 doi:10.20944/preprints202210.0122.v1

Perspectives on Using Connected Vehicles for Transportation Infrastructure Condition Monitoring

Raj Bridgelall, Ph.D. (Corresponding Author)
Associate Professor
Transportation, Logistics & Finance, College of Business
North Dakota State University
PO Box 6050, Fargo ND 58108-6050
Email: raj@bridgelall.com, ORCID: https://orcid.org/0000-0003-3743-6652

Abstract

The condition of surface transportation infrastructure directly affects the economic health of a nation. However, it is difficult to justify the large sums of money needed to extend current methods to monitor all the multimodal infrastructure. The convergence of connected vehicle and cloud computing technologies presents an opportunity to automate the collection of ride quality and imagery data to continuously assess the condition of all roadways and railways. This paper presents several perspectives to help policy and standardization initiatives promote adoption.

Keywords: connected vehicles; freight; mode share; pavement; railroad; sensors

Conflicts of Interest: None

1 Introduction

The economic health of a nation hinges on the ability of its transportation systems to support the safe, reliable, and timely movement of people and goods. As a case study, the U.S. transportation network is multimodal, intermodal, massive, and complex. It contains more than four million miles of public road, more than 600,000 bridges, more than 92,000 miles of rail, more than two million miles of pipelines, more than 25,000 miles of navigable waterways, 185 container ports, and almost 20,000 airports (USDOT 2021). Data analyzed from the U.S. Bureau of Transportation Statics and plotted in Figure 1 suggest that trucks will continue to dominate freight movements in the future (BTS 2022). A correlation analysis of data on U.S. real gross domestic product (GDP) from the U.S. Bureau of Economic Analysis (BEA 2022) and total ton-miles production from the U.S. Bureau of Transportation Statics (BTS 2022) yielded a correlation coefficient of 0.88, which indicates a high positive association. The compound annual growth rate (CAGR) of the U.S. GDP between 1980 and 2020 was 5.1%.

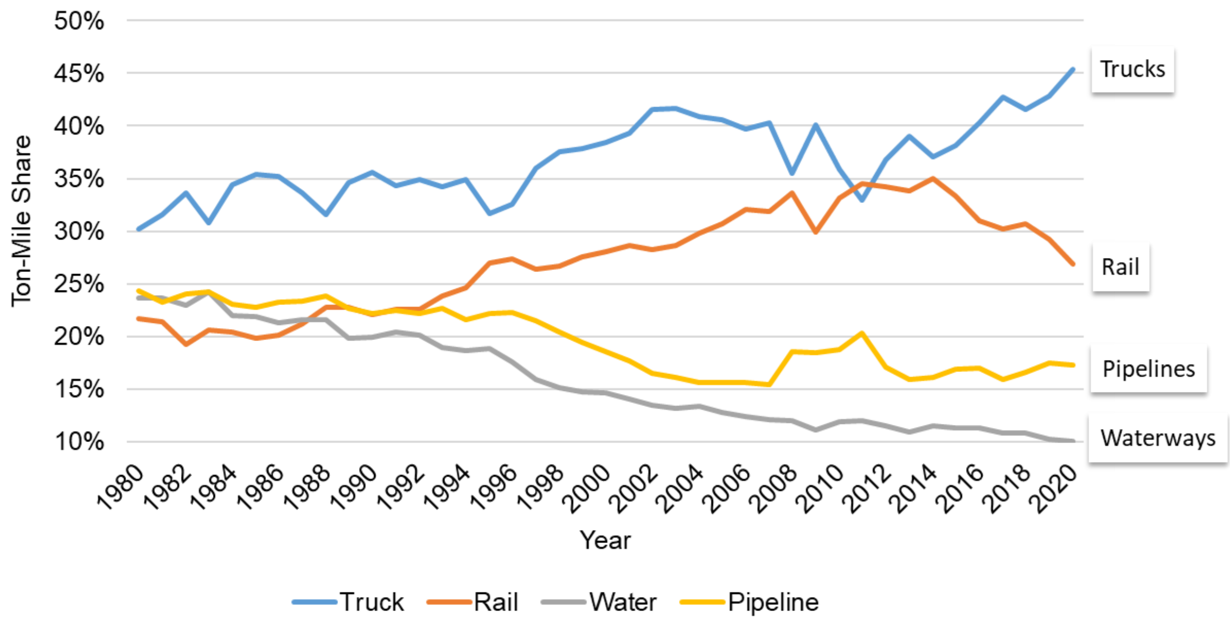

Figure 1: U.S. transportation mode share.

Therefore, sustained GDP growth will increase the demand for both freight vehicles and infrastructure traffic capacity. Consequently, keeping both road and rail infrastructure in a state of good repair will become increasingly critical.

2 Perspectives

The next three subsections provide perspectives into the supply and demand for freight capacity, a background on infrastructure condition monitoring, and the potential to use connected vehicle technology.

2.1 Widening Supply and Demand Gap

The trend in Figure 1 suggests that here has been competing mode shifts between rail and truck since 2008 where the respective ton-mile trends are nearly inverted. Trucks experienced a sharp increase in ton-mile share since 2011 with a CAGR of 3.9% whereas railroads experienced a correspondingly sharp decrease. The trend since 2011 corresponds to an average of 2.3% increase in the U.S. GDP for nine consecutive years before declining after beginning of the global pandemic in 2019. Although the trend suggests that railroads lost mode share to trucks since 2011, railroads will likely continue to lead all modes in moving the heaviest and bulkiest loads most efficiently across greatest distances (AAR 2022).

The sustained growth of e-commerce will likely increase the demand for both truck and road capacity. Based on surveys, interviews, and modeling by Statista, the CAGR for the U.S. e-commerce market will be 14.6% from 2022 to 2025 (Statista 2021). Increasing demands for capacity will further increase congestion levels across the multi-modal roadway and railway networks. Furthermore, a deteriorating infrastructure will deplete capacity, diminish performance, and create more hazards. Figure 1 illustrates the author's perspective on how infrastructure supply and condition affect key aspects of the transportation system and national objectives. Congestion ultimately hampers business efficiencies, curtails productivity, wastes fuel, increases pollutive emissions, and creates unsafe situations. As traffic load density increases with economic expansion, heavy vehicle traffic will further stress the infrastructure and accelerate deterioration. Figure 3 shows that U.S. truck and rail traffic continues to outpace their infrastructure capacity. Hence, without sufficient investments to build capacity and preserve infrastructure, the gap between supply and demand will likely widen. Consequently, the growing

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 October 2022 doi:10.20944/preprints202210.0122.v1

demand to move more heavy loads will increase the extent and severity of infrastructure deterioration.

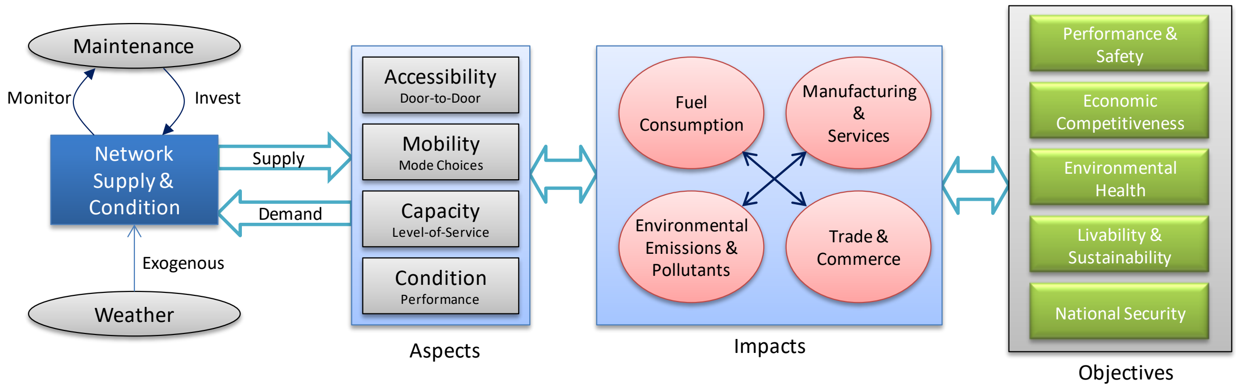

Figure 2: Key interactive elements of a transportation system.

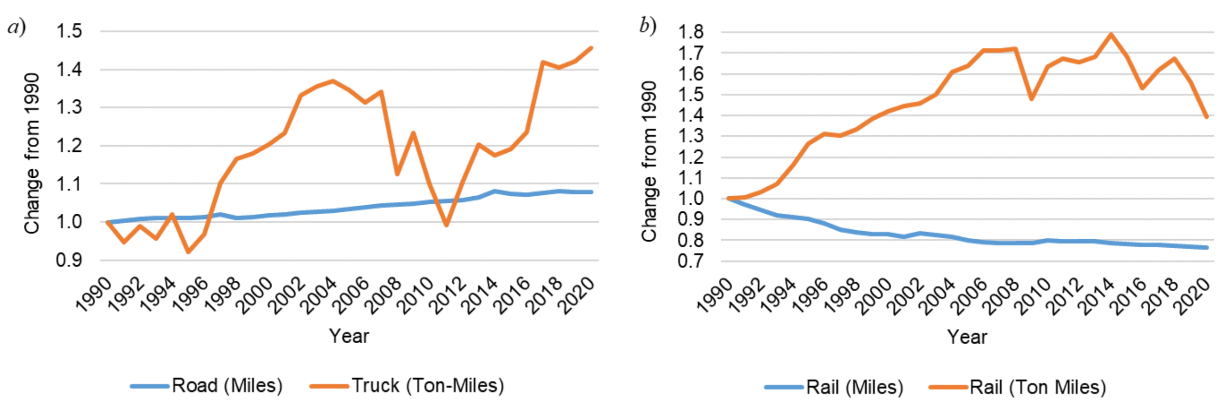

Figure 3: Traffic demand outstrips supply for both a) trucks and b) railroads.

Since 1998, the American Society of Civil Engineers (ASCE) has consistently rated the nation's road condition between D- to D+ (ASCE 2022). Poor pavement condition depletes capacity even in uncongested situations because vehicles cannot safely travel at the posted speed limit. A recent study estimated that driving on roads in need of repair costs U.S. motorists an average of $621 each year in extra vehicle repair and operating costs (TRIP 2022). Rough roads can cause loss of control, which can lead to crashes (Hu, et al. 2017). In addition to the loss of lives, other potential losses include freight damage from excessive vibration, lost revenue from late deliveries to manufacturing facilities, and vehicle damage.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 October 2022 doi:10.20944/preprints202210.0122.v1

2.2 Condition Monitoring Today

Transportation agencies worldwide spend trillions of dollars maintaining infrastructure based on a *worst-first* approach. Studies show that an alternative *preserve-first* approach will reduce asset preservation cost by at least a factor of three, saving hundreds of billions of dollars (FHWA 2022). However, a preserve-first approach requires more frequent monitoring to forecast optimum maintenance triggers.

Railroads do not regularly monitor all network segments because existing manual and inspection-vehicle methods are relatively expensive (Bridgelall and Tolliver 2020). The Class I U.S. railroads must visually inspect most tracks in service as often as twice weekly to comply with the federal track safety standards. However, the defect formation rate increases with traffic load-density (Patra, Bidhar and Kumar 2010), and railroads have been hiring fewer employees (BLS 2021). These trends result in a widening gap between the rate of defect formation and the resources available to find them before they result in accidents, delays, and lost revenue.

Railroads augment visual inspections with automated inspection cars to locate developing and mature defects. However, the overall inspection rate is practically limited because a trailing repair gang must be able to schedule track time, weather permitting, and keep up with the rate of defect discovery. Because many defects are not observable from an inspection vehicle, inspectors must still patrol the tracks by foot. The track capacity available for revenue service is less during inspections because of closures to maintain safety.

Roadway agencies also cannot afford frequent pavement condition monitoring with existing approaches that rely on specially instrumented vehicles and extensive visual inspections. The lack of trained personnel and the need for fast computing resources limits the effectiveness and accuracy of those approaches. Alternatively, visual inspections are labor intensive, time-consuming, irregular, and inconsistent.

2.3 Vision of Using Connected Vehicles

Studies show that preventative maintenance done at the optimum time will extend the lifecycle of a pavement (FHWA 2022). An effective preservation program that doubles the life of a pavement can save states more than three times the cost of reconstruction (NCHRP 2004). Similarly, an optimized track maintenance program can substantially reduce the risk of train derailments (Bridgelall, Chia, et al. 2019). However, those programs are only as effective as the quantity and quality of condition-monitoring inputs.

Using connected vehicles to monitor ride quality and upload images can provide a more consistent, long-term indication of the infrastructure deterioration rate (Bridgelall 2022). Cloud-based computing systems can analyze signals from a fusion of mobile sensors to generate an accurate assessment of infrastructure condition and performance. Railroads can use sensors aboard revenue service trains to isolate both track locations and vehicles that exhibit symptoms of a defect for follow-up remediation (Bridgelall, Chia, et al. 2019). Deterioration models can utilize the uploaded data to forecast optimum maintenance triggers so that railroads and highway agencies can prioritize repair and justify program funding allocations. This continuous monitoring approach using connected vehicles will scale easily with traffic and infrastructure expansion.

In the short-term, regular vehicles can use smartphones to log and upload their geospatial coordinates, ride quality, and roadway imagery. In addition, planners will have access to high-quality location data to improve travel demand models and forecasting. Sensor deployment will result in greater visibility and insights into the state of infrastructure condition and produce more

 doi:10.20944/preprints202210.0122.v1

accurate travel demand projections. With improved forecasting models and data quality, stakeholders will gain the confidence needed to propose policies that improve the efficiency and effectiveness of asset management practices. In the long-term, agencies will begin to standardize the integration of condition-monitoring sensors into connected vehicles. Agencies will also be able to combine road-condition monitoring data from other automated sources such as drones and satellites (Liu, et al. 2022). With early successes, more agencies will begin to realize the benefits of using a connected vehicle approach for data acquisition to help preserve the multimodal transportation infrastructure.

3 Conclusions

Roads and rail are critical to the economic competitiveness of any nation. In the United States, road and rail networks move more freight and people than any other mode of transportation. U.S. economic and population growth will continuously increase the demand for freight transportation. However, the gap has been widening between the supply and demand of road and rail capacities. Without adequate investments in condition monitoring and maintenance, the deterioration rate will increase as more heavy vehicle traffic stresses the infrastructure. Existing methods of condition monitoring are expensive and lack network coverage. Emerging solutions can leverage technological advancements in sensing and connected vehicle technologies to implement a lower-cost, participatory sensing system for network-wide, real-time condition monitoring. With early deployments and testing, agencies will gain improved visibility of the infrastructure condition and stakeholders will gain the confidence to enact policies and ratify new connected vehicle standards that will help preserve the multimodal transportation infrastructure.

4 References

AAR. 2022. *10 Freight Rail Fast Facts.* Washington, D.C.: Association of American Railroads (AAR). https://www.aar.org/wp-content/uploads/2021/02/AAR-10-Freight-Rail-Fast-Facts-Fact-Sheet.pdf.

ASCE. 2022. *Report Card History.* American Society of Civil Engineers (ASCE). Accessed July 9, 2022. https://www.infrastructurereportcard.org/making-the-grade/report-card-history/.

BEA. 2022. *U.S. Economy at a Glance.* Bureau of Economic Analysis (BEA). Accessed July 8, 2022. https://www.bea.gov/news/glance.

BLS. 2021. *Employment in rail transportation heads downhill between November 2018 and December 2020.* U.S. Bureau of Labor Statistics (BLS). October. Accessed July 9, 2022. https://www.bls.gov/opub/mlr/2021/article/employment-in-rail-transportation-heads-downhill-between-november-2018-and-december-2020.htm.

Bridgelall, Raj. 2022. "Characterizing Ride Quality With a Composite Roughness Index." *IEEE Transactions on Intelligent Transportation Systems* 1-10. doi:10.1109/TITS.2021.3140177.

Bridgelall, Raj, and Denver D. Tolliver. 2020. "Closed form models to assess railroad technology investments." *Transportation Planning and Technology* 43 (7): 639-650. doi:10.1080/03081060.2020.1805541.

Bridgelall, Raj, Leonard A. Chia, Bhavana Bhardwaj, Pan Lu, Denver D. Tolliver, and Neeraj Dhingra. 2019. "Enhancement of signals from connected vehicles to detect roadway and railway anomalies." *Measurement Science and Technology* 31 (3): 035105. doi:10.1088/1361-6501/ab5b54.

BTS. 2022. *U.S. Ton-Miles of Freight.* June 14. Accessed July 8, 2022. https://www.bts.gov/content/us-ton-miles-freight.

FHWA. 2022. *Demonstrating the Application of Life Cycle Planning (LCP) on a Pavement Network.* Washington, D.C.: Federal Highway Administration (FHWA), 33. https://www.fhwa.dot.gov/asset/pubs/hif21044.pdf.

Hu, Jiangbi, Xiaojuan Gao, Ronghua Wang, and Shuya Sun. 2017. "Research on Comfort and Safety Threshold of Pavement Roughness." *Transportation Research Record: Journal of the Transportation Research Board* (National Academy of Sciences) 2641: 149-155. 10.3141/2641-17.

Liu, Pengfei, Qing Wang, Gaochao Yang, Lu Li, and Huan Zhang. 2022. "Survey of Road Extraction Methods in Remote Sensing Images Based on Deep Learning." *PFG–Journal of Photogrammetry, Remote Sensing and Geoinformation Science* 90 (2): 135-159. doi:10.1007/s41064-022-00194-z.

NCHRP. 2004. *Optimal Timing of Pavement Preventive Maintenance Treatment Applications.* Washington, D.C.: National Academies of Sciences, Engineering, and Medicine: National Cooperative Highway Research Program (NCHRP). doi:10.17226/13772.

Patra, Ambika Prasad, Sujit Bidhar, and Uday Kumar. 2010. "Failure prediction of rail considering rolling contact fatigue." *International Journal of Reliability, Quality and Safety Engineering* 17 (3): 167-177. doi:10.1142/S0218539310003731.

Statista. 2021. *Digital Markets eCommerce United States.* December. Accessed July 9, 2022. https://www.statista.com/outlook/dmo/ecommerce/united-states.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 10 October 2022 doi:10.20944/preprints202210.0122.v1

TRIP. 2022. *Funding America's Transportation System.* Washington, D.C.: TRIP--A National Transportation Research Nonprofit. https://tripnet.org/reports/funding-americas-transportation-system-march-2022/.

USDOT. 2021. *Pocket Guide to Transportation.* United States Department of Transportation (USDOT), Washington, D.C.: Bureau of Transportation Statistics (BTS). https://www.bts.gov/pocketguide.