Life Cycle Impacts of Fully-Loaded Ready Mixed Concrete (RMC) Trucks

MIT CSHub Research Brief
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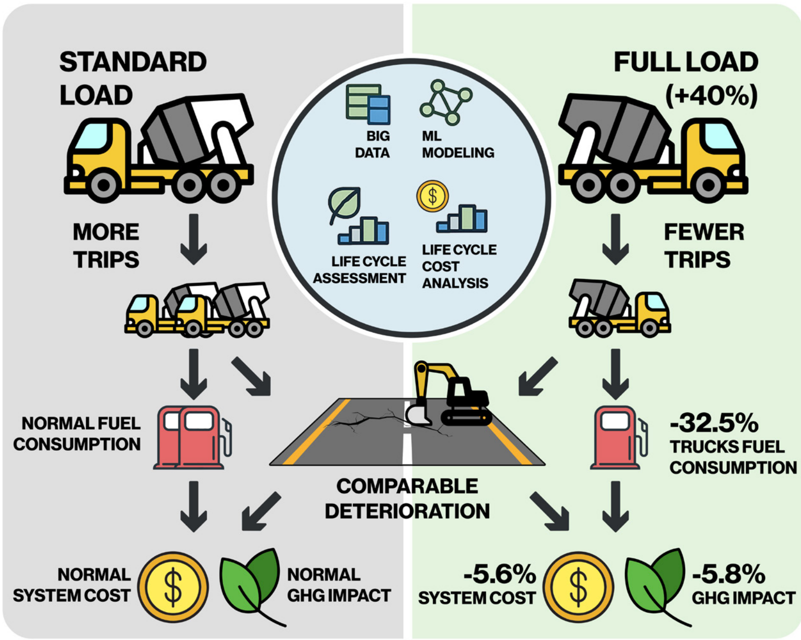


Figure 1: This research shows the tradeoff of standard load vs. fully-loaded RMC trucks, finding that the latter enables 32.5% lower fuel consumption, 5.6% cost savings and 5.8% greenhouse gas (GHG) savings for the truck-pavement system while having comparable impacts on pavement deterioration.

What is a fully-loaded RMC truck?

The concrete industry depends heavily on Class 8 trucks to deliver **ready mixed concrete** (RMC), but strict federal weight limits for standard 3-axle RMC trucks, capped at 54,000 lbs gross vehicle weight (GVW) [1], leaving little room for payload due to the heavy tare weight of these vehicles. In this study, full-loading refers to increasing the truck's payload above this limit (but within its load capacity and design specifications), allowing it to carry more concrete per trip. As such, we define a **fully-loaded RMC truck** as one that operates above this federal gross vehicle weight limit, and within the rated capacity of the vehicle As the industry seeks to improve delivery efficiency, full-loading is being explored as a potential solution that could enhance transportation productivity without compromising pavement performance or safety.

Why study fully-loaded RMC trucks?

As shown in Table 1 on the next page, under the 54,000 lbs regulatory limit, most concrete mixes can only be delivered in quantities up to 6 cubic yards (24,000 lbs) per truckload – nearly 45% less than the truck's full capacity of 11 cubic yards (44,000 lbs) [2]. This leads to higher costs per load, more fuel use and emissions, and requires more drivers per job. This last issue is particularly challenging as the RMC industry has faced an acute driver shortage for more than eight years [3]. To ensure timely, cost-effective construction, it would be valuable to deliver more concrete

Key Takeaways:

- Increasing RMC truck gross vehicle weight limits enhances concrete delivery efficiency and decreases costs.
- Heavier loads cut fuel use and reduce concrete delivery costs per cubic yard.
- Fully-loading RMC trucks does not measurably impact infrastructure maintenance costs or longevity.
- Fully-loading RMC trucks does not change the fuel use or performance of other vehicles on the road.

Standard 3-axle ready mixed concrete (RMC) trucks are federally capped at a gross vehicle weight of 54,000lbs. With the unloaded weight of the vehicle being approximately 30,000lbs, there is about 24,000 lbs (or 44%) available for the payload. However, these vehicles may be capable of carrying a larger payload if components such as the chassis, tires, and brakes are rated for sufficient weight. In this MIT CSHub study, we find that "fully-loaded" RMC trucks (whose weight exceeds federal GVW restrictions) can deliver an equivalent amount of concrete with fewer trips than standard-loaded trucks, creating cost and fuel savings while having comparable impacts on pavements.

Image Source: Adobe Stock

GVW Increase	Maximum GVW ('000s lb)	Truck Tare Weight ('000s lb)	Maximum Payload ('000s lb)	Payload Increase	Concrete Payload (yd³)
0%	54.0	30.0	24.0	0.0%	6.0
10%	59.4	30.0	29.4	22.5%	7.4
20%	64.8	30.0	34.8	45.0%	8.7
30%	70.2	30.0	40.2	67.5%	10.1
40%	75.6	30.0	45.6	90.0%	11.4

Table 1: Summary of various loading scenarios for ready-mixed concrete (RMC) trucks. GVW = gross vehicle weight.

using fewer RMC trucks. This study examines the environmental and economic impacts of such a change in practices and explores whether increased truck productivity can be achieved without compromising pavement performance.

Modeling Methodology

To assess the implications of increased loading, we assumed that all Class 8 trucks are RMC trucks, comprising 10% of the total truck traffic on an interstate highway in Pennsylvania. These trucks typically operate at the federal maximum weight of 54,000 lbs [1], but here we simulate the implications of carrying up to 40% additional gross load, as shown in Table 1, reaching a GVW of 75,600 lbs per truck. Although individual truck loads increase, the total freight or concrete material demand is assumed to remain constant, meaning the same volume of concrete is delivered overall. This means that fewer truck trips occur with full-loading. For this study, we have assumed that increasing the load would increase fuel use per load and may accelerate the rate of pavement degradation.

To evaluate these implications, we applied a software tool developed by the authors that integrates streamlined pavement Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) frameworks [4, 5]. Pavement performance – including its impact on vehicle fuel consumption, maintenance, and construction – was modeled over a 50-year analysis period. To evaluate the effects of increased RMC truck loads, we utilized machine learning (ML) models developed in our earlier studies [6, 7], which enable the direct analysis of elevated axle weights and a flexible assessment of various loading scenarios. The truck fuel consumption was modeled using data provided by Fan et al. (2024) [8], capturing both the direct benefits of more efficient fuel use and the indirect impacts on pavements and public agencies resulting from increased truck loads. All other pavement design parameters are summarized in A1 of Appendix A.

Figure 2 illustrates the overall modeling framework and provides an overview of the truck-pavement system boundaries. This figure highlights the environmental and economic impacts evaluated for trucks across various loading scenarios.

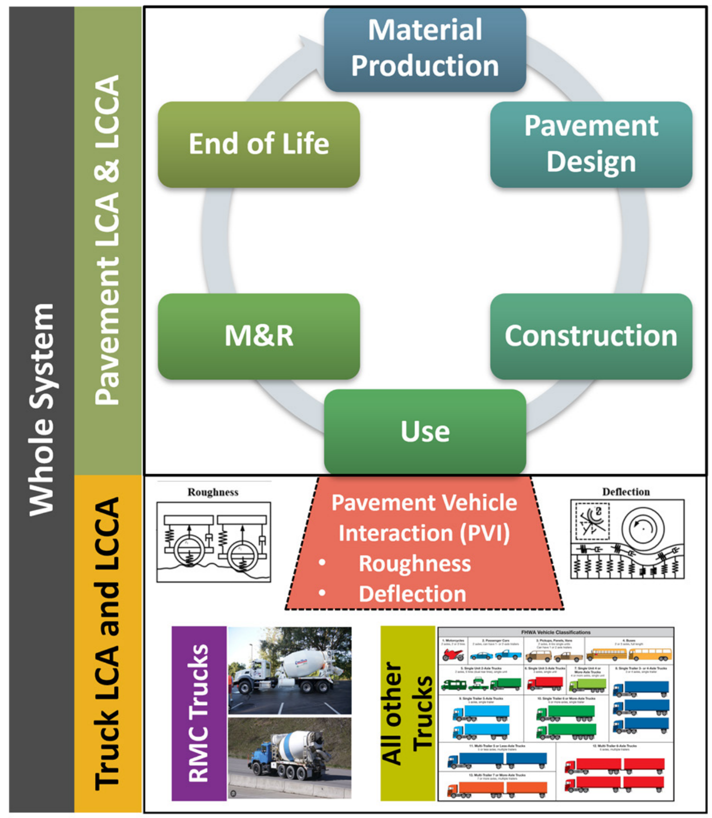
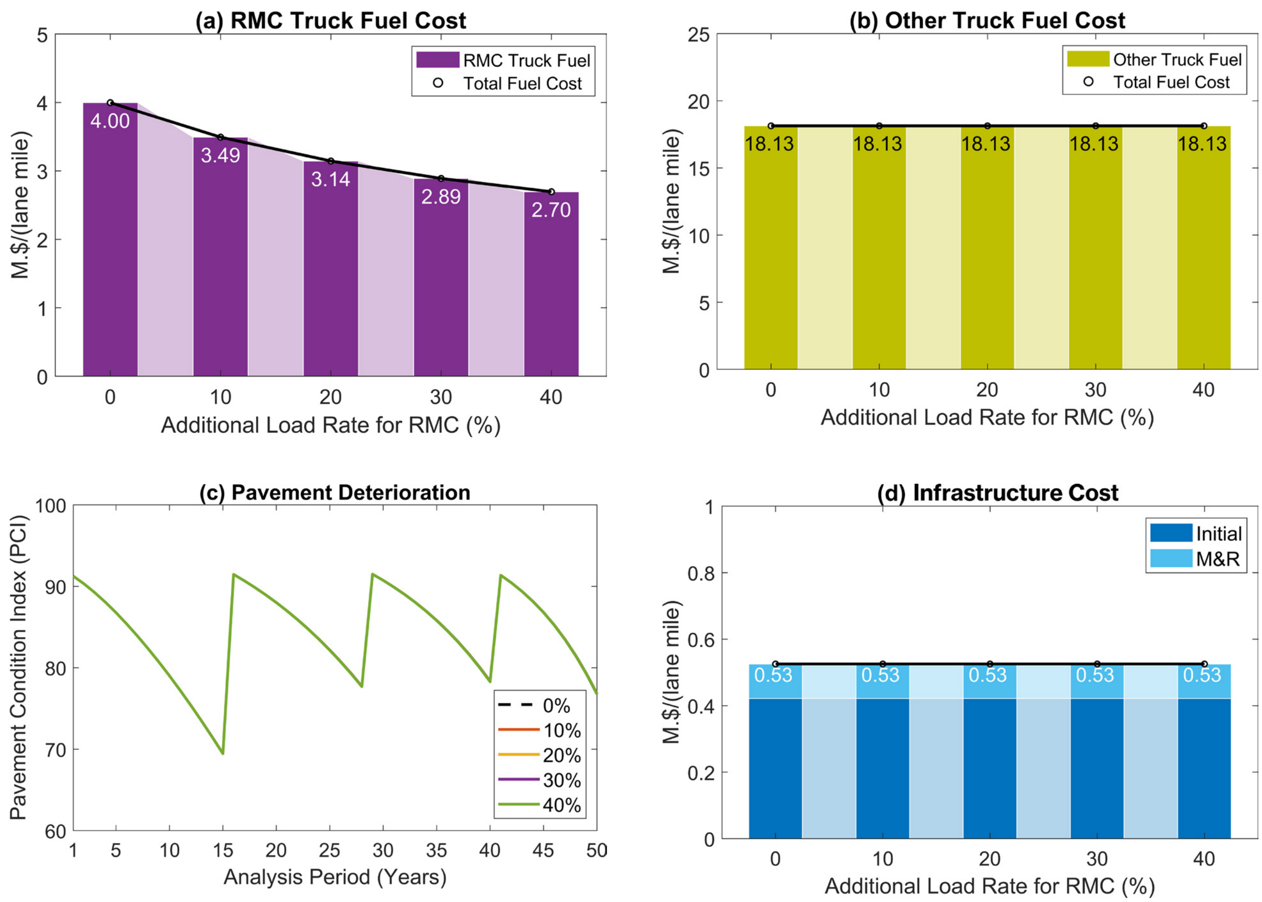


Figure 2: Diagrammatic representation of the research model analyzing RMC trucks with various loading scenarios, showing fuel use, GHG emissions, cost analysis, and pavement performance integration. Note: LCA = life cycle assessment, LCCA = life cycle cost analysis, M&R = maintenance and rehabilitation, RMC = ready-mixed concrete.

Key Findings

Figure 3 presents the results of the economic implications of fully-loaded RMC trucks. As shown in part (a), full-loading results in a 32.5% reduction in fuel use for RMC trucks when these trucks are carrying additional loads that increase the GVW by up to 40%. This occurs because higher load rates reduce the total number of truck trips required, thereby lowering fuel expenditures. As shown in part (b), other truck types sharing the road are not impacted by the increased RMC loads, suggesting that these additional loading scenarios can be implemented without imposing extra burdens on other road users. This is further illustrated in Figure 3(c), where the Pavement Condition Index (PCI) curves for all loading scenarios overlap, indicating that pavement deterioration remains consistent with the baseline condition, even with loading up to 40% additional GVW.

Similarly, the comparable pavement degradation indicates that the original pavement design and planned maintenance and rehabilitation (M&R) activities remain adequate, resulting in unchanged infrastructure costs for agencies, as indicated in Figure 3(d). Regarding the overall societal impact of the truck-pavement system, we observe a 5.6% reduction in life-cycle economic impacts [Figure 3(e)] and 5.8% reduction in life cycle GHG emissions [Appendix B] for RMC trucks with additional loading up to 40%. This trend is further supported by the truck-specific results in Figure 3(a) and (b), which demonstrate significant decreases in operating costs for RMC trucks as load rates increase.



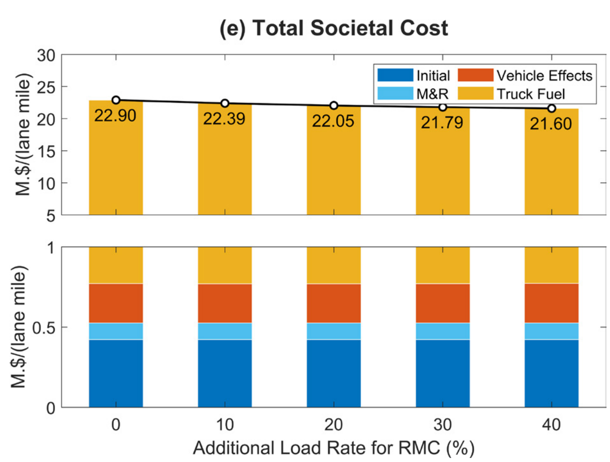


Figure 3: The impact of RMC truck with additional loading for (a) Truck fuel cost for RMC trucks; (b) Fuel cost for other trucks; (c) Pavement deterioration; (d) Infrastructure cost; and (e) the social impact of the truck-pavement system. Note in (c) that all lines are on top of one another; we observed no appreciable difference in pavement deterioration between scenarios.

These findings suggest that allowing controlled full-loading of RMC trucks offers multiple benefits. First, it can help the concrete industry operate more productively, ensuring timely and cost-effective delivery of materials. Full-loading also reduces fuel consumption and cost per cubic yard of concrete delivered, while having no adverse impact on road pavement performance and maintenance costs or the fuel use of other vehicles. Additionally, fewer required trips lead to lower GHG emissions and operational costs, and improved freight efficiency. These results support the adoption of flexible, performance-based weight regulations that align economic productivity with environmental and infrastructure sustainability.

Role of Data-Driven Truck Regulation and Implications for Policy and Practice

Optimizing truck weight limits based on life cycle performance metrics, rather than relying solely on static regulatory thresholds, presents a promising approach to productive and sustainable freight transportation. This study demonstrates how data-driven models can inform cost-effective and balanced regulations tailored explicitly for heavy-duty trucks such as RMC vehicles. The findings provide strong support for adopting more flexible weight regulations that allow safe full-loading of RMC trucks. Such flexibility can improve transportation efficiency by reducing the number of trips required, thereby decreasing GHG emissions and lowering delivery costs, all without compromising infrastructure durability or increasing public expenditures.

From a policy perspective, these results suggest that regulations could be adapted to permit controlled full-loading for RMC trucks and cause no appreciable difference in pavement deterioration while yielding cost and emissions savings due to decreased fuel use. Policies could allow safe full-loading with real-time monitoring and adaptive enforcement to ensure compliance. The framework developed in this study can also guide future policy decisions, including targeted taxation, when assessing full-loading scenarios that present higher risks.

Discussion and Broader Impacts

This study highlights the importance of incorporating life-cycle thinking into transportation policy. Instead of fixed thresholds, performance-based metrics backed by data-driven modeling can support more sustainable and resilient systems. The study also offers a more nuanced view of Pavement-Vehicle Interaction (PVI) under increased axle loads. Using an ML-aided mechanistic-empirical approach, it demonstrates that in a fraction of truck traffic, controlled full-loading does not necessarily accelerate pavement degradation, challenging conventional assumptions and informing smarter freight policies.

Endnotes

[a] Life Cycle Assessment (LCA) and Life Cycle Cost Analysis (LCCA) are approaches that evaluate the environmental and economic impacts of infrastructure or systems over their entire life span, from material production to use and maintenance until the end of life. In this study, they are used to evaluate the trade-offs associated with fully-loaded ready mixed concrete (RMC) trucks, considering both direct impacts and downstream effects on pavement systems.

[b] Pavement-Vehicle Interaction (PVI), also known as vehicle effects, refers to the influence of pavement condition on vehicle fuel consumption and, conversely, the impact of vehicle loading on pavement performance. This study integrates a mechanistic-empirical-based pavement modeling to simulate how increased axle loads affect pavement's long-term performance, and to quantify associated environmental and cost implications.

[c] Pavement Condition Index (PCI) is a standardized metric developed by the U.S. Army Corps of Engineers to quantify pavement surface condition on a scale from 0 (failed) to 100 (excellent). It reflects the extent and severity of surface distresses and is commonly used by transportation agencies to inform maintenance decisions and assess pavement serviceability over time.

[d] Full-loading is modeled by increasing the total axles' gross weight of RMC trucks by 40% over the federal maximum limit, while their trips were reduced proportionately for stable material transport. This approach allows the evaluation of system-level impacts such as reduced trip frequency altered fuel use for trucks, and potential shifts in maintenance demand for the infrastructure system.

References

[1] Federal Highway Administration (FHWA), "Compilation of Existing State Truck Size and Weight Limit Laws-FHWA Freight Management and Operations," US Department of Transportation Federal Highway Administration Freight Management and Operations, 2015.

[2] National Ready Mixed Concrete Association (NRMCA), "About Concrete," [Online]. Available: https://www.nrmca.org/about-nrmca/about-concrete/. [Accessed May 2025].

[3] R. Kirchain, F. Field, E. Unger and E. Moore, "Transforming the Role of the Concrete Delivery Professional: A Study on Innovative Solutions for the Ready Mixed Concrete Industry," Massachusetts Institute of Technology, Cambridge, MA, USA, 2024.

[4] H. Li, M. Zhang, H. Liu, H. AzariJfari and R. Kirchain, "Development of A Streamlined Framework for Probabilistic and Comparative Life Cycle Assessment of Road Pavements," Resources, Conservation & Recycling, vol. 209, p. 107802, 2024b.

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[6] H. Li, S. Sen and L. Khazanovich, "Artificial Neural Networks for Mechanistic-Empirical Concrete Pavement Design: An Efficient Development," in 13th International Conference on Concrete Pavements, Minneapolis, Minnesota,

USA, 2024.
[7] H. Li, H. AzariJafari, R. Kirchain, J. Santos and L. Khazanovich, "Surrogate Modelling of Surface Roughness for Asphalt Pavements Using Artificial Neural Networks: A Mechanistic-Empirical Approach," International Journal of Pavement Engineering, vol. 25, no. 1, p. 2434909, 2024.
[8] P. Fan, G. Song, Z. Zhai, Y. Wu and L. Yu, "Fuel consumption estimation in heavy-duty trucks: Integrating vehicle weight into deep-learning frameworks," Transportation Research Part D: Transport and Environment, vol. 130, p. 104157, 2024.

Related Links

[i] MIT News, May 2025: "3 Questions: Making the most of limited data to boost pavement performance"

[ii] MIT News, August 2024: "New framework empowers pavement life-cycle decision-making while reducing data collection burden"

Citation

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This research was carried out at the MIT Concrete Sustainability Hub, which is solely responsible for the content of this research brief.

Appendix A

Parameters		Values
Traffic	**Traffic system**	Rural Interstate
	Two-way AADT	37,000
	Truck percentage	30%
	Traffic growth rate	0.8% (compound)
	Number of lanes	4 (two directions)
Pavement Design and Maintenance	**PCC slab thickness**	10 in
	Base type	4-in cement treated base with 6-in subbase
	Joint spacing	15 ft
	Slab width	12 ft
	Shoulder type	Tied PCC
	Dowel bar diameter	1.5 in
	M&R schedule	• 100%DG and FDR @ 15 years • 100%DG and FDR @ 28 years • 100%DG and FDR @ 40 years

Table A1: Pavement Design Parameters. AADT = annual averaged daily traffic; PCC = Portland cement concrete; M&R = maintenance and rehabilitation; DG = diamond grinding; FDR = full depth replacement.

Appendix B

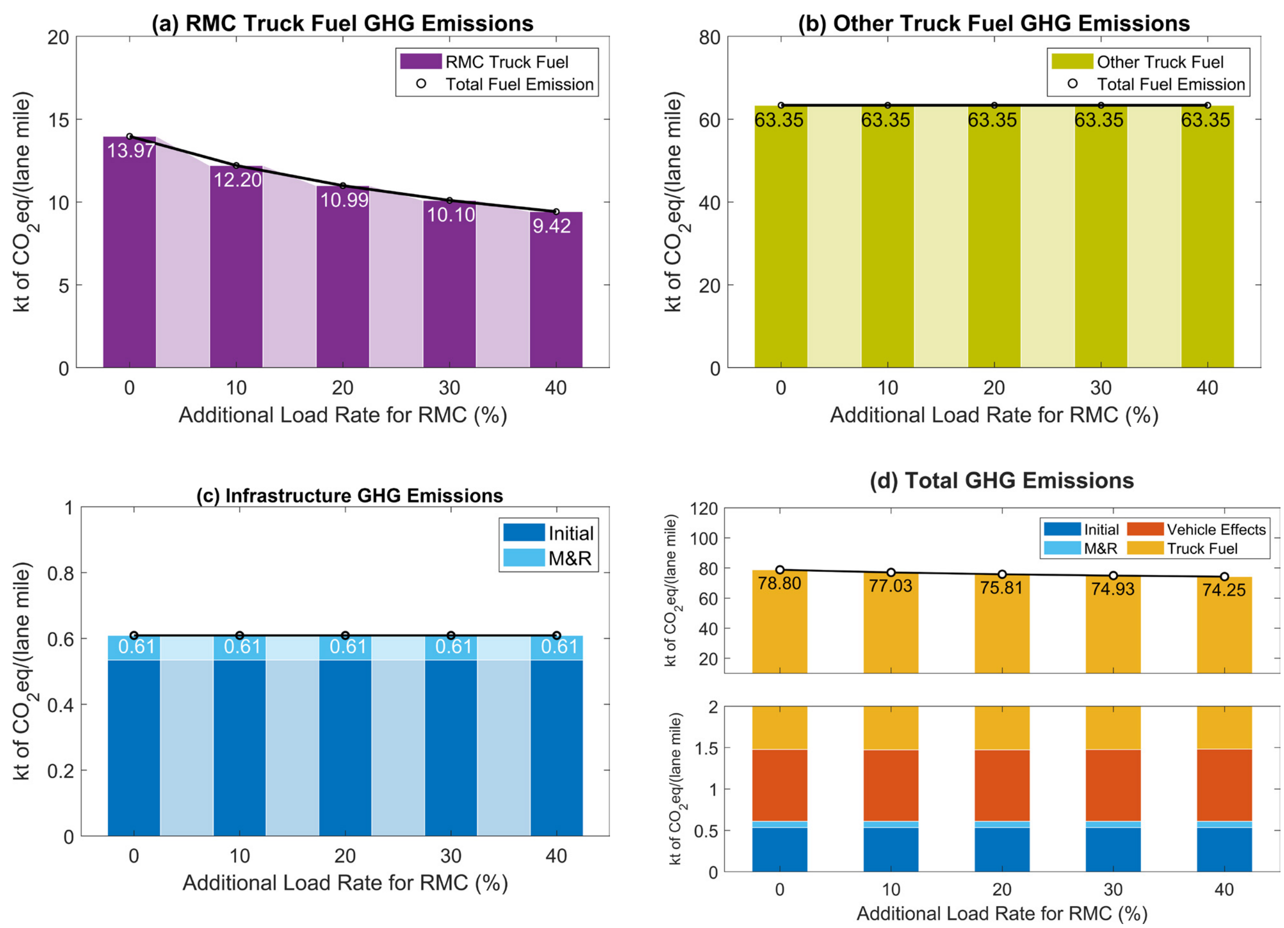

Figure B1: The impact of RMC truck with additional loading for (a) Truck fuel GHG emissions for RMC trucks; (b) Fuel GHG emissions for other trucks; (c) Infrastructure GHG emissions; and (e) the total GHG emission impact of the truck-pavement system.