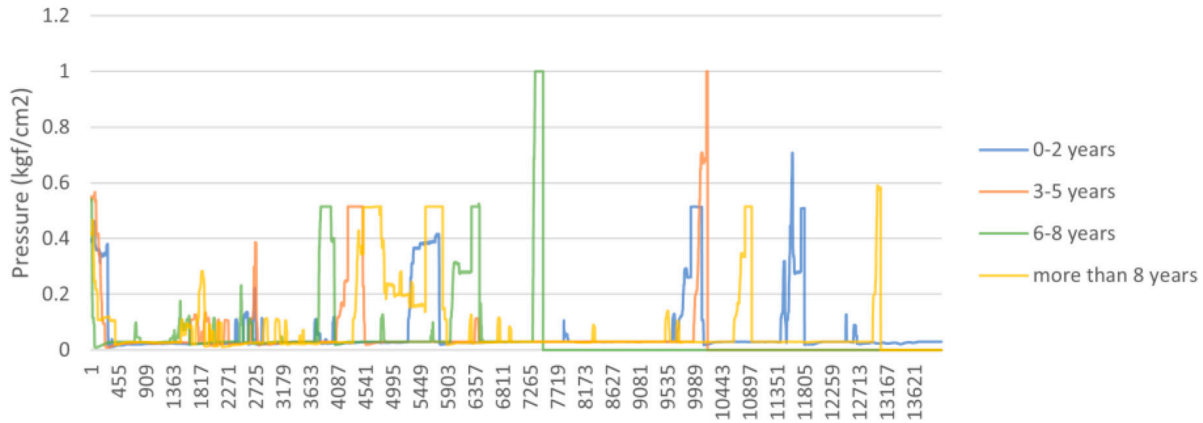


Figure 3.63 Analysis of Brake Pedal Usage by Years of Experience Group in Module 29.4.6.

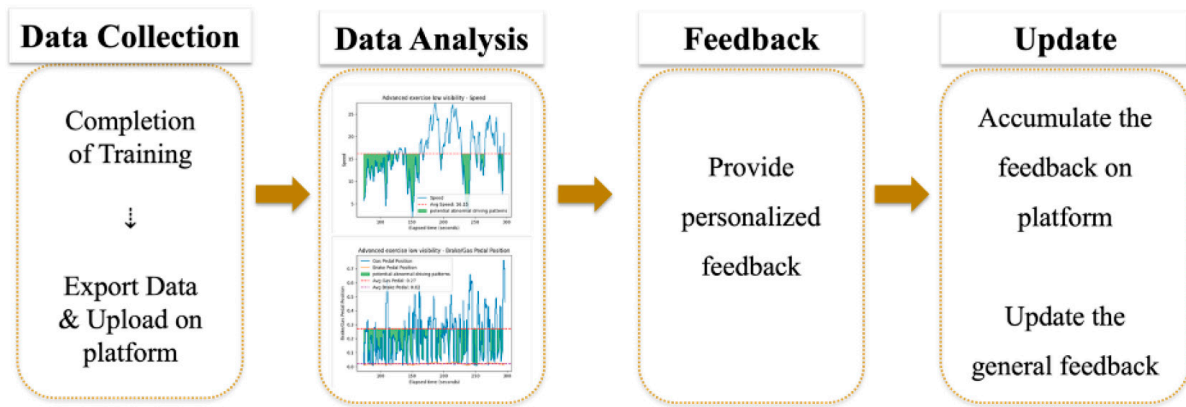


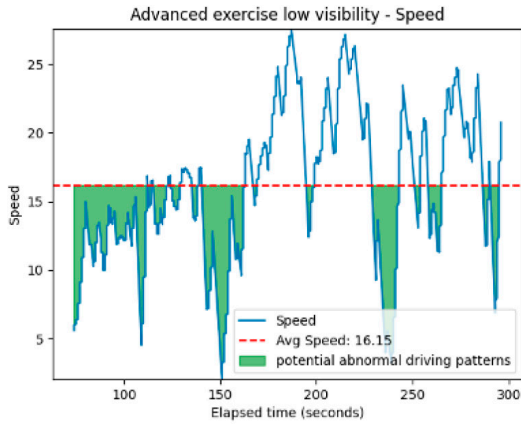
Figure 3.64 Overall Data Analysis Process.

module. That is, while patterns in speed, acceleration, and braking were observable, linking these patterns directly to in-module events or task demands proved challenging. To address this limitation, the research team posed the need for an integrated analysis approach, one that combines raw data with supplementary information, such as video recordings and performance results, to provide a more comprehensive understanding of driver behavior in relation to the simulation context.

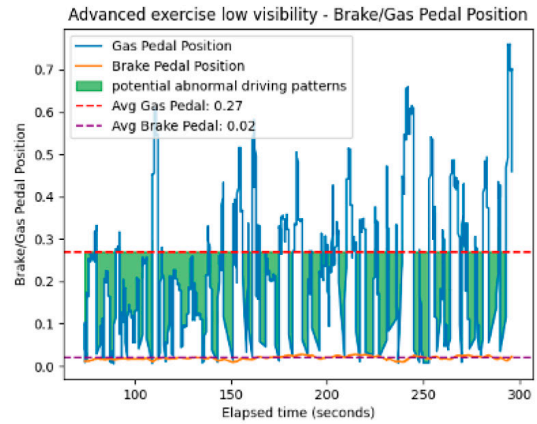
3.2.4.3 Online-Based Performance Results With Generic Feedback. In the third phase of data analysis, the research team developed a structured feedback pipeline that integrates real-time simulator driving data with individualized and group-based performance insights. This approach not only enables the identification of individualized driving patterns, allowing for the detection of personalized driving strategies and anomalies, but also standardizes the instructions of the training program across districts. The goal is to improve driver performance through data-informed feedback loops, as illustrated in Figure 3.64.

Step-by-step process was structured as follows:

1. **Data collection:** Driving data such as speed, gas pedal pressure, and brake pedal pressure were collected from the simulator during training modules (e.g., Module 29.2.6). Raw performance data from all participants were stored for batch analysis. In the training program, the raw driving data were exported from the simulator and uploaded on the platform (e.g., Python environment).
2. **Data analysis:** Raw data were exported and uploaded to a processing platform (e.g., Python environment). Group-level statistical benchmarks were generated (e.g., average speed profiles and control inputs) to serve as references for identifying abnormal behavior.
3. **Anomaly detection:** Potential abnormal driving patterns were flagged by comparing individual performance against these statistical norms. Examples include unusually aggressive acceleration, excessive braking, or sharp deviations in speed.
4. **Event verification via multimodal matching:** Abnormal data points were cross-referenced with (a) Simulator-exported performance summaries; (b) Elapsed time data; and (c) Synchronized video recordings. This enabled accurate identification of critical



(a)



(b)

Figure 3.65 Potential Abnormal Driving Patterns in (a) Speed Profile and (b) Brake Patterns.

events, such as collisions with pedestrians, sidewalks, or barriers, as well as failure in cornering or lane keeping.

5. **Personalized feedback generation:** Identified events were converted into individualized feedback messages, which were stored in a cloud database for each driver’s training log.
6. **Standardization and knowledge accumulation:** As feedback accumulates, frequently occurring patterns are generalized into standardized feedback, forming a knowledge base. Meanwhile, rare but critical individual feedback is retained and becomes a reference for future drivers encountering similar issues.

This feedback loop, visualized in the accompanying diagram, illustrates a scalable and adaptable framework that transitions from raw data to actionable insights. By incorporating both statistical benchmarking and contextual verification, the system enhances the realism, accuracy, and educational value of simulator-based driver training programs. To demonstrate the feedback framework described above, the research team analyzed driving data from Module 29.2.6, focusing on detecting abnormal driving behavior and translating findings into actionable training feedback.

Among 15 participants, the average speed was calculated as 16.15 mph. Figure 3.65a shows a speed profile over time, where segments below the average threshold and exhibiting abrupt fluctuations were identified as potential abnormal driving patterns. These patterns appeared notably at elapsed times 0–100 s, around 150 s, and near 230 s. Figure 3.65b presents the corresponding gas and brake pedal positions, indicating spikes and irregular pressure inputs aligned with the previously identified segments. These anomalies were cross validated by comparing the speed-profile patterns with the corresponding gas- and brake-pedal inputs.

Based on this analysis, the following individual feedback was derived (Table 3.6):

Beyond individual cases, the team consolidated feedback from all participants to identify common feedback themes. Of a total of 32 personalized feedback instances, five were recurring across participants. In total, the analysis produced 32 feedback

TABLE 3.6
Proposed Personalized Feedback.

Issue	Individual Feedback
Collision with the sidewalk while initiating from a parked position	Intervention feedback: Trainers should issue a warning about the risk of sidewalk collisions before beginning the module.
Collision with a median strip during turning	Additional training feedback: Trainers should provide supplemental turning exercises for spatial awareness.
Unsafe proximity to a school bus and a pedestrian	Commentary feedback: Trainers should emphasize maintaining a safe distance and waiting until pedestrians reach the sidewalk.

TABLE 3.7
Proposed Feedback for All Participants.

Common Issue	Standardized Feedback
Navigating curves with lateral instability	Commentary feedback: Encourage drivers to take wider turning radii on sharp curves.
Use of a horn on a jaywalking pedestrian	Commentary feedback: Caution trainees to use the horn appropriately and sparingly, especially near pedestrians.
Collision with the sidewalk while initiating from a parked position	Intervention feedback: Same as above.
Collision with median strip	Additional training feedback: Reinforce vehicle turning practice.
Failure to maintain a safe distance from the front vehicle or pedestrian	Commentary feedback: Emphasize proactive distancing and pedestrian safety.

items from 15 participants, which are five common feedback categories and two minor, driver-specific insights, as shown in Table 3.7. These findings demonstrate the effectiveness of combining raw data, statistical thresholds, and visual evidence to create a structured and meaningful training intervention process.

While the current feedback framework remains in the experimental stage, future efforts will focus on collaborating with trainers through meetings and surveys to develop practical and

standardized feedback protocols for each simulation module to minimize variation in training performance across districts.

3.3 Task 3: Long-Term Training Assessment

In addition to assessing potential gains immediately after the snowplow and CDL driver training, the research team also evaluated potential gains months after the driving simulator training. Data were collected through a survey (named “long-term survey”), focus groups and the analysis of historical INDOT data.

The follow-up long-term survey developed by the research team targeted drivers after approximately 4 months after their simulator-based training. This survey was distributed in two iterations: Year 1 (data collected in late spring through Summer 2024) and Year 2 (data collected late Spring and early Summer 2025). The survey was available to all drivers, including those who did not do any driving simulator-based training, so that a comparative analysis could be performed. The survey could be accessed via a flyer featuring a direct link and QR code and was prominently displayed at two state DOT training facilities in Winamac and Greenfield, Indiana.

In regard to long-term survey design, questions were structured similarly to short-term snowplow surveys for convenience in analysis. To begin with, participants were first asked to provide demographics and operations information including gender, age group, and previously participated training types. Following, two Likert-type questions were provided to participants regarding their current confidence level in driving CDL and snowplow vehicles. An open-ended question was placed at the end of this section to gather any additional information from drivers. Next, to evaluate driver’s long-term perceptions of the simulator training, 14 Likert-type questions related to various aspects of simulator training effectiveness were given to the participants, using a 7-point scale. Then, participants were asked whether they would recommend the simulator training to other drivers and if the allocated simulator training time was adequate. At the end of the long-term survey, two open-ended questions were provided to collect any additional inputs for simulator training benefits and rooms for improvement.

In addition to the long-term survey, the research team also utilized focus groups to collect snowplow and CDL driver’s long-term perceptions regarding the simulator training. Potential participants were contacted and recruited by email or phone through an INDOT’s preselected contact list approximately 5 to 6 months after the snowplow driver trainings in each location. The focus groups were conducted in-person at the Greenfield and Winamac training facilities. Before the start of the focus group, participant consent was obtained, and participants were also asked to fill out a short demographics survey. During the focus groups, the research team asked participants to deliberate about their perceptions of the driving simulator equipment, training and its effectiveness. Participants’ input was audio recorded for transcription purposes, and the discussed information was written on a board for better interaction. Participants were asked to review the written discussion summary on board for accuracy before the end of the focus groups. Results presented here are a compilation of focus groups in both locations. Moreover, our

analysis is based on the written summary as well as transcriptions that assist in explaining the written information.

Moreover, historical snow operation data was collected and analyzed to examine how INDOT can leverage these insights to inform labor allocation, training needs, and incident management, as well as to evaluate the effectiveness of the snowplow driving simulator.

3.3.1 Long-Term Survey

In terms of the results, the Year 1 long-term survey collected 25 valid responses from June 2024 to December 2024, three of which did not participate in the simulator training. In terms of participants’ age distribution, the research team recorded only one young driver (18–34 years old), while drivers with age from 35 to more than 65 years old were the majority ($n = 22$, 95.6%). By comparison, the Year 2 long-term survey collected a slightly larger number of valid responses from 30 participants, from March to July 2025, from which one driver did not attend any of the simulator trainings. When it comes to age distribution, the participants in Year 2 survey consisted of a much larger portion of young drivers ($n = 16$, 53.3%). Also, an additional question in Year 2 asked participants regarding their previous working experience, from which 20 out of 27 collected responses indicated that they had 3 years or less of experience driving as a CDL driver. Due to the little number of survey respondents that did not participate in the simulator driver training, the research team was not able to perform a comparative analysis between drivers that did not attend the driving simulator training and the ones that did attend it.

Results indicate that survey participants from the Year 1 were highly confident in both driving snowplows (mean = 6.39, med = 7, $n = 23$ and CDL-required vehicles (mean = 6.62, med = 7, $n = 23$). For Year 2, though a similar finding of high confidence level in CDL driving (mean = 6.28, med = 7, $n = 29$) was recorded, the participants reported a lower confidence level for the snowplow driving (mean = 5.59, med = 6, $n = 29$). This seems aligned with the lower confidence score reported in Year 2 snowplow driving, in which the group had a larger percentage of novice drivers. When compared with the short-term results for each type of training, drivers’ confidence level continued to grow months after the conclusion of the simulator training. This is expected as drivers move on from training to actual practice and refine their techniques and provides information about potential benchmarking of confidence and comfort level for different seasons, although with a lower response rate can affect the reliability of these numbers.

Next, drivers who underwent driving simulator training were asked additional questions. Using a 5-point Likert-scale, both Year 1 (mean = 4.38, med = 4, $n = 21$) and Year 2 (mean = 4.11, med = 4, $n = 29$) participants highly recommended INDOT to continue using the driving simulators for training. In other long-term measurements, more consistent findings were discovered between Year 1 and Year 2 results. For example, participants from both years indicated that the simulator was easy to learn, with a slightly higher score in Year 1 (mean = 6.19, med = 6, $n = 21$) when compared to the Year 2 results (mean = 5.67, med = 6, $n = 29$).

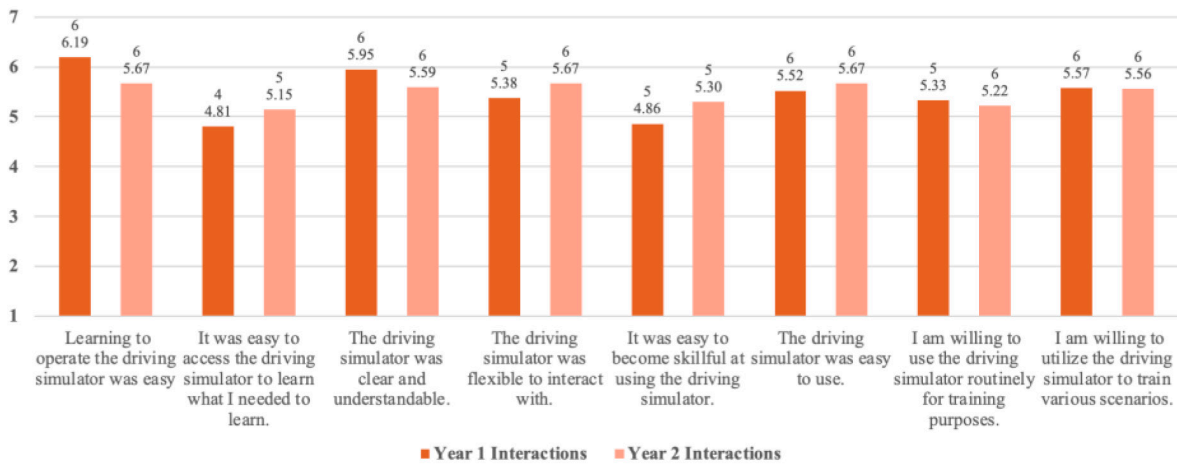


Figure 3.66 Comparison of the Median and Average of Long-Term Perceptions Toward Simulator Interactions (1–7 Scale) Between Years 1 and 2.

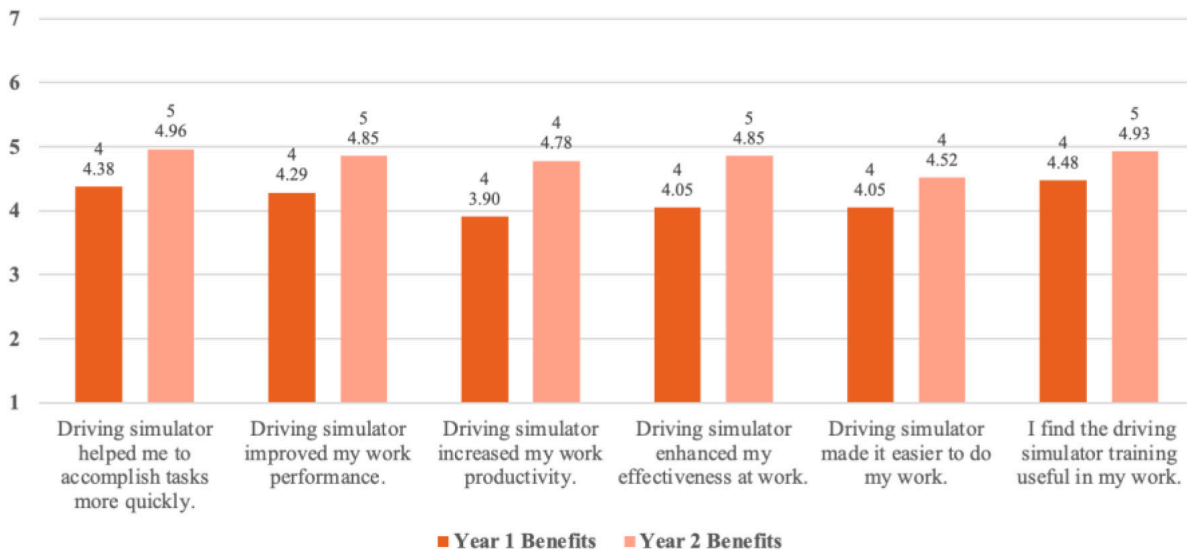


Figure 3.67 Comparison of the Median and Average of Long-Term Perceptions Toward Simulator Benefits (1–7 scale) Between Years 1 and 2.

Following, participants implied the interaction with the simulator was very clear and understandable. More items measured related to drivers’ long-term perceptions toward simulators can be found in Figure 3.66. We noted from both years’ results that the two lowest scores were related to simulator access and easiness to become skillful at the driving simulator, which may be expected due to the novelty of training, as well as the fact that driving simulators are located at a centralized location within each INDOT district, which may be somewhat far from some trainees. Overall, all items were measured above the scale midpoint, which indicate participants’ general positive, long-term sentiment toward the simulator.

In addition, participants responses from both years indicated above average rating for simulator training benefits, as summarized in Figure 3.67, with slightly higher scores noted for items “I find the simulator training useful in my work,” and “training with a driving simulator helped me to accomplish tasks more

quickly.” It is worth noting that participants from Year 2 survey gave higher ratings for all items related to simulator training benefits. On the other hand, Year 1 (mean = 2.90, med = 3, std = 0.09, n = 21) and Year 2 (mean = 2.74, med = 3, n = 29) participants both pointed out that the allocated training time was adequate, which aligned with previous short-term results. Albeit the low number of responders, the results for perceived simulator training benefits suggest that participants view the simulator as a practical aid for their job training, with strong endorsement for its usefulness and its ability to speed task completion. Such results match with short-term survey findings, as well as some previous DOT reports for snowplow training (Masciocchi et al., 2007; O’Rourke, 2011; Strayer et al., 2024).

When it comes to the open-ended questions in Year 1, a total of 16 responses were received for training benefits, of which a majority (n = 15) of the responses indicated that the simulator training could be beneficial for new drivers or

used as a refresher for skills. One driver implied that he or she did not see any benefits from such training. Furthermore, when asked about any improvements that could be made, 12 responses were collected. Drivers provided suggestions for simulator training improvements primarily related to hardware and software features. Such feedback included greater realism in graphics, plow routes, and cabin views (n = 5), diverse scenarios and malfunction equipment practice (n = 3). The remaining participants indicated various information such as recommendations of simulator training to novice drivers or expressed concerns over motion sickness.

During Year 2, 18 valid responses were collected from participants regarding simulator benefits. Specifically, many drivers (n = 12) noted that the simulator could be a good tool for new drivers to gain perspective of snow and plow controls, five drivers implied that the simulator did not provide any benefits as some of them already had extended experience in driving trucks. The remaining one driver believed certain scenarios would be helpful for training. When it comes to suggestions for improvements (n = 12), participants suggested improvements in simulator realism (n = 5), including more immersive and expansive maps, sound effects, and potentially better view perspective for truck and coned areas. Other participants provided various information, including more challenges, more training on backing maneuvers with trailers, as well as addition of curtains for better privacy.

Based on responses in Year 1 and Year 2's open-ended questions, it can be inferred that the perceptions about the simulator training as a useful training tool remained positive. This finding has been consistently noted with short-term training results from the present studies, as well as previous DOT reports and research (Masciocchi et al., 2007; Morgan et al., 2011; O'Rourke, 2011). On the other hand, simulators were found to be constrained in terms of realism under certain scenarios, and improvements for cabin views along with diverse training routes could also be made.

3.3.2 Focus Groups (Years 1 and 2)

In terms of the results, during Year 1, a total of nine drivers participated in two focus group sessions in May and July 2024, averaging 6.8 years of experience. Based on the demographics survey response, which was collected before, participants highly recommended the driving simulator training (mean = 4.56, med = 5, n = 9) to others, using a 5-point Likert-scale question. When it comes to Year 2, two focus group discussions were held during May 2025, with a total participant amount of 23 drivers. Results from the demographics survey indicated that the participants had an average plowing experience of 4.9 years. Similar to the drivers' perceptions from Year 1, simulator training was also recommended by the second round of participants (mean = 3.96, med = 4, n = 23).

Specific findings per focus group can be found in Appendix B for both 2024 and 2025 focus groups. The main findings from participants from both sessions in Year 1 and Year 2 can be summarized in the following comments about INDOT's driving simulator training programs:

- Advantages:
 - Good tool for training and evaluation;
 - Some good scenarios/modules;
 - Beneficial for novice drivers to gain some perspectives of plow tasks and environment;
 - Can be used for targeted training through different configurations;
 - Makes overall training time more efficient.
- Disadvantages/challenges:
 - Technical limitations such as haptic inputs, physics, and graphics (e.g., mirrors and driver cabin);
 - Some unrealistic scenarios such as city driving, backing up, and plow movement;
 - Experience of motion sickness on some scenarios;
 - Limited value for experienced drivers;
 - Lack of real-world plow routes.
- Suggestions:
 - Inclusion of a wider range of modules, from different weather/mechanical conditions to various driving techniques, as well as customized scenario for actual plow routes;
 - Improve realism in both graphics and physics;
 - Early start of the training;
 - Use of data to debrief;
 - Adding more realistic challenges;
 - Differentiate modules for novice and experienced drivers.

For items under advantages, the results align well with 2023–2025 short-term snowplow simulator training surveys. Comparable benefits were also documented across multiple as previous DOT technical reports (Kihl et al., 2006, 2007; Masciocchi, et al., 2006, 2007; O'Rourke, 2011; Strayer et al., 2004), from which simulator training are perceived to be particularly beneficial for novice drivers, and it can be used as training tools to offset potential dangers from real-world environment. On the other hand, some technical limitations such as unrealistic graphics, lack of sensible feedback, and inaccurate controls were also noted in previous DOT studies (Kihl et al., 2006, 2007). Another disadvantage suggested by the focus group was limited training effectiveness for experienced drivers (with more than 5 years of plow experience), which echoed with findings from previous DOT reports. For example, Arizona DOT report indicated that their experienced drivers learned minimal new things from the simulator training, and trainers viewed it as more of a refresher for experienced groups (Kihl et al., 2006). In addition, the survey results from an Illinois DOT study implied that experienced drivers received much less ratings than novice drivers when asked for recommendations of simulator training (O'Rourke, 2011). Also, similar to findings in short-term snowplow surveys, it is suggested for trainers pay extra cautions in regard to drivers' physical conditions as cases of motion sickness were reported.

For future implications, the aggregated focus group feedback suggested that early start of simulator training could be better for drivers to adapt. Meanwhile, the differentiation of modules for novice and experienced driver training was recommended as it could further enhance allocation of training resources and improve training efficiency. In addition, data generated during the simulator training can be used for briefing so that drivers will be informed about their performance and limitations. Moreover,

expansion of scenarios such as wider selection of training scenarios such as inclusions of customized scenarios, unexpected driving events and road conditions were suggested. This suggestion aligned with the efforts from ODOT, from which Ash et al. (2022) developed a customized virtual environment that mimics actual ODOT training facilities to further boost training realism. To summarize, future incorporation of these enhancements will not only help address the realism gaps but also position the simulator training program as a scalable and data-driven complement to the on-road training.

3.3.3 Historical Data Collection

The research team collected a historical dataset about detailed records of work activities, including associated costs, labor rates, and working hours in the districts. For example, it is recorded based on the individual employee’s activity and subactivity with three costs (material, equipment, and labor cost), rate, working hours in the districts (e.g., Fort Wayne, Greenfield, Laporte, Crawfordsville, Vincennes districts) and labor class code (e.g., highway technician, seasonal winter program worker, etc.).

The analysis of historical snowplowing involves examining patterns across Indiana; exploring how INDOT can leverage these insights to inform labor allocation, training needs, and incident management; and evaluating the effectiveness of the snowplow driving simulator in improving driver performance (focus on Greenfield and LaPorte districts). The research team conducted (1) inference of severe weather conditions, (2) analysis of driver labor structure, (3) establishment of incident base-lines, and (4) evaluation of simulator effectiveness.

3.3.3.1 Inference of Severe Weather Conditions.

Accurate inference of severe weather conditions is critical for winter operations, as it directly influences the scheduling and frequency of snowplow shifts. Such conditions can lead to extended work hours, increased driver fatigue, and variations in operational performance. To address this, the research team analyzed historical snowplowing data to infer severe weather conditions and evaluate whether districts appropriately deployed snowplow drivers in response to those conditions. To simplify regional comparisons, six INDOT districts were grouped into three broader regions: (1) North (e.g., Fort Wayne, LaPorte), (2) Central (e.g., Greenfield, Crawfordsville), and (3) South (e.g., Seymour, Vincennes). The research team assumed that districts located at higher latitudes, specifically those in the North region, would experience a higher frequency of severe weather conditions.

The research team conducted the t-test analysis to determine whether there is a statistically significant difference in the total working hours, calculated by summing the working hours of all drivers participating in the same activity, between non-severe days and severe days. Severe days are identified using a Gaussian distribution of total working hours, where a day is classified as severe if its z-score exceeds 1.5. As a result, the severe days counted 1,306 and the normal days counted 47,984 in the North region, the severe days counted 610 and the normal

TABLE 3.8
Comparison of Average Working Hours Under Severe and Normal Weather Conditions Across North, Central, and South Regions.

Factor	Regions		
	North	Central	South
Severe days count	1,306	610	457
Normal days count	47,984	26,301	15,799
Daily total working hours (severe)	25.90	24.72	26.76
Daily total working hour (normal)	9.44	9.55	8.61
Average deployed drivers (severe)	2.33	2.25	2.63
Average deployed drivers (normal)	1.02	1.02	1.03

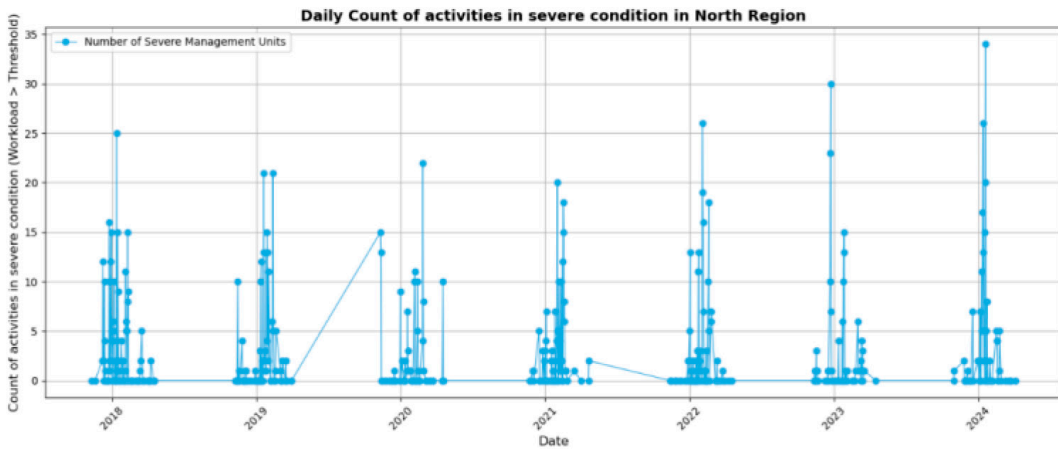
days counted 26,301 in the Central region, and the severe days counted 457 and the normal days counted 15,799 in the South region, as shown in Table 3.8.

Regions at higher latitudes showed a greater number of snowplow operations, and the count of severe conditions was also higher in the North region, regardless of the total number of working days. Notably, although the South region recorded the fewest severe weather conditions, it exhibited the highest daily total working hours (26.76 hr) and the highest average number of deployed drivers per activity (2.63). Specifically, the daily total working hours per driver (10.18 hr; i.e., individual workload) is the lowest among the three regions (11.12 hr in the North region [25.90 hr/2.33 drivers] and 10.99 hr in the Central region [24.72 hr/2.25 drivers]). It implies that the South region may be managing driver deployment more efficiently than the other regions. This may be attributed to factors such as the size of the area covered by drivers and the distribution of personnel assigned to snowplow operations.

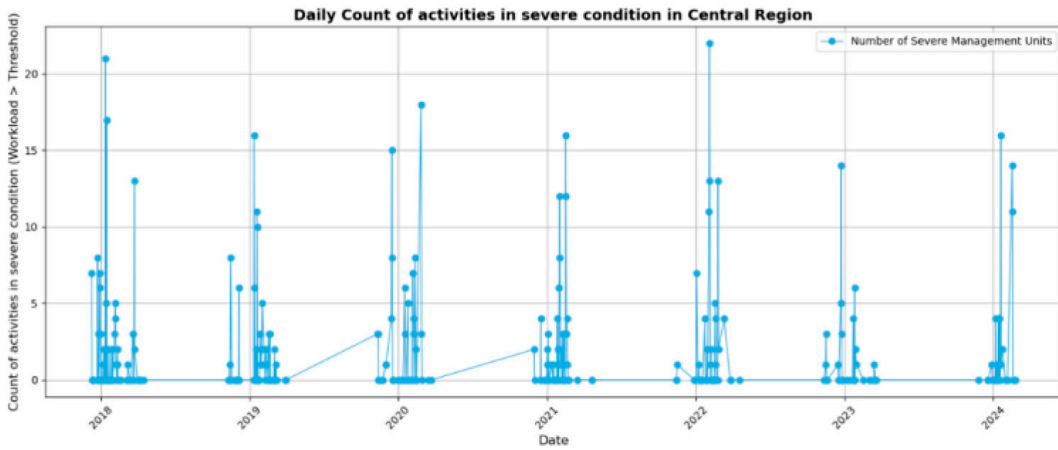
Furthermore, regional variations in daily activities, when the individual workload in the specific management unit is higher than threshold (16.78 hr), were illustrated using time series plots, organized by date and year, as shown in Figure 3.68. Results showed that the North region consistently increased the number of severe conditions since 2018 and the peak in 2024. Meanwhile, in the Central and South regions, a higher number of severe conditions were observed in 2022 and 2018, whereas the number was relatively low in 2020.

The total working hours t-test statistical analysis inferred severe conditions based solely on daily total working hours. To extend this analysis, the research team applied unsupervised cluster learning to group the severe conditions; (1) normal days, (2) typical severe days, and (3) extreme severe days, by incorporating multiple facts that may influence the inference of severe weather conditions, including total hours, material costs, cost per travel miles, and the number of employees.

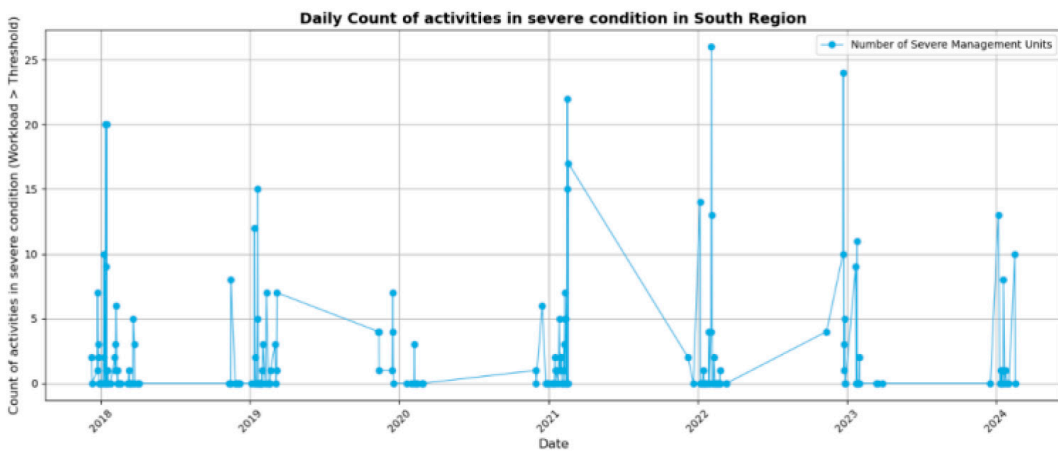
Figure 3.69 presents three clusters of employees based on the number of deployed personnel and their working hours. For example, in the North region (Figure 3.69a), Cluster 0 represents medium workload with medium number of deployed drivers (i.e., typical snowy condition), Cluster 1 indicates high individual workload with a large number of deployed drivers (i.e., extreme weather condition), and Cluster 2 corresponds with low individual workload and small number of deployed drivers (i.e.,



(a)

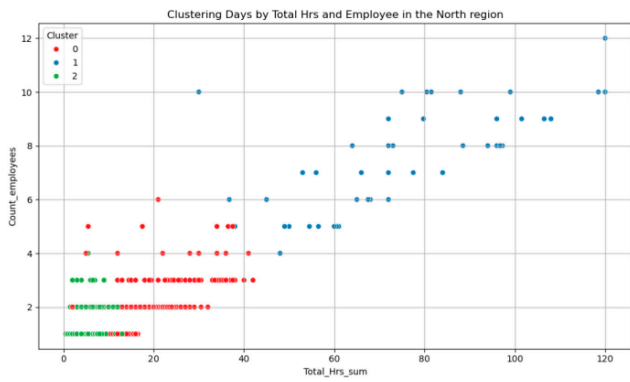


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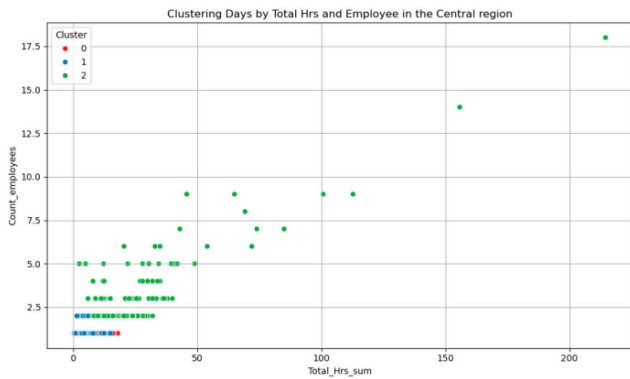


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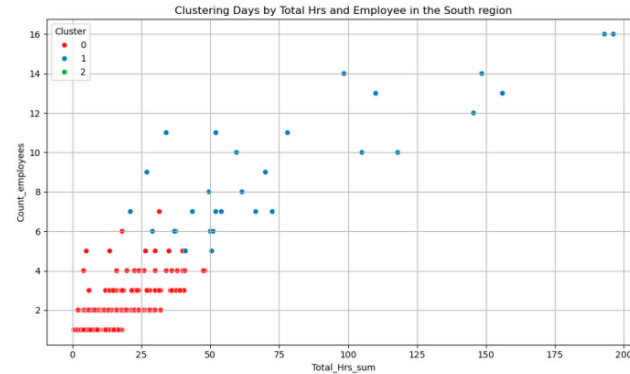
Figure 3.68 Time Series of Count of Activities Across Three Regions, When the Individual Workload in the Management Unit is Higher Than the Threshold Workload (16.78 hr).



(a)



(b)



(c)

Figure 3.69 Clustering of Severe Condition Events Across Three Regions Based on Daily Total Working Hours and Deployed Drivers (i.e., Workforce).

normal weather condition). In the Central region (Figure 3.69b), Cluster 0 and 1 represent days with low individual workload with small number of deployed drivers, while Cluster 2 indicates high workload with a large number of deployed drivers. In the South region (Figure 3.69c), Cluster 0 corresponds to days with normal weather condition, Cluster 1 indicates extreme snowy condition, and Cluster 2 reflects typical snowy condition.

Table 3.9 shows the daily total working hours per cluster for each region. Across all three regions, Cluster 2 in the North and

TABLE 3.9
Summary of Clustering Results of Daily Total Working Hours, Material Costs, Cost Per Travel Miles, and Deployed Drivers, Under Three Weather Conditions.

Region	Cluster	Daily Total Working Hours	Material Costs	Cost Per Travel Miles	Deployed Employees
North	0	12.27	\$1,745.22	\$8.46/miles	1.11
	1	77.38	\$7,631.84	\$4.13/miles	7.43
	2	8.43	\$544.41	\$3.70/miles	1.01
Central	0	11.20	\$2,470.65	\$12.11/miles	1
	1	8.68	\$738.64	\$4.72/miles	1
	2	20.26	\$1,434.19	\$6.59/miles	2.2
South	0	9.00	\$1,172.43	\$6.77/miles	1.07
	1	76.93	\$17,554.09	\$8.18/miles	9.23
	2	7.50	\$1,585.22	\$1,585.22/miles	1

South regions, and Cluster 1 in the Central region, snowplow operations on normal days typically involved a single driver working less than 9 hr. In the North and Central regions, material costs for normal-day operations were generally below \$1,000. On the other hand, clusters associated with severe conditions illustrated distinct patterns across the three regions. In the North region, although 7.43 snowplow drivers were deployed to manage the severe condition, they failed to prevent high individual workload (10.41 hr per single driver) against highest daily total working hours (77.38 hr). In the Central region, operations on typical severe days were conducted consistently with normal days and fewer personnel were deployed, indicating limited deployment of workers in response to severity. In the South region, workforce allocation appeared to be optimized, with high resource consumption used to effectively manage extreme and typical severe conditions. South region effectively managed extreme and typical winter conditions with high deployment and high resource consumption, achieving lower individual workload. These findings imply that the Central region requires a more efficient workforce deployment strategy, and the North region requires to increase in personnel deployment during typical and extreme severe conditions. However, future studies should address the following limitations. First, the analysis did not incorporate actual weather events, such as the amount and duration of snow precipitation, which are likely to influence deployment decisions and outcomes. Second, this analysis did not account for the timing of driver deployment across regions, including patrols and brine pre-treatment. These limitations suggest that additional contextual and operational data are needed to more accurately evaluate the deployment strategy in future research.

3.3.3.2 Analysis of Driver Labor Structure. Snowplow drivers are primarily classified under labor classes “Highway Technician 1, 2, 3” and “Highway Technician Supervisor.” These individuals are often categorized into full-time drivers

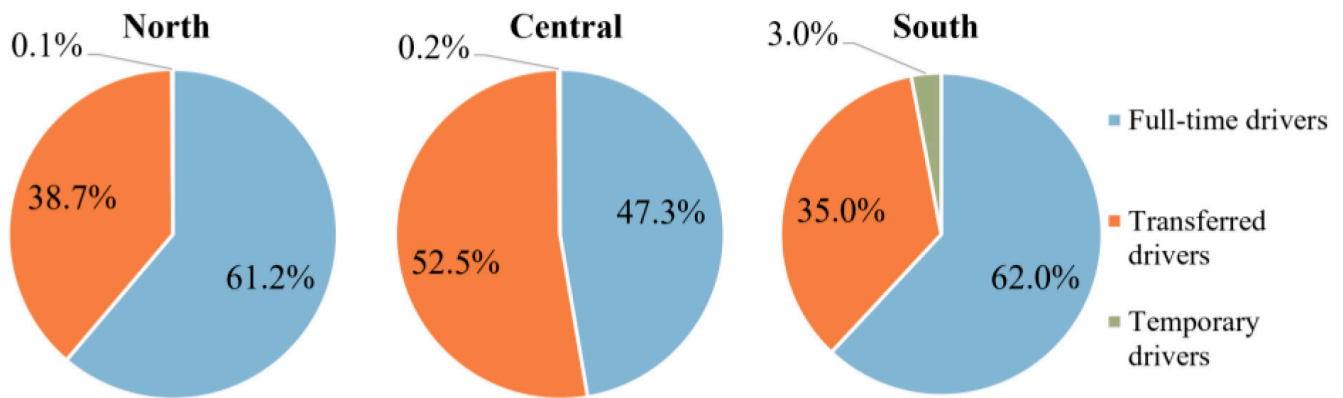


Figure 3.70 Proportions of Full-Time, Transferred, and Temporary Drivers in Three Regions.

(full-time drivers), who are not recorded as borrowed labor in the historical datasets under labor class, such as “Highway Technician 1, 2, 3” and “Highway Technician Supervisor,” and temporary snowplow drivers are categorized under labor class, such as “Seasonal State Worker” or “Seasonal Winter Program Worker.” In addition, transferred drivers are recorded as borrowed labor. The research team aimed to examine the proportion of temporary drivers and transferred drivers among snowplow drivers in each region, as well as how this proportion has changed across different seasons (e.g., 2020–21, 2021–22, 2022–23, and 2023–24 seasons). These results are visualized using pie charts, as shown in Figure 3.70, which is for overall result in each region, and Appendix C.

The overall results showed that in the South, where driver deployment was the highest in the severe weather conditions, the proportion of full-time drivers was the highest (62%) among all regions, while the lowest of the proportion of transferred drivers (35.0%) among all regions. The full-time drivers are more familiar with the assigned management unit (tasks) than temporary or transferred drivers. It implies that efforts to stabilize the driver workforce, such as increasing the proportion of full-time drivers or improving the integration of temporary personnel, may enhance the effectiveness of response operations. In addition, South region had the highest reliance on temporary drivers, with 3.0% of snowplow drivers as temporary. In contrast, the North region had the lowest reliance, with only 0.1%, indicating that nearly all snowplow operations were carried out by either full-time or transferred drivers. The operational differences (Table 3.9) align with observed labor structure patterns. As shown in Table 3.9, the South region exhibited optimized workforce deployment during both typical and extreme severe conditions, maintaining high resource use and achieving relatively low individual workloads. Full-time drivers are more likely to be familiar with assigned routes and operational procedures, which may contribute to more efficient task execution and better coordination during high-demand periods. In contrast, the North region had the lowest proportion of temporary drivers (0.1%) but showed a greater dependence on transferred drivers, indicating less workforce stability. These observations suggest that workforce composition, particularly the proportion

of full-time staff, may be a key factor in the successful deployment of snowplow operations under severe conditions.

Furthermore, the research team analyzed seasonal shifts in driver deployment patterns across different regions, as shown in Appendix C. In the North region (Appendix C.1–C.4. left pie chart), the proportion of transferred drivers consistently decreased from 51.3% in 2020–2021 to 38.7% in 2023–2024 season. Also, the proportion of full-time drivers is consistently increased from 49.1% in 2020–2021 to 61.2% in 2023–2024. In the Central region (Appendix C.1–C.4 middle pie chart) the proportion of transferred drivers increased in 2020–2021 (57.3%) to 2021–2022 (58.4. and decreased in 2023–2024 (52.5%). The proportion of full-time drivers decreased in 2020–2021 (41.8%) to 2021–2022 (20.9%) and increased in 2023–2024 (47.3%). In the South region (Appendix C.1–C.4 right pie chart), the proportion of transferred drivers has consistently decreased from 51.3% in 2020–2021 to 35.0% in 2023–2024. The proportion of full-time drivers has consistently increased from 47.3% in 2020–2021 to 62.0% in 2023–2024 season.

3.3.3.3 Investigation of Incident Baselines. The research team investigated whether snowplow-related incidents were associated with working intensity or severe conditions. Additionally, the study examined whether such correlations varied by regions. To align incident records with historical snowplow data, incident dates and driver names were matched with corresponding work dates and names in the historical dataset. As a result, 250 matching data points were successfully identified out of approximately 2,700 records from 2022 to 2025.

As shown in Table 3.10, the overall incident rate was correlated with holidays and severe conditions. The overall incident rate was 0.18% of the entries involved a reported incident in non-holiday workdays and 0.13% in normal weather conditions; in contrast, the incident rate was increased to 0.29% in holiday workdays and to 0.25% in severe snow days. Incidents occurred more frequently among those with high working hours, holidays, or weather conditions.

To further examine the relationship between holidays and incident rates, a time series graph of daily incident rates was created. As shown in Figure 3.71, higher incident rates were

TABLE 3.10
Incident Rate of Snowplow Operations Under Different Conditions, Including Holiday Workdays, Severe Weather Conditions, and Workload.

Factor	Incident Rate (%)
Holiday workdays	0.29
Non-holiday workdays	0.18
Severe Snow days ($z > 1.5$ total working-hours)	0.25
Normal weather conditions	0.13

observed on Christmas (particularly during the 2022–2023 and 2023–2024 seasons), Martin Luther King Jr. Day (2021–2022, 2022–2023, 2023–2024), and Memorial Day (2021–2022, 2022–2023, 2023–2024). These spikes in incident rates may be attributed to heavy weather conditions during those periods, or potentially to an increase in traffic volume due to the holiday. However, the exact cause cannot be determined through data analysis, as both factors may be contributing simultaneously to incidents.

Table 3.11 presents incident rates by districts. The Fort Wayne district has the highest incident rate of 0.229% and the Seymour district has the lowest incident rate of 0.115% among the six districts. The North region exhibited the highest incident rate (0.207%), while the South region showed the lowest (0.131%). It implies that incident rates varied by region, and that such variation may be linked to multiple factors, including the shift to driver deployment, and severe weather conditions

3.3.3.4 Evaluation of Simulator Effectiveness. The research team evaluated the effectiveness of the driving simulator for snowplow training. The snowplow training experiment using a driving simulator was conducted in the Greenfield and Laport districts for the 2023–2024 and 2024–2025 seasons. The participants are largely affiliated with INDOT as Highway Technician 1, 2, 3 or Highway Technician Supervisor. Based on this information, the validation of the effectiveness of the driving simulator can be conducted to extract the change of

TABLE 3.11
Incident Rates of Snowplow Operations Across Different Six Districts.

Regions	Districts	Records	Incidents	Incident Rates (%)	Regional Average Incident Rates (%)
North	Fort Wayne	26,173	60	0.229	0.207
	Laporte	37,026	71	0.192	
Central	Crawfordsville	17,763	34	0.191	0.173
	Greenfield	20,381	32	0.157	
South	Vincennes	9,665	15	0.155	0.131
	Seymour	15,604	18	0.115	

TABLE 3.12
Statistical Summary of Daily Total Working Hours Before and After Training.

Metric	Pre-training	Post-training	t-statistic	p-value
Average work hours	9.60 hours	9.26 hours	3.00	<0.003

performance metrics (e.g., driver’s work behavior) before and after simulator training implementation. The research team evaluated the average variation in work hours and compared the differences between skill level and age groups.

The research team conducted the t-test statistical analysis, which involves the hypothesis: the average work hours are higher in pre-training than in post-training. Overall results showed that there was a statistically significant decrease in daily total working hours after post-training, as shown in Table 3.12. It implies that the simulator training may have contributed to more efficient task completion.

Furthermore, the research team conducted a demographic subgroup analysis of the effectiveness of simulator training for snowplowing. There are two subgroups: (1) skill level and (2) age groups.

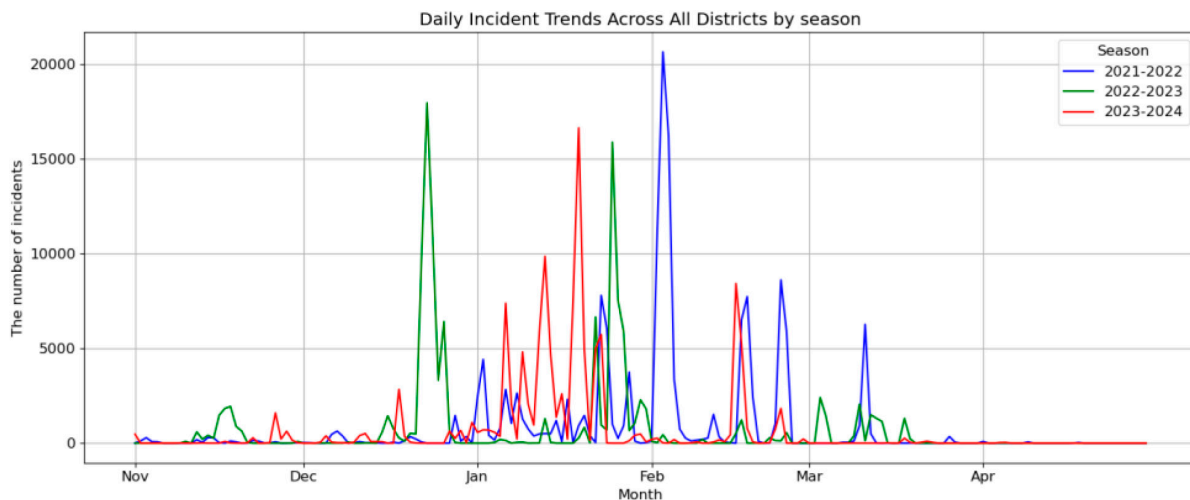


Figure 3.71 Time-Series of Daily Total Incidents Occurrence During Snowplow Operations (All Districts).



Figure 3.72 Comparison of Daily Total Working Hours Before and After Simulator-Based Training Across Different Skill Level.

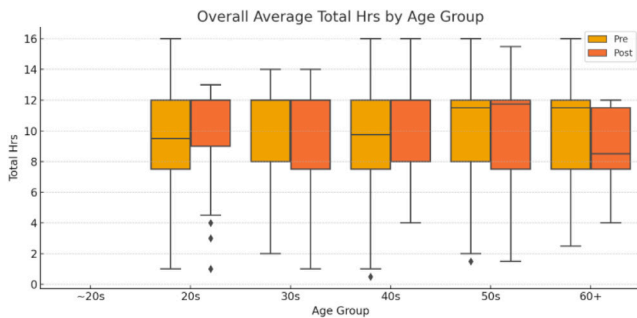


Figure 3.73 Comparison of Daily Total Working Hours Before and After Simulator-Based Training Across Different Age Groups.

In the skill level-based analysis, participants were categorized into novice (20 drivers), who have experienced snowplowing for less than 3 years, and experienced (11 drivers), who have experienced snowplowing for more than 3 years. The analysis of average working hours by skill level revealed notable differences in the impact of simulator training between experienced and novice drivers, as shown in Figure 3.72. While experienced drivers showed minimal change in median work hours pre- and post-training, the variability in their hours decreased slightly, indicating more consistent performance. In contrast, novice drivers showed a clear reduction in both median work hours and variability following the training. It implies that the simulator program was particularly effective for less experienced drivers, likely to help them improve operational efficiency and task familiarity. These findings suggest that simulator-based training may offer greater benefits for newer personnel by standardizing and optimizing their work behavior.

The age-based analysis revealed notable differences in simulator training effects across age groups as shown in Figure 3.73. There are nine drivers in their 20s, eight drivers in their 30s, five drivers in their 40s, six drivers in their 50s, and three drivers aged 60 and above. Participants in their 40s and 50s demonstrated the most significant reductions in average working hours after training, indicating that these groups may have benefited more from efficiency improvements. In contrast, participants in their 20s and 30s showed relatively stable work patterns, with only slight changes in median work hours and variability,

indicating consistent performance both before and after the training. The 60+ group showed the least consistent pattern, with high variability and minimal overall change, possibly due to diverse physical capacity or insufficient sample size. Overall, the training appeared to have the strongest impact on middle-aged workers, while younger and older participants demonstrated more stable or heterogeneous responses.

3.4 Task 4: Case Studies

Two state DOT agencies that are currently successfully using a driving simulator in their driving training program were identified. The research team visited and collected information about the driving simulator training program of the two state DOTs including types and numbers of simulators, number of trainees, duration of training, and equipment maintenance and upkeep approach to assist with establishing long-term implementation practices.

3.4.1 Case Study 1

The research team visited one state DOT in November 2023, a training facility that employs a combination of fixed and mobile driving simulators to support driver training for new hires and CDL candidates. The program accommodates classes of 35 to 40 trainees each session, with distinct training protocols for new hires and CDL candidates. For new hire training, the simulator operates for approximately 6 hr per class, split into 3-hr sessions over 2 days, with half the class training each day. CDL training requires 5–10 hr per class, conducted over 2–3 days, depending on the trainees’ needs. The facility does not mandate specific training modules; instead, a simulator expert collaborates with trainers to tailor scenarios to individual trainee requirements, ensuring flexibility in addressing diverse skill levels and learning objectives.

The equipment setup includes one L3 Harris simulator and one Caterpillar simulator, both stationed at the facility for maintenance and operations training. Additionally, a mobile training trailer, equipped with one L3 Harris and one Caterpillar simulator and powered by a generator, extends training capabilities to various locations. Maintenance practices emphasize cleanliness, with fans used to cooling the four computers powering the simulators. A fire extinguisher and warning triangle kit are kept on-site, doubling as tools for vehicle inspection training. Maintenance costs are minimal, with no expenses incurred unless upgrades are required. The state DOT has no immediate plans to expand or upgrade its current simulator setup, indicating satisfaction with the existing infrastructure for meeting training demands.

This case study highlights the operational efficiency of combining fixed and mobile simulators to deliver flexible, scenario-based training. The absence of mandated modules allows for personalized training, while low maintenance costs and strategic equipment use demonstrate a sustainable model for long-term implementation. These insights inform INDOT’s considerations for simulator usage rates, equipment placement, and adaptable training structures.

3.4.2 Case Study 2

The research team visited this state DOT in November 2024 to gather information about their driving simulator training programs. The research team examined a mobile training program utilizing a 43-ft trailer equipped with two L3 Harris simulators, deployed across 14 divisions, two statewide events, and ten recruiting events annually. The simulators are scheduled for approximately 50% of the year, reflecting a strategic approach to maximizing their reach and impact. Training sessions vary in duration based on participant numbers and skill levels, ensuring that instruction is tailored to specific group needs. Between 2022 and 2024, the program trained 1,666 new operators, with no session exceeding 20 participants. On average, each employee received 1.5 hr of simulator-based training, balancing efficiency with comprehensive skill development.

The mobile setup enables the program to serve diverse geographic areas and event types, from division-specific training to broader recruitment initiatives. The flexibility in scheduling and session duration accommodates varying participant skill levels, making the program adaptable to both novice and experienced operators. The high input of trainees underscores the program’s capacity to scale training efforts while maintaining manageable group sizes for effective instruction.

This case study illustrates the advantages of a mobile simulator platform for widespread training delivery. The program’s ability to train a large number of operators across multiple locations highlights effective usage rates and strategic equipment placement. These findings provide INDOT with valuable data for optimizing simulator deployment and designing training programs that balance scale, accessibility, and individualized instruction.

3.5 Task 5: Review of Indiana-Based Agencies and Potential Synergies

As part of the research project, the team also explored synergies with other public agencies in Indiana. Potential public agencies and institutions that train CDL drivers and use driving simulators included:

- High-schools offering commercial driver license (CDL) training programs (for examples, see: Reiff & Schoon, 2024, and Zeleski, 2023);
- Community colleges also offering CDL classes (for example, see Ivy Tech Community College, n.d., and Vincennes University, n.d.);
- Several municipalities working with the state’s LTAP.

However, after initial evaluation, it was determined by the research team and the Study Advisory Committee (SAC) that training goals, geographical distribution, and driver demands of municipalities were better aligned with INDOT’s for the purpose of future partnerships. Therefore, further explorations to assess municipal needs were performed.

In partnership with the LTAP, the research team estimated the demand for driver training from municipalities based on current number of CDL drivers in those municipalities and an average 11% turnover rate of drivers in Indiana municipalities, as described by Hubbard et al. (2023). Although the numbers were estimated, it is noted that the reliability of the calculations is

TABLE 3.13
Number of INDOT Drivers Per District, 2023 (n = 1,848).

District	Full Time Drivers	Transfer Drivers	Total Drivers
Greenfield	102	262	364
LaPorte	157	195	352
Seymour	170	165	335
Crawfordsville	145	145	290
Fort Wayne	137	152	289
Vincennes	114	104	218
Total	825	1,023	1,848

TABLE 3.14
Number of INDOT CDL Trainees Per District, 2022 (n = 396).

District	CDL trainees
Greenfield	125
LaPorte	77
Crawfordsville	71
Fort Wayne	66
Seymour	39
Vincennes	18

difficult to assess due to the largely decentralized nature of local drivers—that is, different municipalities may define different training requirements for their drivers, which may or may not include driving simulators. Even for those municipalities that do incorporate the driving simulator in their training programs, scope and length of training may also vary. Given these difficulties, the high demand of seat time by INDOT and through communications with the SAC, the research team decided to focus this business case on estimating INDOT’s needs in terms of (a) simulator use time per district and (b) number of simulators per district in order to train drivers in a timely manner. Following INDOT’s guidance, the business case will provide an analysis at the district level.

To do this, the research team utilized the number of drivers per INDOT district from the calendar year of 2023, and information for CDL trainees from calendar year 2022. Table 3.13 displays the number of drivers in each district, as well provides a breakdown for type of driver. Greenfield and LaPorte, the two districts selected for the pilot implementation covered in this report, are the districts with the largest number of drivers, with Greenfield relying more on transfer drivers than any other district. Greenfield and LaPorte are also the districts with the highest number of CDL trainees, as indicated in Table 3.14. We note the number of CDL trainees is important because of the high number of simulator training hours for CDL trainees established by INDOT (approximately 10 hr per trainee).

Following, the research team utilized the seat time as used in this pilot implementation for CDL driver training and snow-plow driver training to assess the usage of driving simulators per district. We have also added a one-on-one training option that INDOT could use for remediating or improving targeted skills. Table 3.15 includes the list of assumptions made for this business case.

TABLE 3.15
Training Assumptions.

Characteristics	Type of Training		
	New CDL	Snowplow	Refresher
Seat time	10 hr/trainee	1 hr/trainee (4 trainees per 4 hr training)	2 hr/trainee
Seasonality	Year-round	Fall (Sep, Oct, Nov, Dec)	Spring, Summer
Frequency	Once per trainee per license type	Once per trainee per year	Once per trainee per year
Target Trainees	New drivers, upgrading drivers	All drivers	10% of total drivers

For day duration, we have assumed that, for each working day, the first and last hours will be reserved for driving simulator set up and maintenance. Furthermore, INDOT drivers follow different work schedules depending on the month. From April to October, drivers work 10 hr per day and work Monday through Thursday. From November to March, drivers work 8 hr per day, from Monday through Friday. Therefore, we assumed the driving simulators would be used 6 hr per day, 5 days per week from November through March, and 8 hr per day, 4 days per week from April to October. Because of these changes, our business case is based on monthly uses and also accounts for holidays, using state holidays in 2025 for reference (based on list from Indiana State Personnel Department, 2025).

Based on our estimates, a total of 6,224 hr of driving simulators will be needed across all INDOT districts for all training types combined. These hours are translated in days of use per month in Table 3.16 and Figure 3.74. Our analysis highlights the extremely high demand on driving simulators for training in Fall for all but one district. Moreover, Greenfield district driving simulator use is at capacity nearly every month and nears 200% capacity in November. Beyond being the district with the most drivers, the Greenfield district also trains more new CDL drivers per year than any other district, which adds to the total year-round demand.

A second layer of analysis looked more closely at the peak training season (Fall) to evaluate the spread of time for snowplow driver training, considering the driving simulator used at capacity

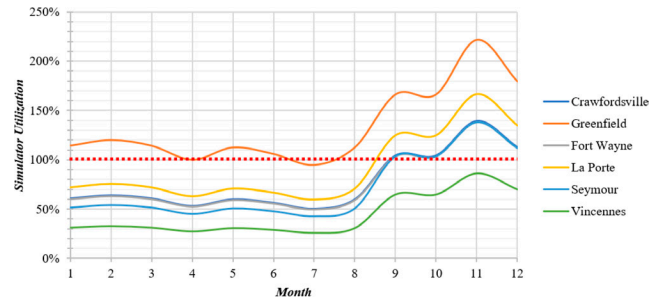


Figure 3.74 Driving Simulator Usage Percentage Per District.

for CDL training and snowplow driver training. Similarly to the usage capacity, we have considered a maximum of 8 hr per day for September and October, and 6 hr per day for November and December. Additionally, we have considered 2 sessions of CDL training per month. Each month was considered to have 1/12th of the yearly trainees per each district. Our calculations start with considering maximum capacity for the month of October, following by additional weeks before and after that month.

A first analysis evaluated the number of trainees per month, when considering one driving simulator per district. However, for this analysis, it would be impossible to train all drivers for winter operations, due to the high utilization of the driving simulator per CDL trainees. This was the case, even when considering all months of the year. A second analysis, shown in Table 3.17, considered two driving simulators in Greenfield, and in this case, the location with the longest training for winter operations would be LaPorte, from July to December. Figure 3.75 shows the estimated number of weeks needed to train all snowplow drivers for winter operations., highlighting in red the period in which all districts will be performing snowplow driver training. This period is estimated to include 9 weeks, starting in the first week of October. For the visualization we have assumed that all months have 4 weeks, though this varies greatly. As seen in the picture, all districts will require more than one month to train all their drivers, with Vincennes needing the least amount of time (9 weeks), and LaPorte the longest (20 weeks), which might not be ideal.

TABLE 3.16
Estimated Usage of Driving Simulator in Days Per Month, Per INDOT District.

District	Days/Month											
	Jan	Feb	Apr	May	Jun	Jul	Aug	Sep*	Oct*	Nov*	Dec*	
Business Days Available	21	20	21	18	16	17	19	17	17	17	21	
Available Seat Time per day	6	6	6	8	8	8	8	8	8	6	6	
Crawfordsville	11.2	11.2	11.2	8.4	8.4	8.4	8.4	16.5	16.5	22.0	22.0	
Greenfield	19.0	19.0	19.0	14.3	14.3	14.3	14.3	24.5	24.5	32.7	32.7	
Fort Wayne	10.5	10.5	10.5	7.9	7.9	7.9	7.9	16.0	16.0	21.3	21.3	
LaPorte	12.3	12.3	12.3	9.3	9.3	9.3	9.3	19.1	19.1	25.5	25.5	
Seymour	6.8	6.8	6.8	5.1	5.1	5.1	5.1	14.6	14.6	19.5	19.5	
Vincennes	3.5	3.5	3.5	2.6	2.6	2.6	2.6	8.8	8.8	11.7	11.7	

*Snowplow driver training months

TABLE 3.17
Estimated Monthly Trainee Distribution for Snowplow Driver Training and CDL Training for July Through December*.

District	Type	Number of Trainees Required	Total Hours Per Month	Trainees Per Month						Total Drivers Trained
				Jul	Aug	Sep	Oct	Nov	Dec	
Crawfordsville	Snowplow trainees	290	varies	-	51	76	76	42	50	295
	CDL trainees	71	60	6	6	6	6	6	6	72
	% Driving Simulator Time used			39%	87%	100%	100%	100%	87%	
Greenfield	Snowplow trainees	364	varies	-	-	41	162	94	71	368
	CDL trainees	125	110	11	11	11	11	11	11	132
	% Driving Simulator Time used			36%	43%	55%	100%	100%	72%	
Fort Wayne	Snowplow trainees	289	varies	-	68	76	76	42	33	295
	CDL trainees	66	60	6	6	6	6	6	6	72
	% Driving Simulator Time used			39%	100%	100%	100%	100%	74%	
LaPorte	Snowplow trainees	352	varies	82	58	66	66	32	56	360
	CDL trainees	77	70	7	7	7	7	7	7	84
	% Driving Simulator Time used			100%	100%	100%	100%	100%	100%	
Seymour	Snowplow trainees	335	varies	-	-	96	96	62	86	340
	CDL trainees	39	40	4	4	4	4	4	4	48
	% Driving Simulator Time used			26%	31%	100%	100%	100%	100%	
Vincennes	Snowplow trainees	218	varies	-	-	-	116	82	27	225
	CDL trainees	28	20	2	2	2	2	2	2	24
	% Driving Simulator Time used			13%	16%	15%	100%	100%	37%	

*Based on 10-hr working days (4-day weeks), maximum of 8 driving simulator hours July through October and on 8-hr working days (5-day weeks), maximum of 6 driving simulator hours in November and December.

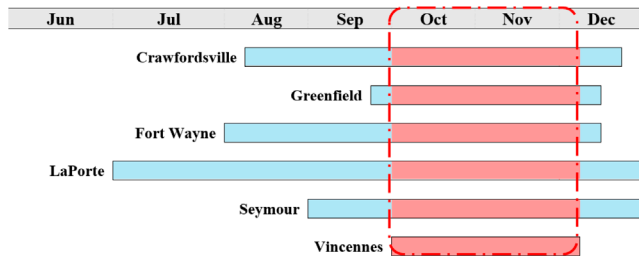


Figure 3.75 Weekly driving Simulator Usage for snowplow Driver Training.

4. ISSUES AND CHALLENGES

Throughout the 2 years of data collection, the research team identified a series of issues and challenges for the implementation of driving simulators in INDOT’s snowplow driver training. They mainly relate to low research response rates in some phases, equipment (driving simulator and research equipment), training and implementation. To start, our long-term analysis may be hindered by the low response rate the research group obtained for focus group participation and long-term survey. For the focus group, the low participation rate can be explained by the limited participation of trainees in the driving simulator training, due to its pilot nature, and for employee turnover, that is, drivers leaving INDOT employment. Similar issues affected the evaluation of drivers’ performance long-term. For long term survey, we note that, even though all drivers in both Greenfield and LaPorte district were invited to participate, in both cases participation from the driving simulator and, especially, the

nondriving simulator group were lower than expected. Future iterations should review recruitment procedures to maximize participation.

In terms of equipment, we highlight that we originally wanted to utilize an eye-tracking device to evaluate trainee engagement with the driving simulator. However, we encountered challenges in integrating the eye-tracker device with the driving simulator system. The eye-tracker device initially selected for the study experienced persistent connectivity issues when interfaced with the simulator software and hardware. These issues resulted in inconsistent data capture, synchronization problems, and interruptions in real-time tracking, thereby affecting the reliability and continuity of the experiments. Despite efforts to troubleshoot the problem, including software updates and configuration adjustments, the incompatibility remained a limiting factor. This challenge highlighted the importance of verifying cross-compatibility between research technologies early in the equipment selection process. As an alternative, we expanded the analysis of simulator-based performance data to explore differences between novice and experienced driver groups. However, the simulator performance data were only available for participants who consented to share their simulator usage data in the post-intervention survey. To link simulator data with driver characteristics (e.g., skill level, age group, years of experience), identifiable information between the simulator logs and survey responses needed to be matched, while ensuring that all personal identifiers were decoded and handled outside the research team to preserve confidentiality. During this process, we encountered missing identifiers in several simulator training records, which limited our ability to match data. As a result, only a small number of usable data points were collected. This

limited sample size may not fully represent the broader range of driving patterns, reducing the generalizability of the findings from this specific analysis.

Following, related to the driving simulator equipment, we noted that, consistent with previous state DOT reports, a few drivers have experienced discomfort while using the driving simulator. This seems to vary by person and also by certain scenarios. When this type of training is expanded to all INDOT drivers, INDOT should be aware of this issue and take into consideration its interactions with drivers' disabilities and limitations.

Scenario selection should also be refined to include the ones most relevant to INDOT's conditions. For example, it was mentioned that the update in Fall 2024 on how parking maneuvers are evaluated in the CDL exam is not yet reflected in the corresponding scenario. Another example is that drivers' assigned routes may significantly differ from what is used in the training, additional (or different) scenarios could be chosen to better match driver assigned routes, keeping interest and engagement levels in this type of training high. Additionally, recommendations for the use of the driving simulator for experienced snowplow drivers are less than novice drivers. This issue also came up frequently in focus groups. Upon further discussion, it seems that the issue is more related to scenario selection than the equipment itself. Therefore, more experienced drivers could be trained with more advanced scenarios to keep the training relevant and interesting, while still maintaining a minimum number of baseline scenarios as refreshers for their yearly winter operations training.

Some drivers in the focus group also mentioned some physical aspects of the simulator could be changed to provide a more realistic experience. This includes mainly mirror positioning and a wider field of vision.

In terms of training, the only issue found consistently in both years is the use of driving simulator data for debriefing. The driving simulator procured provides a series of training data, including acceleration and break patterns, scores (for modules that support this data), time stamps and records the interaction of the trainee with the module. And, while feedback has been constantly provided to drivers, training data have not been constantly used. Moving forward, it is important that trainers understand what type of data can be obtained from the simulator and how they can use these in their debrief.

Finally, in terms of implementation, our projections show that the seasonality in use of driving simulators may pose a challenge for its effective implementation across the state. It is noted that Greenfield will require an additional simulator to be able to train all districts' drivers, which is mainly due to the high number of drivers and also high turnover rates. LaPorte may be able to train all drivers, but it could require starting snowplow driver training in July, which may not be ideal. Therefore, future research in the implementation phase should evaluate the ideal and maximum length of time between snowplow driver training and the start of the snow season. We acknowledge that snow season in each district may differ and, therefore, should be evaluated at the district level. Additionally, future research could evaluate additional ways to mitigate the imbalance of seat

time required in different districts and increase simulator accessibility to drivers in INDOT subdistricts.

In addition to access and scheduling challenges, a key issue was the need to evaluate the return on investment (ROI) of simulator-based training. While this preliminary implementation provided promising evidence of performance gains and workload reduction. It is also important to quantify the comparative costs of simulator-based versus on-road training.

5. CONSIDERATIONS FOR THE USE OF DRIVING SIMULATORS IN TRAINING

The implementation of driving simulators in INDOT's driver training programs has demonstrated several positive outcomes, particularly for new and less experienced drivers. Feedback from trainees highlights the enthusiastic reception of simulator training, with drivers expressing high satisfaction with both the equipment and the training experience. This positive response underscores the simulators' ability to create a supportive learning environment that boosts confidence early in the training process.

A key factor in the simulators' effectiveness is the realism of training scenarios. Drivers showed greater interest in scenarios that closely reflected real-world driving conditions, as these felt more relevant to their daily responsibilities. On the other hand, less realistic scenarios, while still valuable, garnered lower engagement, suggesting that scenario design plays a critical role in maintaining trainee focus and motivation. This observation suggests that investing in high-fidelity scenarios tailored to Indiana's unique road and weather conditions could further enhance training outcomes.

For drivers with limited experience, the simulators provided a unique opportunity to explore truck driving techniques and operational perspectives in a risk-free setting before advancing to hands-on training. By simulating diverse situations, from routine highway driving to low visibility situations, the simulators enable novice drivers to develop a mental framework for decision-making and situational awareness before operating actual vehicles. This preparatory step has proven invaluable in bridging the gap between theoretical instruction and practical application and will reduce the learning curve during on-road training and minimizing risks associated with inexperience.

Short-term gains in confidence and comfort were particularly observed among snowplow drivers, particularly in the second year of the program. Although baseline confidence ratings were lower in Year 2 compared to Year 1, these gains highlight the simulators' potential to address specific operational challenges. Similarly, CDL training yielded positive results, with only two minor areas of negative feedback warranting further review to refine future sessions. These findings affirm the simulators' value as a versatile tool for enhancing driver preparedness and confidence across diverse training contexts.

Beyond immediate training outcomes, the simulators have sparked broader discussions about their potential to reshape INDOT's training culture. The ability to customize scenarios and track performance data offers opportunities to personalize training, catering to individual driver needs and fostering a culture

of continuous improvement. Moreover, the simulators' success with new drivers suggests potential for early career retention, as trainees who feel well-prepared are more likely to remain committed to their roles. However, the variation in scenario realism and the need to investigate CDL feedback indicate areas for refinement to maximize the program's long-term impact.

6. RECOMMENDATIONS

Building on the demonstrated successes of the driving simulator program, INDOT has a unique opportunity to expand and refine its training initiatives to meet both current and future operational needs. The simulators' extensive library of unexplored modules presents a strategic avenue for broadening training scope, particularly for experienced drivers who may benefit from advanced skill development. We recommend INDOT develops a tiered training curriculum that includes a mandatory annual core training program for all drivers, focusing on fundamental skills like defensive driving and vehicle maintenance checks. This core program can be complemented by specialized modules for seasoned operators to cover advanced topics such as complex route navigation, extreme weather operations, or integration of new vehicle technologies. By tailoring content to varying experience levels, INDOT can ensure that training remains engaging and relevant, fostering professional growth and adaptability across its workforce.

To enhance training accessibility and capacity, we suggest INDOT procures an additional driving simulator for the Greenfield district, a high-demand area where scheduling constraints have limited training opportunities. This investment would alleviate bottlenecks, allowing more drivers to access simulator-based instruction without excessive delays. In addition, the timing of snowplow driver training, particularly in the LaPorte district, warrants careful evaluation to align with seasonal demands. By scheduling sessions closer to the onset of winter and coordinating with weather forecasts, INDOT can ensure drivers are adequately prepared for snow and ice operations, enhancing safety and operational efficiency. To further optimize resource utilization, we recommend (a) evaluating the use of an additional itinerant simulator (mounted on a truck-trailer), that could travel between districts and minimize pressure on fixed driving simulators; and (b) establishing a district-sharing framework for simulator access based on training needs. This collaborative model would ensure broad access, particularly for time-sensitive snowplow training, while maximizing the return on equipment investments.

As driving simulators become a staple of INDOT's training programs, clear communication about their role is essential to set appropriate expectations. We recommend that trainers inform drivers that simulators are a supplementary tool designed to enhance, not replace, real-world experience. While some scenarios may lack visual realism due to technical limitations, their value lies in reinforcing fundamental learning objectives, such as decision-making under pressure or proper vehicle handling. Regular briefings or orientation sessions could reinforce this message, ensuring drivers focus on skill acquisition rather than graphical fidelity. Furthermore, we suggest INDOT leverages the wealth of performance data generated during simulator

sessions to enhance driver debriefs. By analyzing metrics such as reaction times, error rates, or scenario completion efficiency, trainers can provide targeted feedback, helping drivers address specific weaknesses and build strengths. This data-driven approach could also inform broader training adjustments and identify common skill gaps across trainees.

To sustain and scale the simulator program, it would be beneficial for INDOT to establish a comprehensive evaluation framework to assess its effectiveness and guide future enhancements. This framework, maintained by INDOT's training division, can include standardized metrics for evaluating trainee performance, instructor feedback, and program scalability. Key indicators could include trainee confidence gains, skill retention rates, and the correlation between simulator training and on-road performance. Regular evaluations would enable INDOT to identify the best practices, address emerging challenges, and justify continued investment in simulator technology. To support such justification, it is also important to assess the comparative costs of driving simulator training with exclusively BTW driver training to ensure cost-effectiveness. Specifically, the time and expense of running similar training scenarios using actual snowplow trucks, including fuel, equipment wear and tear, and safety-related risks, should be compared to the operational costs of simulator use (e.g., maintenance, software updates, hardware depreciation). Moreover, exploring partnerships with simulator manufacturers or other state transportation agencies could provide insights into advanced scenario development or cost-effective maintenance strategies, further strengthening the program.

These recommendations aim to position INDOT's driving simulator program as a model for innovative, scalable, and driver-centric training. By expanding training content, optimizing resource allocation, leveraging data, and establishing robust evaluation mechanisms, INDOT can enhance driver preparedness, improve operational safety, and adapt to evolving transportation demands in Indiana.

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APPENDICES

Appendix A. Survey

Appendix B. Focus Group Summaries

Appendix C. Historical Data Analysis – Driver Labor Structure

Appendix A. Survey

A.1 CDL Driving Training Operations (Pre-intervention survey, Year 2)

1. Based on your current driving experience and judgement, please rate **your comfort level** at performing the tasks outlined below in a INDOT vehicle that requires a CDL driver's license.

Task	Extremely Uncomfortable	Moderately Uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Moderately comfortable	Extremely comfortable
Changing gears	-	-	-	-	-	-	-
Overtaking other vehicles	-	-	-	-	-	-	-
Changing traffic lanes	-	-	-	-	-	-	-
Turning right	-	-	-	-	-	-	-
Judging stopping distances	-	-	-	-	-	-	-
Merging and exiting highway/interstates	-	-	-	-	-	-	-
Driving at appropriate speed for different road conditions	-	-	-	-	-	-	-
Reversing	-	-	-	-	-	-	-
Parking	-	-	-	-	-	-	-
Driving at night	-	-	-	-	-	-	-
Backing	-	-	-	-	-	-	-
Avoiding small objects (road debris) when driving	-	-	-	-	-	-	-
Avoiding large objects (such as animals or stopped vehicles on road) when driving	-	-	-	-	-	-	-
Driving in low visibility conditions (such as white outs, heavy rain, heavy fog)	-	-	-	-	-	-	-
Multitasking to control additional truck elements	-	-	-	-	-	-	-
Maintaining control of vehicle	-	-	-	-	-	-	-
Crossing railroad tracks	-	-	-	-	-	-	-

2. On a scale of 1 (not confident at all) to 7 (extremely confident), how would you rate your current confidence level in passing the commercial drivers' license (CDL) driving exam, if you were to take it now?
- 1 (not confident at all)
 - 2
 - 3
 - 4 (moderate confident)
 - 5
 - 6
 - 7 (extremely confident)

Perceptions of Simulator

3. Have you had previous experience in a driving simulator?
- Yes, on my own (through gaming or demonstrations)
 - Yes, other. Please specify where: _____
 - No
4. How interested would you be in training your CDL skills using a driving simulator?
- Not interested at all
 - Slightly interested
 - Moderately interested
 - Very interested
 - Extremely interested

Closing

5. Is there anything else you would like to add regarding CDL driver training or driver training using a simulator?

A.2 CDL Driving Training Operations (Post-intervention)

Demographics

1. Circle your age group:

- 18-24
- 25-29
- 30-34
- 35-39
- 40-44
- 45-49
- 50-54
- 55-59
- 60-64
- 65+
- Prefer not to say

2. Circle your gender:

- Male
- Female
- Prefer not to say

3. Which class of CDL do you currently hold (from Indiana or other states), if any?

- Restricted Class A
- Unrestricted Class B
- Restricted Class B
- None of the above and this is the first time I'm applying for a CDL

4. Which class of CDL are you applying for with the current training?

- Unrestricted Class A
- Restricted Class A
- Unrestricted Class B
- Restricted Class B

CDL Driving Training Operations

5. Based on your current driving experience and your judgement, rate **your comfort level** at performing the tasks outlined below in a INDOT vehicle that requires a CDL driver's license.

Task	Extremely Uncomfortable	Moderately Uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Moderately comfortable	Extremely comfortable
Changing gears	-	-	-	-	-	-	-
Overtaking other vehicles	-	-	-	-	-	-	-
Changing traffic lanes	-	-	-	-	-	-	-
Turning right	-	-	-	-	-	-	-
Judging stopping distances	-	-	-	-	-	-	-
Merging and exiting highway/interstates	-	-	-	-	-	-	-
Driving at appropriate speed for different road conditions	-	-	-	-	-	-	-
Reversing	-	-	-	-	-	-	-
Parking	-	-	-	-	-	-	-
Driving at night	-	-	-	-	-	-	-
Backing	-	-	-	-	-	-	-
Avoiding small objects (road debris) when driving	-	-	-	-	-	-	-
Avoiding large objects (such as animals or stopped vehicles on road) when driving	-	-	-	-	-	-	-
Driving in low visibility conditions (such as white outs, heavy rain, heavy fog)	-	-	-	-	-	-	-
Multitasking to control additional truck elements	-	-	-	-	-	-	-
Maintaining control of vehicle	-	-	-	-	-	-	-
Crossing railroad tracks	-	-	-	-	-	-	-

6. On a scale of 1 (not confident at all) to 7 (extremely confident), how would you rate your current confidence level in passing the commercial drivers' license (CDL) driving exam, if you were to take it now?

- 1 (not confident at all)
- 2
- 3
- 4 (moderate confident)
- 5
- 6
- 7 (extremely confident)

Perceptions about the Driving Simulator Training Equipment (interactions with hardware and software)

7. How involved were you in the virtual environment experience?

- Not involved at all
- Slightly involved
- Moderately involved
- Very involved
- Extremely involved

8. How enjoyable was your experience with the driving simulator?

- Not enjoyable at all
- Slightly enjoyable
- Moderately enjoyable
- Very enjoyable
- Extremely enjoyable

9. How accurately did the simulator equipment seem to replicate your real-world experiences?

- Not accurately at all
- Slightly accurately
- Moderately accurately
- Very accurately
- Extremely accurately

10. Please rate your perceptions (from ‘terrible’ to ‘excellent’) about specific hardware and software features in the simulator.

	Poor	Fair	Average	Good	Excellent
Equipment responsiveness (how quickly the simulated truck responded to your physical input)	-	-	-	-	-
Simulator fidelity to the controls of a INDOT truck	-	-	-	-	-
Visual input (graphical quality)	-	-	-	-	-
Audio input (sound)	-	-	-	-	-
Haptic input (vibration or other tactile sensation)	-	-	-	-	-
Believability of scenarios	-	-	-	-	-
Range of scenarios used in training	-	-	-	-	-

11. Did you experience any physical discomfort (such as headache, nausea, dizziness) while driving the simulator?

- Not at all
- A little discomfort (did not impact driving)
- A moderate amount (my driving was affected)
- A lot (utilizing the simulator was difficult)
- A great deal (I could not complete the training)

12. Did you receive debrief or feedback from trainers during the use of simulators?

- No
- Yes – Collective feedback
- Yes – Individual feedback
- Yes – Both collective and individual feedback
- I don’t know

Perceptions of Training Delivery with the Driving Simulator

13. Rate the usefulness of specific aspects of the simulator training, including the lecture portion.

	Not useful at all	Slightly useful	Moderately useful	Very useful	Extremely useful
Overall training with a driving simulator	-	-	-	-	-
Debrief / feedback from trainers during the simulator driving session	-	-	-	-	-
Content on non-routine situations with driving simulator	-	-	-	-	-
Content about speed management with driving simulator	-	-	-	-	-
Content about space management with driving simulator	-	-	-	-	-
Content about good communication with driving simulator	-	-	-	-	-

14. Would you recommend using a driving simulator for training to other CDL trainees?

- Definitely not
- Probably not
- Undecided
- Probably yes
- Definitely yes

15. Was the time allocated for you to drive the simulator equipment adequate?

- Definitely not
- Probably not
- Undecided
- Probably yes
- Definitely yes

16. Which part of the driving simulator training do you think was most effective and why?

17. What are your top 3 takeaways from simulator-integrated training?

Closing

18. Is there anything else you would like to add related to CDL driver training or driver training using a simulator?

A.3 Winter Operations (Pre-intervention)

- Based on your previous driving experience and judgement, please rate your comfort level driving an INDOT snowplow truck (as shown in the figure above) to perform the tasks outlined on the next page. Choose the option that best matches your self-perception.

Task	Extremely Uncomfortable	Moderately Uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Moderately comfortable	Extremely comfortable
Overtaking other vehicles	-	-	-	-	-	-	-
Changing traffic lanes	-	-	-	-	-	-	-
Turning right	-	-	-	-	-	-	-
Judging stopping distances	-	-	-	-	-	-	-
Merging and exiting highway/interstates	-	-	-	-	-	-	-
Driving at appropriate speed for different road conditions	-	-	-	-	-	-	-
Reversing	-	-	-	-	-	-	-
Backing	-	-	-	-	-	-	-
Parking	-	-	-	-	-	-	-
Driving in tandem	-	-	-	-	-	-	-
Plowing near ditches and edges	-	-	-	-	-	-	-
Avoiding small objects (such as mailboxes and road signs) when plowing	-	-	-	-	-	-	-
Avoiding large objects (such as stopped or parked cars and pedestrians) when plowing	-	-	-	-	-	-	-
Plowing during whiteouts	-	-	-	-	-	-	-
Multitasking to control equipment (salt deposition, blade, etc.,)	-	-	-	-	-	-	-
Maintaining control of vehicle	-	-	-	-	-	-	-
Utilizing a wing plow	-	-	-	-	-	-	-

- On a scale from 1 (not confident at all) to 7 (extremely confident), how would you rate your current confidence level in your snowplow driving skills utilizing various INDOT snowplow trucks to per maintenance operations, including snowplowing and treating roads during the snow season?

Truck Type	1 (not confident at all)	2	3	4 (moderately confident)	5	6	7 (extremely confident)
Regular plow	-	-	-	-	-	-	-
Tow plow	-	-	-	-	-	-	-
Wing plow	-	-	-	-	-	-	-
Belly plow	-	-	-	-	-	-	-

3. At this moment, prior to starting your training, if INDOT called you during a snow emergency, how confident would you feel about plowing snow in that situation?
- I hope they never call on me
 - I would not mind doing it
 - I am looking forward to that call

Perceptions of Simulator

4. Have you had previous experience in a driving simulator?
- Yes, I have trained using a simulator through INDOT before
 - If yes, how many times? _____
 - Yes, on my own (through gaming or demonstrations)
 - No
5. How interested would you be in training your snowplow skills using a driving simulator?
- Not interested at all
 - Slightly interested
 - Moderately interested
 - Very interested
 - Extremely interested

Closing

6. Is there anything else you would like to add related to winter operations driver training or snowplow driver training using a simulator?

A.4 Winter Operations (Post-intervention)

Demographics

1. Circle your age group: 18-24

- 25-29
- 30-34
- 35-39
- 40-44
- 45-49
- 50-54
- 55-59
- 60-64
- 65+

2. Circle your gender:

- Male
- Female
- Prefer not to say

3. How many snow seasons have you been plowing snow for INDOT?

Note: Only count snow seasons that you have plowed snow for INDOT, which might be less than the number of years you have been working for INDOT.

4. Have you plowed snow before you started plowing snow for INDOT?

- No
- Yes. Please explain where and how long:

5. What is your main work assignment at INDOT?

- Maintenance department (snowplowing is your main winter assignment)
- Other department (transfer driver, meaning plow snow for INDOT only occasionally)
- Other (please describe):

Winter Operations

6. Based on the training you have just received, your previous driving experience and judgement, please rate **your comfort level driving an INDOT snowplow truck (see example in figure above) to perform the tasks outlined in this page.** Choose the option that best matches your self-perception.

Task	Extremely Uncomfortable	Moderately Uncomfortable	Somewhat uncomfortable	Neutral	Somewhat comfortable	Moderately comfortable	Extremely comfortable
Overtaking other vehicles	-	-	-	-	-	-	-
Changing traffic lanes	-	-	-	-	-	-	-
Turning right	-	-	-	-	-	-	-
Judging stopping distances	-	-	-	-	-	-	-
Merging and exiting highway/interstates	-	-	-	-	-	-	-
Driving at appropriate speed for different road conditions	-	-	-	-	-	-	-
Reversing	-	-	-	-	-	-	-
Backing	-	-	-	-	-	-	-
Parking	-	-	-	-	-	-	-
Driving in tandem	-	-	-	-	-	-	-
Plowing near ditches and edges	-	-	-	-	-	-	-
Avoiding small objects (such as mailboxes and road signs) when plowing	-	-	-	-	-	-	-
Avoiding large objects (such as stopped or parked cars and pedestrians) when plowing	-	-	-	-	-	-	-
Plowing during whiteouts	-	-	-	-	-	-	-
Multitasking to control equipment (salt deposition, blade, etc.,)	-	-	-	-	-	-	-
Maintaining control of vehicle	-	-	-	-	-	-	-
Utilizing a wing plow	-	-	-	-	-	-	-

7. On a scale from 1 (not confident at all) to 7 (extremely confident), how would you rate your current confidence level in your snowplow driving skills utilizing various INDOT snowplow trucks to perform winter maintenance operations, including snowplowing and treating roads during the snow season?

Truck Type	1 (not confident at all)	2	3	4 (moderately confident)	5	6	7 (extremely confident)
Regular plow	-	-	-	-	-	-	-
Tow plow	-	-	-	-	-	-	-
Wing plow	-	-	-	-	-	-	-
Belly plow	-	-	-	-	-	-	-

8. After this training, if INDOT called you during a snow emergency, how confident would you feel about plowing snow in that situation?

- I hope they never call on me
- I would not mind doing it
- I am looking forward to that call

Perceptions of Simulator Training (interactions with hardware and software)

9. How involved were you in the virtual environment experience?

- Not involved at all
- Slightly involved
- Moderately involved
- Very involved
- Extremely involved

10. How enjoyable was your experience with the driving simulator?

- Not enjoyable at all
- Slightly enjoyable
- Moderately enjoyable
- Very enjoyable
- Extremely enjoyable

11. How accurately did the simulator equipment seem to replicate your real-world experiences?

- Not accurately at all
- Slightly accurately
- Moderately accurately
- Very accurately
- Extremely accurately

12. Please rate your perceptions (from ‘terrible’ to ‘excellent’) about specific hardware and software features in the simulator. Choose the option that best matches your answer.

	Poor	Fair	Average	Good	Excellent
Equipment responsiveness (how quickly the simulated truck responded to your physical input)	-	-	-	-	-
Simulator fidelity to the controls of a INDOT snowplow truck	-	-	-	-	-
Visual input (graphical quality)	-	-	-	-	-
Audio input (sound)	-	-	-	-	-
Haptic input (vibration or other tactile sensation)	-	-	-	-	-
Believability of scenarios	-	-	-	-	-
Range of scenarios used in training	-	-	-	-	-

13. Did you experience any physical discomfort (such as headache, nausea, dizziness) while driving the simulator?

- Not at all
- A little discomfort (did not impact driving)
- A moderate amount (my driving was affected)
- A lot (utilizing the simulator was difficult)
- A great deal (I could not complete the training)

14. Did you receive debrief or feedback from trainers during the use of simulators?

- No
- Yes – Collective feedback
- Yes – Individual feedback
- Yes – Both collective and individual feedback
- I don't know

Perceptions of Training

15. Rate the usefulness of specific aspects of the simulator training, including the lecture portion. Choose the option that best matches your answer.

	Not useful at all	Slightly useful	Moderately useful	Very useful	Extremely useful
Overall training	-	-	-	-	-
Debrief/feedback from trainers during the simulator driving sessions	-	-	-	-	-
Content on non-routine situations	-	-	-	-	-
Content about speed management	-	-	-	-	-
Content about space management	-	-	-	-	-
Content about good communication	-	-	-	-	-

16. Would you recommend this training for other snowplow drivers?

	Definitely not	Probably not	Undecided	Probably yes	Definitely yes
Novices snowplow drivers (0 to 3 years plowing snow)	-	-	-	-	-
Transfer snowplow drivers with 4+ years plowing snow on occasion	-	-	-	-	-
Experienced full-time snowplow drivers with 4+ years plowing snow full time)	-	-	-	-	-

17. Was the time allocated for you to drive the simulator equipment adequate?

- Definitely not
- Probably not
- Undecided
- Probably yes
- Definitely yes

18. Which part of the training do you think was most effective and why?

19. What are your top 3 takeaways from simulator-integrated training?

Closing

20. Is there anything else you would like to add related to winter operations driver training or snowplow driver training using a simulator?

A.5 Long-term Survey

Demographics

1. Circle your age group: 18-24

- 25-29
- 30-34
- 35-39
- 40-44
- 45-49
- 50-54
- 55-59
- 60-64
- 65+
- Prefer not to say

2. Circle your gender:

- Male
- Female
- Prefer not to say

3. Which driving simulator training did you attend in the previous year at INDOT?

- Simulator-based snowplow driver training
- Simulator-based new CDL driver training
- Simulator-based snowplow driver training AND CDL driver training
- I did not attend any simulator-based training

Operations

4. What is your current confidence level from 1 (not confident at all) to 7 (extremely confident) in driving a regular INDOT CDL-required vehicle?

- 1 (not confident at all)
- 2
- 3
- 4 (moderate confident)
- 5
- 6
- 7 (extremely confident)

5. What is your current confidence level from 1 (not confident at all) to 7 (extremely confident) in plowing snow with an INDOT snowplow truck?

- 1 (not confident at all)
- 2
- 3
- 4 (moderate confident)
- 5
- 6
- 7 (extremely confident)

Perceptions of Simulator

Only answer this portion of the questionnaire if you have attended any of the INDOT driving simulator training

6. For the next section, on a scale from 1 to 7, please mark - based on how much influence the driving simulator training had on your work.

- 1 = Extremely disagree
- 2 = Quite disagree
- 3 = Slightly disagree
- 4 = Neither
- 5 = Slightly agree
- 6 = Quite agree
- 7 = Extremely agree

Perceived Use (PU)

Training with a driving simulator helped me to accomplish tasks more quickly.	1	2	3	4	5	6	7
Training with a driving simulator improved my work performance.	1	2	3	4	5	6	7
Training with a driving simulator increased my work productivity.	1	2	3	4	5	6	7
Training with a driving simulator enhanced my effectiveness at work.	1	2	3	4	5	6	7
Training with a driving simulator made it easier to do my work.	1	2	3	4	5	6	7
I find the driving simulator training useful in my work.	1	2	3	4	5	6	7

Perceived Ease of Use (PEU)

Learning to operate the driving simulator was easy for me.	1	2	3	4	5	6	7
I found it easy to access the driving simulator to learn what I needed to learn.	1	2	3	4	5	6	7
My interaction with the driving simulator was clear and understandable.	1	2	3	4	5	6	7
I found the driving simulator to be flexible to interact with.	1	2	3	4	5	6	7
It was easy for me to become skillful at using the driving simulator.	1	2	3	4	5	6	7
I found the driving simulator easy to use	1	2	3	4	5	6	7

User Acceptance (UA)

I am willing to use the driving simulator routinely for training purposes.	1	2	3	4	5	6	7
I am willing to utilize the driving simulator to train various scenarios.	1	2	3	4	5	6	7

7. Would you recommend INDOT to keep using the driving simulator for driver training?

- Definitely not
- Probably not
- Undecided
- Probably yes
- Definitely yes

8. Thinking back on your driving simulator training experience, was the time allocated for you to drive the simulator equipment adequate?

- Too little time
- Slightly little time
- Adequate time
- Slightly much time
- Too much time

9. Thinking back to your experience, what do you think were the benefits of using a driving simulator for training?

10. Thinking back to your experience, how do you think INDOT's driver simulator training can be improved?

Closing

11. Is there anything else you would like to add related to INDOT's simulator-based training?

Appendix B. Focus Group Summaries

Table B.1 Summarized Year 1 focus group information.

Date	May 2024	July 2024
Advantages	Good tool for measuring experience and age effect on driving; Beneficial for new drivers; Good matchup between reality and training; Promote safer driving behavior	Provides good visual sensation; Useful tool for new drivers; Good modules; Create awareness; Offer additional training for targeted drivers; Provide second perspective
Disadvantages	Motion sickness; Poor spatial awareness in some scenarios; Some haptic feedback lack of realism; Unrealistic urban scenarios; Unstandardized training format; Peer pressure	City module not realistic enough; Plow movement not realistic enough; Lack of some physics; Not 100% sensory e.g. lacks olfactory input; Scheduling logistics for seat time
Suggestions	Experience all modules; More allocated time for new drivers; Early start of the training; Go over performance data after training	Include more truck configurations and radio communication; Add realistic challenges (e.g. windshield freeze, ice;) Add more plow in CDL training; Provide earlier training; Debrief the training

Table B.2 Summarized Year 2 focus group information.

Date	May 2025 – Group A	May 2025 – Group B
Advantages	<p>New drivers can experience a variety of weather conditions; Valuable perspective for new drivers; Realistic vehicle-physics reactions (e.g., response delay, steering); Trainers can set and control specific scenarios (plowing, highway, ice-covered roads); Group sessions work well for logistics and peer feedback; Reduce fear of driving large-frame vehicles; Great tool for new drivers to practice test skills and calibrate expectations; Provides useful feedback for CDL progression (e.g., Class B → A); Makes overall use of training time more efficient</p>	<p>Seat time is good (enough to get comfortable and effective) — helpful for novice drivers; Helps with adverse-weather expectations; Sliding practice is good on the simulator; Can train with different truck configurations (tow-plow, wing-plow) and Class A manual transmission; Small groups are good for learning (> 1 and ≤ 4); Efficient use of time for CDL when DBW is not available; Train without using fuel/vehicle</p>
Disadvantages	<p>Motion sickness increases during longer sessions—especially on turn scenarios; Lack of differences between truck brands/models; Limited added value for highly experienced drivers (≈ 5 snow seasons or more); Cannot fully replace hands-on training in an actual vehicle; Lack of standardized equipment makes realism hard to match across fleets; Narrow roads, steep drop-offs and varying lane-width scenarios are missing; Mirror graphics lack fidelity; Real-world crashes involve many variables, so it’s tough to narrow lessons into discrete modules; Best recommended for drivers with ≤ 5 years’ experience—beyond that, use only for periodic refreshers</p>	<p>Graphics in some backing scenarios may be deceiving — feels easier in person; Some people experience simulator discomfort; Missing truck “weight” feels; Does not mimic all truck types; Does not mimic tiredness of actual shifts; Graphics could be improved (e.g., mirror depth); Lower trainee ratings may relate to simulator limitations; Number of trainers needed for targeted training is high (optimal 2–3 drivers); Cabin is more enclosed; Lack of performance reports or clear way to review results post-training; No real-world snowplow routes</p>
Suggestions	<p>Improve realism in physics & graphics; Packed snow, windshield freeze, snow-drift effects; Wipers flying off, low-beam LED headlights; Manhole covers and backing into salt domes; Overhead obstacles, faulty equipment, plowable markers; Finer time/RPM increments for engine responses; Offer more city-driving scenarios (plus practice tests) for new drivers; Provide a top-view map that shows the driver’s location in real time; Rotate the library of scenarios each year; Differentiate novice drivers and add surprise or challenging events; Separate modules for experienced/novice drivers; Let users review performance reports before and after training; Increase the screen’s field of view; Combine CDL and snow-plow modules into a unified track for novice drivers; Add pre-trip inspection practice inside the simulator (for CDL testing); Include lane-transition and narrow work-zone simulations; Incorporate brine-truck physics for more specialized training; Indicators for on/off-ramp scenarios (mini GPS map, top view); Add in-simulation suggestion prompts for self-assessment; Offer post-session data analysis to highlight progress</p>	<p>Option to toggle training noises; Windshield icing/wipers-off + snow-drift scenarios; Mimic actual routes; Differentiate asphalt vs. concrete; Create exhaustion scenario; Add aggressive drivers (interstate) including semis; Add blown-tire realism; Hydraulic-failure plow (non-responsive); Improve slide-regain practice; Mimic different truck types; Provide report before training + varied repetitions; Useful for seasonal drivers and new hires around October; Offer new situations for experienced drivers (~ 5 snow seasons); Clarify simulator capacity; Add interactive elements; Enhance sound fidelity (standard vs. loud mechanical noise)</p>

Appendix C. Historical Data Analysis – Driver Labor Structure

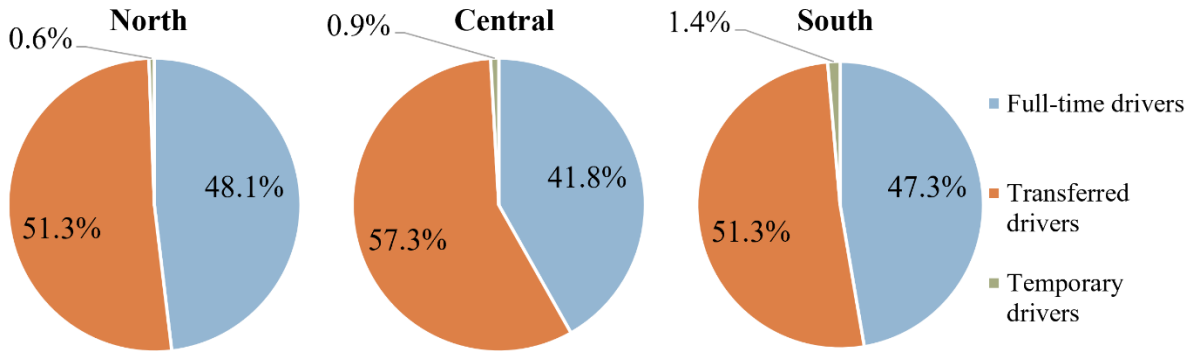


Figure C.1 Percentages of driver types in the North, Central, and South regions 2020–2021 season.

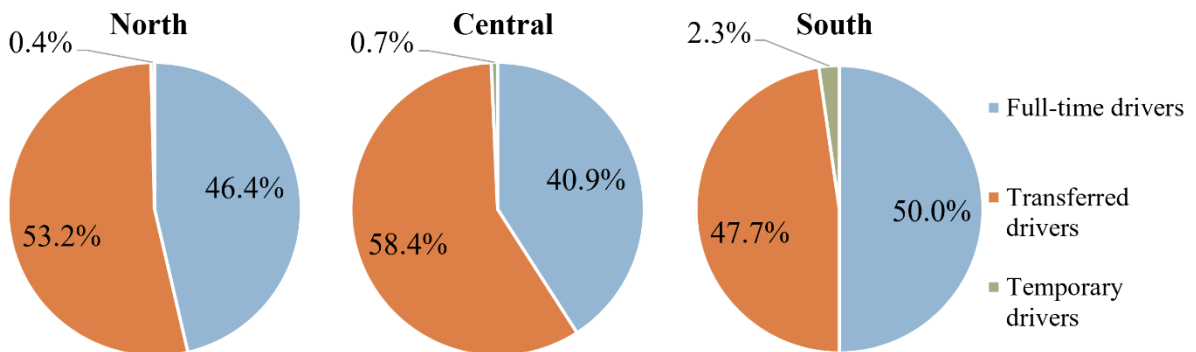


Figure C.2 Percentages of driver types in the North, Central, and South regions 2021–2022 season.

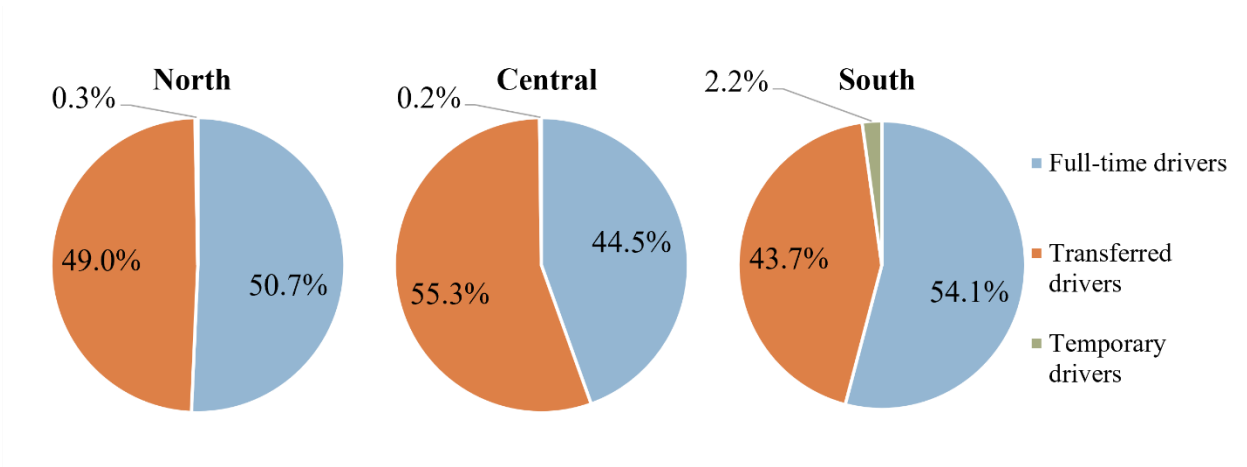


Figure C.3 Percentages of driver types in the North, Central, and South regions 2022–2023 season.

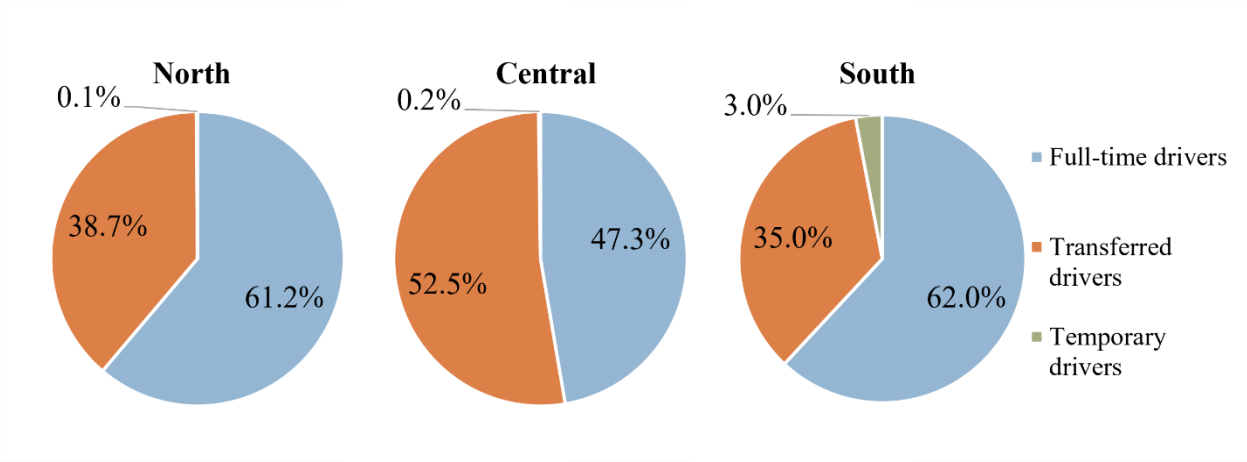


Figure C.4 Percentages of driver types in the North, Central, and South regions 2023–2024 season.

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 docs.lib.purdue.edu/jtrp/.

Further information about JTRP and its current research program is available at engineering.purdue.edu/JTRP.

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