Exploring the Future of Autonomous Truck Platooning: A Focus on Trust and Reliability

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ABSTRACT

Autonomous truck platooning has the potential to revolutionize the freight industry, improving efficiency and cost. However, its reliability and fault tolerance remain uncharacterized in real-world conditions, posing risks in widespread adoption. Understanding the fault points in computing systems is necessary to create reliable, dependable technology. I propose analyzing the fault tolerance of truck platooning systems in real-world scenarios. Compiling and analyzing common failure points in current sensor, communication, and routing systems is critical for the future development of the technology. The data collected through the study will also provide insights into the utility and need of recovery mechanisms, creating safer, more reliable truck platooning systems. Future work will leverage these findings to develop more fault-tolerant and intuitive platooning systems.

1. INTRODUCTION

In the United States, over 70% of freight is transported on trucks (USDOT, Bureau of Transportation Statistics, 2023). Trucks serve as a cornerstone of the US economy and autonomous truck platooning will revolutionize the industry by improving fuel efficiency, increasing roadway capacity, and reducing operational costs. By linking multiple trucks using vehicle-to-vehicle (V2V) communication and coordinated driving systems, platooning enables trucks to drive in a tightly-coupled unit with short following distances, reducing drag and enhancing fuel economy. While significant research has been done in the reliability of general autonomous vehicles, the fault tolerance and reliability of these truck platooning systems remain uncharacterized in the real-world environment (Dabboussi, et. al., 2018).

Platooning relies on the successful operation of numerous devices: sensors, communication networks, decision-making algorithms, routing algorithms, and the vehicle itself. These devices must work together to form a system that communicates in real-time with other trucks following at a distance shorter than the legal distance without this technology. Failures in any of these components, such as sensor malfunctions, communication delays, or hazardous road conditions, may disrupt the system, leading to potentially dangerous situations, not only for the truck but also other drivers sharing the road. Current research focuses on controlled environments or simulations, leaving a gap in understanding the behavior and fault-tolerance of these systems in real-world conditions (Hu, et. al., 2024). To address this critical gap in research, I propose a study analyzing the faults found in operational platooning systems.

2. RELATED WORKS

Understanding the reliability of truck platooning in real-world scenarios requires a foundation in previous research analyzing the performance and safety of the systems in simulated and controlled environments. A systematic review highlights the prevalence of human-centric experiments in prior studies (Botelho, et al., 2025). While these findings are valuable for the development and integration of truck platooning in the trucking industry, they come with an important limitation: because drivers are aware their activities are being closely monitored, the studies may not fully capture true system fault tolerance under realistic conditions.

I propose building on the methodology presented by Banerjee, et al. (2018). This study analyzed disengagement records reported by the California Department of Motor Vehicles. Disengagement is the swapping of control from the autonomous driving system (ADS) to the driver in the vehicle. Although this study was foundational in assessing and characterizing the fault tolerance in ADS, building upon these findings in truck platooning to determine the shortcomings in current technology is necessary to ensure safe, reliable systems. By building on this study's methodology, we gain insights into real-world use and can better assess system performance under various external conditions.

Recent research has also examined the importance of communication reliability and network latency in truck platooning, as vehicles rely on V2V and vehicle-to-everything communication for maintaining coordinated movement. Studies have shown that as the distance between nodes increases, the latency of packet delivery also increases (Osman, et al., 2021). Increased latency could cause platoon disruptions, especially in heavy traffic where cars may disrupt the platoon formation, which is more likely as the following distance increases (Castritius, et. al., 2021). These unpredictable factors introduce additional strain on the complex systems within autonomous truck platooning, highlighting the need for a quantitative evaluation of the reliability in a variety of environments.

3. PROPOSED DESIGN

The assessment of fault tolerance of autonomous truck platooning systems requires analysis of real-world data. The critical point of this methodology is ensuring drivers gain experience with truck platooning systems, and their actions are not influenced by the knowledge of participating in a study.

My proposal includes four distinct steps:

1. Data Collection
2. Data Standardization
3. Analysis of Failure Points
4. Fault Tolerance Assessment.

These phases will provide a systematic approach to the analysis of common failures within truck platooning systems and identify the effectiveness of current fault tolerance methods.

3.1 Data Collection

The data collected for this study will come from a variety of sources including operational logs and incident reports, onboard sensor and communication data, and environmental and traffic data.

3.1.1 Operational Logs and Incident Reports

Data from fleet operators using truck platooning technologies will be gathered and standardized to identify common real-world failures. Incident reports should be filed following system disengagements (automatic or manual), sensor malfunctions, and communication failures. This will provide insights into what operators observe as failures in functional systems, granting insights into common fault points.

3.1.2 Onboard Sensor/Communication Data

I propose continuous real-time logging from onboard sensors and communication networks. Like the black box in airplanes, these logs will capture critical operational data, allowing further analysis for the identification of common patterns preceding faults. By compiling and analyzing this data, researchers will gain insights for predictive fault identification, thus improving system reliability.

3.1.3 Environmental and Traffic Data

Finally, environmental data such as poor road conditions, weather and traffic levels, which will be highly correlated with faults, will be collected. Heavy traffic will challenge truck platooning systems, because other vehicles will be weaving in and out of the platoon, forcing the control system to make small real-time adjustments which will heavily strain the system. By understanding the operating conditions surrounding faults, improvements can be made to enhance system reliability in response to these challenges.

The combination of the perspective of fleet operators, sensor data, and the external factors surrounding faults, critical patterns can be identified, and the least fault tolerant components can be isolated and improved, improving the overall system.

3.2 Data Standardization

To ensure consistency across different datasets, the disengagement and fault reports will be standardized using methods adapted from Banerjee, et al. (2018). In this study the disengagement and accident reports will be sorted categorically based on keywords, and the provided descriptions of the incidents.
The top-level incident categories include:

1. Perception and Sensor Failures
2. Communication Failures
3. Control and Decision-Making Failures
4. Mechanical System Failures

3.2.1 Perception and Sensor Failures

Perception and sensor failures will include any sensor shutdowns or loss of data transmission between the sensor and the control system. This includes radar, LiDAR, cameras, or other sensors, that cause missing data or blind spots that hinder the control system's performance. This category identifies faults within the sensing hardware, where persistent sensor failures indicate a need for redundancy or improved component reliability.

3.2.2 Communication Failures

Communication failures will include any breakdown in communication within the platoon or to external infrastructure. A slow or faulty line of communication within the platoon disrupts synchronization leading to potentially dangerous situations. Failures in infrastructure communication, including GPS and route planning systems, can further exacerbate these risks. This category identifies issues within the communication protocol, where persistent slow networks, or loss of information necessitate more fault-tolerant communication protocols and networks.

3.2.3 Control and Decision-Making Failures

Control and decision-making failures will include faults within the control system. This includes failure to correctly interpret sensor data, incorrect gap maintenance (accelerating or braking incorrectly), and failure to correctly interpret other driver's behavior. This category identifies issues within the machine-learning algorithms backing the control system, where persistent faults indicate a need for revision and logic analysis.

3.2.4 Mechanical System Failures

Mechanical system failures will include faults within the real-time operating components, including failure to actuate brake systems in time and erratic acceleration periods. Delayed braking in emergency situations can lead directly to collisions, while jittery acceleration disrupts platoon formation. This category identifies issues within the real-time operating system, where persistent failure or late mechanical actuations indicate a need for faster decision-making mechanisms or more reliable actuation protocols.

The standardization of the data collected will provide a normalized, comprehensive overview of the least fault-tolerant components, and highlight areas for future innovation, providing a foundation for the analysis of failure points.

3.3 Analysis of Failure Points

With the standardized categorization of faults, the next step is to analyze these failure categories for frequency and severity. By analyzing the frequency of faults in each category we identify which faults occur the most often, while analyzing the severity of faults will indicate which category has faults most detrimental to overall system reliability and safety. By quantifying and analyzing both aspects, which failure types pose the most significant threat to safety and reliability can be identified.

The severity ranking will follow the ISO 26262 standard, which evaluates system components based on severity, exposure, and controllability. The combination of these elements is used to assess the risk of the failure of a component from A to D, with D representing the most critical failures. Adapting this framework to autonomous truck platooning is intuitive and provides a standardized method of quantifying risk (Debouk, 2019).

In addition to quantifying frequency and severity within categories, the correlation and failure propagation across categories will also be analyzed. If the failure of a subset of the system causes complete system failure, the reliability of that subset must be examined, not necessarily the entire system. By identifying the most critical elements within the overall system, it highlights areas in need of development and further fault tolerance assessment.

3.4 Fault Tolerance Assessment

Following the quantification of failure frequency and severity, this step will assess the system's ability to tolerate and recover from failures. Fault tolerance is essential to maintain safety and system functionality. This assessment will focus on the methods in place to detect, identify, and recover from failures within each system category.

By evaluating fault tolerance strategies, this step identifies which methods are the most effective in resisting critical system failure following faults. For example, if most faults identified occur within the sensors, incorporating redundancy, by incorporating additional identical sensors, may aid in improving system reliability by compensating for single sensor failures (Peiravi, et. al., 2022). Utilizing the findings from previous steps, the most fault-tolerant implementations can be identified and shared, making these methods standard as development continues.

4. ANTICIPATED RESULTS

The comprehensive analysis of the faults identified in autonomous truck platooning following this methodology will highlight current system shortcomings. The identification and further analysis of the most fault-prone components will contribute to future research into improving the reliability of these components within autonomous truck platooning.

I anticipate most of the faults identified will be present in the communication and decision-making systems. Autonomous truck platooning is an evolving industry and like the introduction of autonomous passenger vehicles, the decision-making system will be the most error prone (Banerjee, et. al., 2018). The decision-making system must handle evolving external events, the coordination of multiple vehicles, while accounting for the additional physical challenges of a truck. Unlike passenger vehicles, trucks with trailers require slower changes in speed, making it more difficult to adjust to sudden changes.

The coordination of multiple vehicles is the most novel component within the system, making it the most prone to errors. Ensuring fast, secure and reliable connections between vehicles will be one of the most difficult challenges as autonomous truck platooning continues to develop.

5. CONCLUSION

Autonomous truck platooning has the potential to revolutionize the freight industry by improving efficiency, reducing operational costs and reducing environmental impact. However, ensuring the reliability and fault-tolerance of these systems is crucial for their safe deployment. By analyzing fault events, we gain a better understanding of the system's shortcomings and can address them to make safe, reliable systems that will continue to power the United States.

6. FUTURE WORK

The foundation of understanding common fault-points and prevailing recovery mechanisms will inform future studies. Future work will involve more in-depth analysis of specific detection, prevention and recovery mechanisms. Advancements in each of these fields will be critical to improving the overall reliability and safety of autonomous truck platooning.

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