A Human-Centered Approach to Sustainability: Empowering Behavioral Change in the Transportation Sector

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Within the past decade, climate change has come into focus as a "wicked problem" by governments and institutions alike on account of overwhelming scientific evidence linking greenhouse gas emissions to human activity. The combustion of fossil fuels in the transportation industry, in particular, has been revealed as the greatest contributor to greenhouse gases in the United States of America (USA), accounting for nearly 30% of total annual emissions (United States Environmental Protection Agency, 2020). Key transportation players must therefore swiftly acknowledge and remedially act to curb their emissions or jeopardize escalating the adverse effects of climate change. Because of their ability to be managed and environmentally incentivized, fleet vehicles, or groups of automobiles and trucks operated by a commercial enterprise or government organization, have emerged as holding the promise of large, rapid systematic change in this arena.

To combat transportation emissions, a growing number of automotive corporations have engineered electric vehicles to replace traditional, eco-destructive internal combustion engine (ICE) vehicles omnipresent. Electric vehicles present enormous potential, albeit in the long-term as nearly six out of ten automotive manufacturing decision-makers believe that the mass adoption of fully electric vehicles will likely not happen until 2030 (Farmer, 2020). Hence to address short-term sustainable goals, one strategy often overlooked yet has proven immediate reductions in fuel usage and subsequent emissions by approximately 5 to 20% is eco-driving: a set of fuel-efficient driving styles and behaviors (Rakotonirainy, 2011). Eco-driving allows drivers to directly influence fuel economy while operating ICE vehicles by controlling for factors such as idle time, brake use, vehicle speed and acceleration (McIlroy & Stanton, 2016).

With the rise of the Internet of Things, driver behavior data can now be collected and transmitted in real-time to management via telematic technology. In recent years, organizations have adopted fleet telematic technologies at an accelerating pace and in 2019, it was reported that 86% of fleets have employed telematics (Teletrac Navman, 2019). Telematics have allowed for fleet managers to assess the efficiency and effectiveness of fleet operations, notably as it relates to eco-driving training programs of action. Despite investment in telematics devices, the expected performance improvements don't materialize unless there are programs in place to nudge sustainable behavior. Consequently, there exists a need to evaluate the efficacy of eco-driving programs embedded into the fleet driving system in order to ensure sustainable driving habits. As such, this paper will explore how a combination of strategies, from simple eco-driving advice to hands-on training with an instructor to in-vehicle feedback devices, should be incorporated in fleets to reduce fossil fuel consumption. This will be achieved by comparing scientific journal articles studying eco-driving behavioral programs, evaluating resultant fuel savings and assessing the role of humans and non-humans to effectively empower sustainable driving with systematic intervention.

Actor-Network Theory Analysis of the Fleet Driving System

Actor-Network theory, proposed by Bruno Latour, is the theory that offers situational programs of action, goal-directed behavior for human beings to function through artifacts, are not accomplished from strictly human actors or technological artifacts. Instead, programs of action are stimulated by a collective effort between technology users, behavioral aids embedded in the technology and behavior-enforcing allies within the operating network (Schulz-Schaeffer, 2006). This reciprocal relationship between the social and technical in actor-network theory is coined as delegation (ibid). As we delegate the work of humans to technology, technologies successively delegate behavior back onto the social. Fundamentally, human actions are bounded by technologies that delegate how and what we should do within a sociotechnical network. Moreover, Latour argues there are "missing masses" which lie within our sociotechnical networks that can be deliberately designed and implemented to constrain or shape the actions of other humans (Latour, 1992). By considering the human side of technological artifacts and identifying how non-human components hold agency, human behavior can be manipulated to facilitate desirable programs of action.

In order to understand the programs of action, or "scripts", Latour uses an analogy surrounding a network with hotel customers as the user, a hotel manager as the behavior-enforcing ally and the Berlin key as the technological artifact. The Berlin key has a design which forces visitors to close and lock doors, mediating a relationship between the human actors and allies to shut their door at night. Nevertheless, the technological design of a system cannot fully encompass every potential program of action, and therefore socio-technical actors and behavioral aids are necessary to perform scripts (Latour, 1992). For example, every hotel customer who is given the key knows they must return it upon leaving, but the key alone is not enough to fulfill the program of action sought out by the manager. In order to incentivize hotel customers to return their key after use, the manager employs successive strategies including oral notices, written notices and weights on keys. As more of these strategies are executed jointly, the percentage of customers performing the scripts increases incrementally to constitute a significant impact (Figure 1).

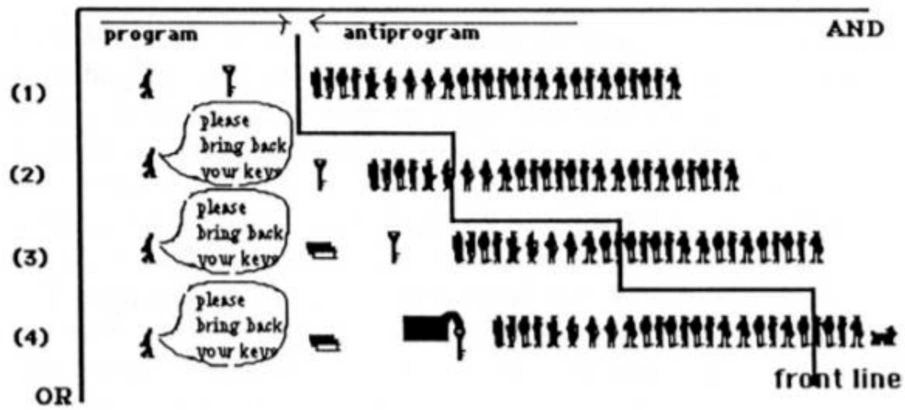

Figure 1: Sequential components used by a hotel manager to modify the attitudes of hotel customers to returning their key; Berlin Key Analogy (Latour, 1992).

Building upon Latour's original Actor-Network Theory, Callon offers that "technologies cannot be considered simply as servants or as subordinates [for] they participate fully in action and cognition, as partners of humans and not as instruments in their hands" (Callon, 2004, p. 4). He states that there are two different types of intervention to support human agency: active agency – supplying a human with information for them to independently make their own decisions when operating technology, and passive agency – utilizing technology to shape the behavior and make decisions so that the human is no longer a self-mastering individual (ibid). These two types of human agency can be explained succinctly with the case of an automobile driver. Traditionally, a driver is unobstructed by the automobile to think and act as they desire when in operation. So even though, the driver's predetermined thoughts, feelings and attitudes are cultivated by their environment and experiences, they actively control and are responsible for their choices on the road (active human agency). On the other hand, information and communication technology (ICT) devices can be used in the automobile to process road and vehicle-specific data to provide information from route planning to real-time fuel economy. Although, the individual is still the driver, many of his capabilities have been delegated to the technology actant (passive human agency). Henceforth, both passive and active human agencies operate in parallel within the actor-network theory and are a significant factor in the evaluation of how programs of action are accomplished.

Within the field of sustainability, there is a dichotomy between environmental attitudes and subsequent action (Harvey, 2013). Due to this dichotomy, Latour claims that society has drifted towards deploying technologies that decouple human behavior from environmental impacts, such as the electric vehicle; however doing so will only promote poor human consumption habits and hinder progress in addressing climate change (Latour, 2015). By taking a human-centered approach to sustainability, it can be better understood how technology can be inscribed deliberately to empower behavioral change passively or actively in human actors. Given the nuanced and interdisciplinary nature of the technology, sustainability and human consumption in the fleet driving system, actor-network theory is a suitable framework for outlining the relationships between each relevant actor and element within the sociotechnical network (Figure 2). In this case, the three types of actors are fleet drivers (users), eco-driving behavioral intervention tools (behavioral aids) and fleet managers (behavior-enforcing allies).

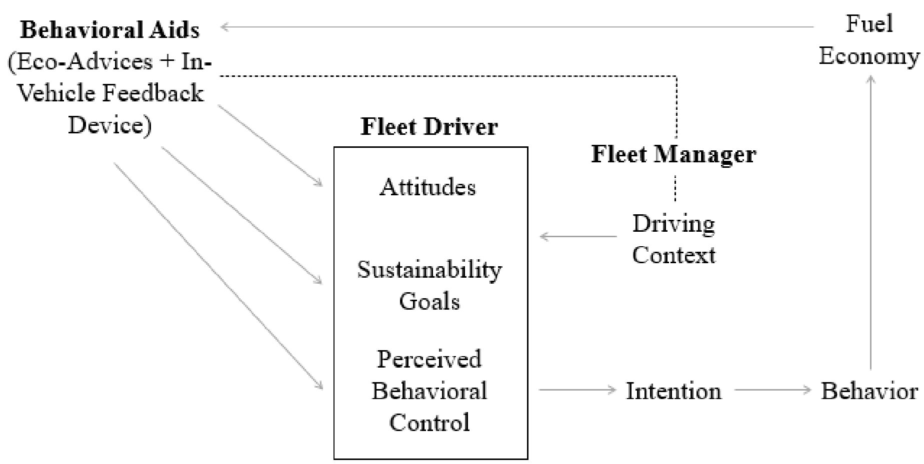

Figure 2: Sociotechnical network of the fleet driving system (Stillwater, Kurani, & Mokhtarian, 2017).

The employment of a combination of engineered inscriptions in the fleet vehicle system, from in-vehicle ICT feedback devices to eco-driving simple advice to eco-driving training with an instructor, have been studied scientifically, however there lacks a comprehensive examination into the social components and sequential effect of common eco-driving learning inscriptions to support fuel-efficient programs of action. Latour’s Berlin Key will be transposed to the fleet driving system to understand the complex relationship between automotive technological artifacts, human actors, and allying components in manipulating eco-driving behaviors directly. Ultimately, actor-network theory will be a foundational tool to support the evaluative analysis of human and non-human actors in lowering fuel consumption amongst fleet drivers.

Case Context: Eco-Driving and Telematics

Fleet managers are responsible for cutting costs and upholding the principles of Corporate Social Responsibility (CSR) throughout the organization. For managers who strive to reduce fuel usage and environmental impact, adopting a culture of eco-driving is simple, yet effective. A change in driver behavior style corresponding to eco-driving can be applied to any vehicle regardless of age or size, can take effect across an entire fleet of vehicles immediately at low cost, and can result in economic savings, improved fuel efficiency and safer drivers (Barkenbus, 2010). While the potential benefits of eco-driving for reducing vehicle emissions are evident, isolated eco-driving initiatives launched by governments and institutions around the world have found varying levels of success in improving fuel efficiency. And more significantly, despite a wide range of eco-driving schemes being implemented independently, there hasn't been a rigorous evaluation of the successive effect of eco-driving initiatives relative to fuel savings (Luther & Baas, 2011). At the core of eco-driving evaluation is telematic technology. Telematic sensors electronically log data on a number of parameters that compromise sustainable driving behavior, including idling time, braking occurrences, and acceleration, and use regression modeling to simulate its impact on fuel consumption. Fleet managers further can utilize telematics to gain insights on changes in performance and fuel economy of fleet operations when incorporating applicable strategies. Three eco-driving strategies that have proven individual merit on a low-budget are in-vehicle feedback systems, eco-driving lectures, and in-vehicle advice with an instructor (ibid). A remodeling of the fleet driving system to include these interactive educational strategies are essential to inform drivers about best practices and shape their attitudes towards sustainability to align with fleet management objectives.

Research Design

A neglected solution to curbing emissions is facilitating eco-driving styles, particularly in a goal-directed setting, even though it has proven to hold merit in enhancing fuel efficiency while optimizing economic utility. Research has demonstrated that instructive intervention is needed for individuals to regularly perform and maintain eco-driving techniques. In this research paper, I will address the question: *What role do both technology-centric and human-centric programs embedded in the fleet driving system play in fostering sustainable behavior?* This research will explore programs, from simple eco-driving advices to hands-on training with an instructor to in-vehicle feedback devices, which can intervene in the driving system to yield fewer greenhouse gas emissions. Ultimately, a tiered layout of eco-driving behavioral programs will be analyzed to justify how fleet managers can feasibly impose sustainable driving to be the norm, rather than the exception.

Eco-driving research efforts focused on operational decision making, while limited in number, have established behavioral aids and educational programming as viable methods for fleet managers to reduce their carbon footprint in an economical fashion. The mainstream introduction of telematics in commercial vehicles and emphasis on transportation-related emissions has unlocked the opportunity to not only understand the role that driving parameters have on fuel economy, but also cross compare different eco-driving enforcing technologies and social training programs. By reviewing eco-driving scientific journal articles from 2000-present, it was established that existing literature exclusively compares the effectiveness of technological in-vehicle eco-driving devices or social training strategies, but there lacks sociotechnical discourse integrating these two types of strategies together. Five cases discussing the application of one or two eco-driving strategies, or programs, in field trials were identified and selected for their homologous approach on fleet-based drivers and efficacy results concerning the assessment of simple theoretical eco-driving, practical eco-driving training with an instructor and the use of in-vehicle display dashboards. For each case study, information on social and technological components that played a role in the development and implementation were pulled. This includes significant qualitative deductions on the capabilities and shortcomings for each distinct eco-driving program studied. Relevant interpretive knowledge from eco-driving meta-studies, accounts from primary focus groups and testimonials with fleet management experts were collected to supplement case study findings. For the purposes of the case comparison, average fuel consumption decrease, defined as the percent difference in gallons of fuel consumed per mile between before and after the employment of the training mechanism, was utilized as the dependent variable for comparing the effectiveness of singular and joint strategies. The case comparison will utilize the aforementioned key components from actor-network theory from the mix of eco-driving programs for an evaluative sustainability analysis (considering environmental, economic and safety dimensions) to derive suggestions for fleet management personnel. Fundamental social and technical components of each case in the investigation are summarized below (Figure 3).

Case Study/Journal Article Title	**Country**	**Program 1**	**Program 2**	**Human Agency, Intervention** (*Passive/Active, Human/Non-Human*)	**Average Fuel Consumption Decrease**
"Fuel Consumption and Gas Emissions of an Automatic Transmission Vehicle following Simple Eco-Driving Instructions on Urban Roads" (2)	Australia	Simple Theoretical Eco-Driving Advices	-	Active Agency, Human Intervention	7%
" Comparing Effects of Eco-Driving Training and Simple Advices on Driving Behavior"	France	Practical Eco-Driving Training with Instructor	-	Passive Agency, Human Intervention	11.3%
"A Driver Advisory Tool to Reduce Fuel Consumption"	United Kingdom	In-Vehicle Feedback Display Dashboard	-	Passive Agency, Non-Human Intervention	7.6 – 12%
"Positive Effects of Eco-Driving in Public Transport – A Case Study in Novi Sad" (3)	Serbia	Simple Theoretical Eco-Driving Advices	Practical Eco-Driving Training with Instructor	Hybrid Agency, Human Intervention	11.71%
"A prototype fuel efficiency support tool" (4)	Netherlands	Simple Theoretical Eco-Driving Advices	In-Vehicle Feedback Display Dashboard	Hybrid Agency, Hybrid Intervention	16%

Figure 3: Eco-driving programs case comparison table.

Results Overview

A driver's behavior is shaped by both the product and the social system they are working within, thus the vehicle system they are operating can be deliberately designed with a specific activity in mind, like fuel efficiency (Mcllroy & Stanton, 2017, p. 11-12). A system's form can be designated in such a way to influence behavior by not only making drivers aware of their choices but also affecting beliefs and intentions with goal setting and information provision (Mcllroy & Stanton, 2017, p. 13). Mcllroy outlines three core types of behavior intervention strategy relating to energy use: antecedent strategies which provide a driver with information before a behavior is formed, feedback provision which provides a driver with information in real-time as behavior is being administered, and consequence strategies which punish or reward behavior (ibid). Since consequence strategies have demonstrated narrow gains, the proceeding case comparison focuses solely on comparing antecedent strategies and feedback provisions. The findings from the case comparison reveal that a solo strategy giving the driver active agency can be expected to reap 7% fuel savings, whereas a single passive agency strategy can be expected to realize upwards of 12% (Figure 3). When combining two human interventions, one active and one passive, the added savings are negligent, yet when implementing a fully hybrid system, an in-vehicle feedback display with a human eco-driving advice component, the savings are maximized at 16% over the long-term. These results are on par with the International Transport Forum's finding that there is an added 5% in fuel savings when there is continuous feedback beyond initial training (Barkenbus, 2010, p. 764) and Sanguinetti's deductions that feedback is more effective when it is included with multiple modalities, information with both passive and active agency mechanisms (Sanguinetti, 2018, p.19).

The Effectiveness of Eco-Driving Programs: Case Comparison Analysis

The most basic, cost-effective way for fleet managers to improve the fuel economy of their fleet operations is by simply providing drivers with advice regarding how to drive in an eco-friendly manner. After being told to simply accelerate and brake smoothly, slow down and watch speed, anticipate the road ahead and avoid unnecessary abrupt braking, choose the appropriate speed, monitor RPM and avoid excessive RPM, participants in an Australian case study decreased their fuel consumption by 7 percent on average (Larue, Malik, Rakotonirainy, & Demmel, 2014, p. 590). Complications with the case study arise when discussing safety, long-term consistency and thoroughly addressing all parameters which affect eco-driving. The practice of hypermiling, or fuel consumption techniques involving limiting gas pedal and brake usage, can be commonly misconstrued for eco-driving advice when safety is traded off for the execution of these goal-directed behaviors (Barkenbus, 2010, p. 763). Plus, reminders to apply these driving principles should be delivered on a monthly or even weekly basis to reinforce organizational goals and learning. It is important to label this trial as short-term gains given that the impacts of this strategy have been proven to diminish over time in long-term studies (Sanguinetti, 2018, p. 20). Still, the resulting data from the study is relevant for supporting the claim that simple eco-driving instructions statistically significant change RPM, driving parameters and fuel consumption.

While providing theoretical information about eco-driving is conventional, some individuals may prefer a more hands-on learning approach. In a separate French study, one group of participants was provided with the "golden rules" of eco-driving, similar to the advice aforementioned, while another independent group was given practical eco-driving training with a professionally licensed eco-driving instructor in a light-weight vehicle (Andrieu & Saint Pierre, 2012). The findings illustrate that the two methods are statistically insignificant from each other, theoretical training decreasing average fuel consumption by 12.5 percent versus 11.3 percent realized when provided with practical training with an instructor (ibid). Considering resource constraints surrounding hiring instructors, as opposed to a fleet manager delivering widely accepted principles, this case contends that theoretical training is a more sensible method from a cost-benefit analytical perspective.

Feedback displays which provide drivers with a visual or auditory assessment on how successful they are in achieving maximum fuel economy performance are emerging as a popular behavioral-aiding tool. Generally, the design is a simple horizontal bar that changes color and length based on driver behavior and total fuel efficiency of the trip (Barkenbus, 2010, p. 766). A driver display tool which provides instantaneous visual feedback and audible warnings was tested on different vehicles in a field observation showed a fleet fuel consumption reduction of 7.6 percent for light weight vehicles and 12 percent for vans (Vagg, Brace, Hari, Akehurst, & Ash, 2013). These numbers offer comparable sustainability improvements to the aforementioned solo training methods, but alternate research indicates that driver support tools may also be ignored by drivers for being too distracting. Therefore, the mere presence of a driver support tool is insufficient, the design and perceptions of the system that it operates within must be carefully considered (Mcllroy & Stanton, 2017, p. 15).

By employing these eco-driving programs in combination, it can be hypothesized that fuel consumption savings should successively increase. On this note, it has been established that people provided with simple advice without motive to apply it still develop energy conservation behaviors when supplied with dynamic feedback (Mcllroy & Stanton, 2017, p. 14). Building upon simple eco-driving instructions with other methods, the efficacy of joint eco-driving programs can be better understood. In a Serbian study, three bus drivers ranging in motivation were first introduced to the basic techniques of eco-driving in a two-hour theoretical training setting then given practical training with in-vehicle instructor feedback (Basaric et al., 2016, p. 3). Ultimately, this joint program realized an average 11.71% reduction in fuel consumption with fuel consumption savings. Compared to the aforementioned French study which employed only theoretical guidance, the difference in fuel economy gains are negligible when adding an additional human intervention strategy (Basaric et al., 2016, p. 4). Conversely, a two-fold hybrid study blending theoretical guidance and eco-driving feedback technology realized a different outcome. This Dutch study was performed so that one set of drivers were given verbal instructions to drive with eco-friendly behaviors and a second set given both the verbal cue in combination with a constant visual and auditory feedback on fuel economy from an in-vehicle display (van der Voort, Dougherty, & van Maarseveen, 2001). Using a driving simulator, individuals with the feedback display decreased their fuel consumption on average by 16 percent, 7 percent more than those without (ibid).

Fleet management eco-driving initiatives are found to be most efficacious when technology-centric and human-centric programs are utilized in union, regardless of whether the driver is truly eco-conscious or not. The human element is important for providing the drivers with the set of goal-directed behaviors and informing them that their decision-making holds value. The technology element is significant for helping nudge drivers in the direction of applying the goal-directed behaviors. Furthermore, in-vehicle feedback displays and simple behavioral advice coupling the user to conduct mindful decisions co-dependently in the fleet system was established in the case comparison to be the dominant multi-dimensional strategy (Figure 4).

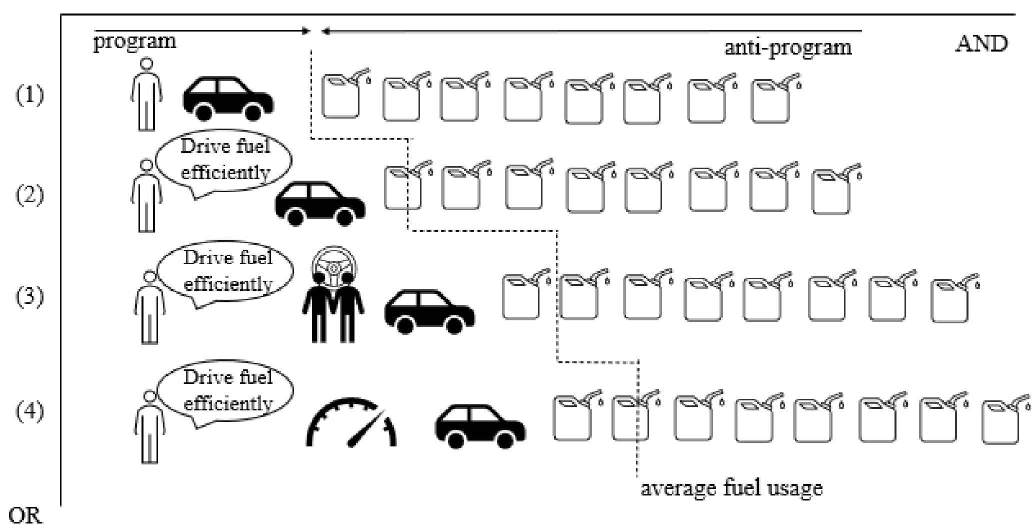

Figure 4: Sequential components used by a fleet manager to modify the attitudes of drivers to operate with greater fuel efficiency.

Case Comparison Implications

This work holds significance for it offers evidence that rethinking the fleet driving system from top-to-bottom and identifying potential "missing masses" which can be embedded in technological or social artifacts does hold value in understanding how to apply programs of action (eco-driving) and prevent subsequent anti-programs (poor driving behaviors) from arising (Latour, 1992). Latour argues that by modelling and recognizing that non-humans have an active social role in the actor-network, the more human behavior is enriched. These findings further assert that a hybrid of technologies and non-human actors allow heterogenous actors to forge new individual attitudes and help collectively transform social behavior (Callon, 2004).

Mainstream media has yet to adopt such a dynamic model, with many politicians and scientists pushing for the adoption of completely human-decoupled technological solutions, from cruise control and "eco-mode" software in vehicles to electric and hybrid vehicles. As such, deploying these technologies has shown to even be less effective. Using cruise control has proven to improve fuel savings only by around 7% in light-weight vehicles (Sivak & Schoettle, 2012) and the implementation of Devise Systems software, a technology that alters a vehicles code to idle slower and shift differently to boost fuel efficiency, resulted in less than a 6% increase in fuel economy when enabled in a large fleet field test (Centofante, 2021). And given the age of some fleets, cruise control may not be a feature and a Devise software retrofit may not be possible in all vehicles without replacement. Even though electric and hybrid vehicles can enhance fuel efficiency by more than 30%, due to the major expense of purchasing a car, only about 7% of vehicles are replaced in a single year, making a full switch from ICE to electric and hybrid vehicles gradual (Barkenbus, 2010, p. 763). And eco-driving results will become even more substantial in the future as fleets convert to hybrid vehicles since performance is extremely sensitive to behavior (Barkenbus, 2010, p. 764).

Limitations

The greatest limitation of this investigation is the unstandardized nature of the case comparison. Testing methods differ from field trials to driving simulators, the study periods range from comparing two runs to data collected over a 45-day period, vehicles range from light-weight sedans to buses, and the number of drivers studied vary from three drivers to over a hundred drivers. Differing locations restrict the case comparison by contributing to extensively separate public perceptions of eco-driving (e.g., drivers in France may be more receptive to changing behavior than those in Serbia) and inconsistent traffic flows. Inconsistent jargon regarding program methodology contributes to difficulties in comparing these cases, even though case selection was completed with standardization and bias in mind. For example, eco-driving advices in one journal article may indicate a two-hour theoretical training seminar whereas in another it may mean a driver being delivered a short briefing on how to drive efficiently. Other limitations include results being misinterpreted, diminishing returns in a long-term setting and new problems (mainly safety) emerging without proper utilization of programs. One fleet driver in the UVA FM focus group mentioned the Hawthorne Effect, stating that "[telematics] make you mindful of driving safety and speed." Furthermore, drivers may behave differently because they know that they are being monitored, and not directly due to an eco-driving initiative. A randomized, controlled study for driving behavior would account for all the discrepancies in the analysis and is necessary for future research. Lastly, the findings in the paper are restricted solely to the fleet social ecosystem, which accounts for less than 10% of vehicles on roads, meaning that the effects a behavioral transformation are fairly bounded given the specialized segment of the target agents of change.

Future Work

Future work of this investigation would involve a more thorough analysis of eco-driving programs, including monetary and non-monetary consequence incentives for exceeding target sustainability metrics provided by fleet managers. It would be beneficial to increase the number of programs studied jointly to three or four in order to explore ways to the fuel efficiency threshold from operational behavioral decision-making. Considerably more work will also need to be done to understand the best ways to teach eco-driving theoretically and ways to enhance drivers' motivation to use the in-vehicle systems as more information on user acceptance would help us to establish a greater degree of accuracy in the design and development of innovative in-vehicle systems. Lastly, the effect of eco-driving programs should be scaled outside of the fleet system to any conventional driver.

Impact

This research has influenced my perspective as an engineer by bringing to light the role that technologies and social groups have in collectively benefitting each other. The case comparison results depict that a balance in work delegation to human and non-human actors leads to greatest sustainable gains. This work has further taught me that technology should work to enhance human behavior, instead of displacing it and that investing in hybrid eco-driving initiatives immediately can organically improve our climate situation. By revolutionizing our understanding of the relationship that we have with technology and taking responsibility for the role human agency plays in climate impact, engineers can better design technological products and systems to empower sustainability and put the USA in a better position to cut greenhouse gas emissions in half by 2030.

Conclusion

The U.S. transportation sector has been unsuccessful in generating far-reaching transformational change to lower carbon emissions. This can be explained partially due to the role of the driver being repeatedly neglected in shaping vehicle performance. The recent emergence of telematics in fleet-driven vehicles has allowed for an evaluation of human-centered behavioral intervention strategies. This work has developed a comprehensive evaluative sustainability assessment framed by Actor-Network Theory on three eco-driving strategies: theoretical advices, practical training with an instructor and in-vehicle feedback displays. A combination of in-vehicle feedback displays with theoretical advices, or hybrid intervention, was explored to be the most effective strategy within the case comparison. Still, large investments and proper deployment of these programs in public and private fleets are necessary to realize these fuel savings and subsequent carbon emission reductions. To enable this transformation, fleet managers should mandate theoretical instruction on eco-driving behaviors once per quarter to all vehicle operators and gradually retrofit vehicles with in-vehicle eco-driving feedback devices. Nevertheless, the implementation of devices and training programs like these are not a substitute for car manufacturers to make concentrated efforts to improve fuel economies, but complementary. They are only one piece of the puzzle to controlling emissions in the transportation sector and an approach that be taken advantage of right now.

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