At the Breaking Point

How Bus Operators Cope with Transit Technology Failures and What That Can Tell Us About the Integration of Future Innovations

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Abstract

This paper examines the cascading effects of technical failures in transit, focusing on the challenges faced by bus operators when communication, passenger-facing, and mechanical technologies fail. Through a diary study, we gather operator accounts of critical tools like radios, mobile data terminals (MDTs), payment systems, and ramps, alongside their failures. Issues like radio outages, GPS malfunctions, and broken fare systems lead to operational delays, safety risks, and increased stress. Triaging breakdowns becomes crucial to operations and drivers adapt by using personal phones in emergencies, highlighting gaps in system integration. As transit electrifies its fleets and considers a wider range of innovations, these failures offer key insights into the challenges ahead, emphasizing the need for robust, adaptable systems that ensure operational continuity and protect worker well-being amid rapid technological change.

CCS Concepts

• **Human-centered computing → Empirical studies in HCI**.

Keywords

Transit technology; Bus operations; Diary study; Maintenance and repair; Infrastructural endurance

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1 INTRODUCTION

In Asheville, North Carolina, three electric buses sit idle at the city's transit maintenance facility, emblematic of the challenges inherent in adopting advanced transit technologies [70]. Purchased in 2018 with the promise of reducing emissions and modernizing- the city's transportation fleet, these buses now face persistent technical issues ranging from software glitches to broken components—exacerbated by the manufacturer's bankruptcy [45]. Meanwhile, the city's remaining biodiesel and hybrid buses endure increased wear and tear, further straining maintenance resources. This scenario reflects a broader trend: the transition to innovative transit technologies often encounters unanticipated hurdles, raising critical questions about design, reliability, and the role of workers in ensuring safety and service continuity.

Proposals for the future of bus transit increasingly emphasize integrating advanced technologies, including autonomous driving systems, real-time data analytics for dynamic scheduling and route optimization, and the expansion of electrification. Smart infrastructure, deployed through connected traffic signals and dedicated bus lanes, aims to minimize delays, while mobile apps and AI-driven systems are being developed to provide personalized travel recommendations and expanded fare payment options. Proponents tout the potential of these technical interventions to make bus transit more competitive with private vehicles and better suited to modern urban mobility demands. However, the successful adoption of these innovations depends not only on their technical sophistication and realized capabilities but also on their alignment with the operational realities and maintenance practices of existing transit systems.

At the heart of transit operations are bus operators, whose indispensable role in providing safe and reliable transportation is often overlooked in discussions about technological advancement [3, 39, 46–48]. The existing technologies operators rely on today—communication, passenger-facing, and mechanical systems—are prone to malfunctions that undermine both service quality and safety. Drawing on a diary study of 93 bus operators across the United States and Canada, this research provides perspective on the types of malfunctions they encounter, the adaptive strategies they employ to remedy breakdowns, and the broader operational consequences. By focusing on firsthand worker accounts rather than technical reports or performance metrics, this study offers a unique lens through which to understand the lived experiences of operators and their critical insights into system design, safety, service, and reliability. Specifically, we examine the following research questions: 1) What technological malfunctions do bus operators experience on the job; 2) What are the consequences of these failures; and 3) What might existing malfunctions tell us about the implementation and evaluation of future technologies?

Bus operators frequently report issues with essential tools such as radio systems, mobile data terminals (MDTs), fare payment systems, and ramps. Failures in these systems—ranging from complete outages to intermittent disruptions—compromise real-time coordination, situational awareness, and decision-making. These breakdowns often lead to cascading operational inefficiencies, such as missed detour instructions, delayed responses to safety incidents, and heightened stress among operators. In response, some operators describe resorting to temporary workarounds, such as using personal cell phones, despite conflicts with policies prohibiting mobile phone use during operation. This disconnect highlights the need for further attention to the operational realities of today's transit technologies and more worker-centered technology solutions.

Beyond accounting for current system breakdowns, this research underscores for the HCI community the importance of maintaining legacy systems as a foundation for the design and adoption of emergent transit technologies like fleet electrification and driver assistance systems [13]. Aging infrastructure and poorly maintained vehicles create operational instability that is regularly absorbed by frontline workers. Looking ahead, though the field's sight may be fixed on emergent technologies, the need for existing communication and passenger facing technologies will remain. For example, the frequent mechanical and digital breakdowns operators face in traditional fleets may exacerbate reliability issues during the transition to electric buses, which require specialized maintenance, operational protocols (e.g., due to new capacity constraints), and charging infrastructure. Similarly, existing vehicles may lack compatibility with advanced driver assistance systems, undermining the potential benefits of retrofitting fleets. Furthermore, issues that occur on the bus while in service, such as mechanical failures or digital system outages, require adaptation plans to ensure that service can keep running despite degradation. Such workarounds could be considered in advance during new systems designs, however, there will be issues that require human intervention. By prioritizing worker-led integration and maintenance strategies, this research highlights the need for robust, adaptive transit technologies that enhance safety, reliability, and accessibility. In doing so, this work contributes to the development of resilient public transit systems capable of meeting the demands of urban mobility now and into the future.

2 BACKGROUND

Municipal public transit systems within North America include fleets of heavy-duty 40-foot or 60-foot articulated buses operating on a network of routes throughout cities, suburban neighborhoods, and rural areas. Buses are typically diesel powered and may include articulated electrical power when running on routes with overhead power lines. Increasingly, North American transit companies are investing in new low-emission propulsion technologies powered by compressed natural gas, hydrogen fuel cells, or electric batteries. These changes have been motivated by sustainability goals to reduce reliance on fossil fuels [27], lower greenhouse gas emissions [40], and to improve urban air quality [10]. Recently, there have been billions of dollars in grants disbursed for electrification from the U.S. Federal Transit Administration (FTA) [22]. This is changing the face of aging bus fleets that may be over a decade old. [1] However, the introduction of more sustainable bus transportation is not without its challenges due to issues of integrating these new technologies into the context of public transit operations. One illustrative example is Des Moines, Iowa decommissioning all of its recently purchased electric buses due to maintenance issues, limited support from the bus manufacturer, with the buses being fit for road use only 60% of the time (compared to 90% of the time with diesel buses) [12, 15]. Along with electric vehicles, new generations of buses often include forms of advanced driver assistance systems (ADAS). These changes together may have profound impacts on the day-to-day work of maintenance and the impact of technological breakdown.

Buses are also being retrofitted with new technologies based on the evolving needs of bus operators and passengers. During the COVID-19 pandemic, air filtration systems and plastic shields were installed in buses to protect operators and passengers. Unfortunately, there has been a sharp rise in assaults on drivers [50], prompting new cabin enclosure designs to protect drivers [1]. Building on this, the Bus of the Future project [1] proposed a variety of new technologies to protect drivers from assault, reduce driver injury and occupational hazards (such as improved seats and fresh air ventilation), and improve driver visibility and situation awareness around the road (such as better mirrors and computerized obstacle detection systems). These proposed changes include both physical designs and digital systems.

These changes are needed to help ensure a safe work environment and attract new workers to the profession. The experience of operating a transit bus is challenging and impacts workers and their retention [69]. Many of the issues being addressed in the Bus of the Future Project highlight operators' issues, such as bodily strain due to poor ergonomics, respiratory issues due to diesel exhaust fumes, and assaults [1]. Due to these chronic issues and acute ones following the COVID-19 pandemic, there are staffing shortfalls of bus operators and mechanics [6]. This leads to limited capacity for expanding service and maintaining existing bus fleets. Our paper describes many of the on-the-ground effects of this reality.

As with any operational change, the system design and implementation of technologies on buses can impact operators' work. Each system, with its interfaces, controls, and sensors, presents a potential component whose failure can impact and degrade the bus service. As described in this paper, technological failures are managed by operators while en route. Often, operators and maintenance teams will develop strategies for managing technology issues, depending on the scale and severity of the issue or breakdown. Ultimately, transit operators work to continue service for

[1] The FTA (FTA) specifies a 12-year/500,000 mile useful life for heavy-duty 40-foot buses [2]

their passengers despite issues. As new technologies such as electric vehicle propulsion systems, driver assistance, and automation are considered and eventually introduced, it will be critical for system designers and bus manufacturers to understand how current on-the-ground operations work and how transit operators interact with existing and emerging technologies. Beyond designing future systems, transportation companies, operators, and maintenance teams should consider how new technologies will impact their operational, maintenance, and repair procedures to ensure good service and good working conditions. Given this, our research aims to understand how operators experience current technologies in order to provide system designers with considerations for designing future transit innovations that acknowledge infrastructural realities and leverage worker expertise.

3 RELATED WORK

3.1 Emerging Transit Technologies and the Need for Operator Perspectives

Previous work on public transit in DIS primarily focuses on passenger perspectives, such as inclusive design for passengers with accessibility needs [9, 71] and the intersection of gender and mobility in the Global South [5]. These studies aim to inform the design and integration of new technologies that improve user experience. Among these technologies, automation has received relatively more attention, with focus on new possibilities for public transit [5]. Automation research often emphasizes rider perceptions as barriers to broader implementation and examines concerns about safety [17, 36, 57], privacy [24, 56], and accessibility[32, 38, 53], which align with broader priorities for mass transit.

While many HCI studies explore speculative designs or conduct user studies of emerging passenger-facing bus technologies [7, 20, 26, 37, 54], there is a noticeable gap in research focusing on worker perspectives. A notable exception is the work of Pritchard et al., who examine the impact of digital transformations that happened in bus transit in the early 2010s [46–48]. This team conducted ethnographically-oriented research with London bus drivers to understand the impact of three technologies: a driver performance monitoring software, location based services, and tap fare payment replacing cash. Pritchard et al. found that these practices fundamentally changed driving and customer service roles. For example, the introduction of location-based services and GPS tracking [46] enabled real-time monitoring and stricter schedule enforcement by management. While some drivers appreciated the additional information, most drivers strongly disapproved of the change, seeing it as decreasing their autonomy, deskilling aspects of their work, and fostering a "Big Brother' surveillance effect. The authors also point to negative consequences on some riders. With heightened time pressure, some elderly and disabled passengers, who can take more time to service, were given a cold shoulder. Concerns were also raised with the introduction of a driver performance monitoring software, "Drivewell" [48]. While some drivers recognized the value of being able to monitor how smooth a ride they were providing passengers, most had complaints about the system. These ranged from the arbitrary way it scored drivers given how different buses perform to feeling uncomfortable being surveilled ("Big Brother" again) and having performance data extracted. It also added another interface competing for attention alongside road conditions and passengers. Similarly, Pritchard et al. [47] describe how the introduction of a cashless payment system produced new work and driver concerns. Many drivers were appreciative of the way tap payment sped up the boarding process, but in the context of a transition found themselves re-explaining the system to riders repeatedly. They also raised concerns about privacy and populations harmed by the broader societal transition to cashless payment. Overall, these papers speak to the way digital technologies can enhance managerial control, reconfigure basic tasks, and introduce intrusive affordances. To combat these harms, Pritchard et al. call for more worker participation in the design of role transforming technologies[46].

Our work follows this call while attending to other aspects of the empirical realities of use — namely breakdown and failure of existing technologies. We investigate these instances through direct operator experiences, offering analysis across multiple bus technologies to reflect the cascading nature of failure [30, 44]; performance variability in human-machine teaming [29]; and strategies of operator adaptation amidst operational constraints [49]. In doing so, we seek to inform future design, maintenance, and operations practices.

3.2 The Ongoingness of Technological Repair

The study of breakdown and repair has long been foundational in HCI, Computer-Supported Cooperative Work (CSCW), and Science and Technology Studies (STS), foregrounding the labor required to maintain and restore systems under conditions of failure [31, 33, 35, 55]. Within CSCW, Suchman's notion of articulation work captures the often-invisible labor of realigning disrupted systems—work necessitated by design mismatches, shifting contingencies, or infrastructural limits [63]. While central to understanding cooperative action, subsequent scholarship has emphasized that such labor is unevenly distributed. Rather than being equally shared, coordination work often falls to those with less institutional power, whose contributions remain obscured and undervalued [60, 62].

This critical attention to the politics of repair deepens with Jackson's call to "rethink repair" as more than a return to functionality, and rather as a lens onto values, politics, and care embedded in sociotechnical life [33]. Repair, in this sense, is a situated and generative practice that exposes which futures are preserved, and whose labor enables their continuity. Houston et al. [31] further emphasize that the values embedded in repair—what gets fixed, by whom, and why—are shaped by institutional hierarchies, cultural narratives of expertise, and uneven distributions of care. Particularly in public-facing infrastructures, repair is often enacted by frontline workers in improvisational and emotionally attuned ways—forms of labor rarely recognized within dominant accounts of technical work.

These dynamics resonate with Steinhardt and Jackson's concept of anticipation work, which—in the case of repair—draws attention to the labor of identifying, averting, or mitigating breakdowns before they occur [61]. Expanding this view, Jung et al.'s notion of repairedness emphasizes the contingent, negotiated state of "workingness" that follows repair, rejecting binary distinctions between functional and broken [35]. This concept intersects with Cohn et al.'s work on convivial decay, which foregrounds the deliberate management of degradation to ensure graceful decline rather than collapse [13]. Together, these perspectives reframe repair as an ongoing relational practice—raising important questions about who stewards such decay, under what conditions, and with what forms of recognition.

STS scholarship on maintenance further reinforces this temporal and relational view. Studies have shown how the ongoing care of systems is entangled with the identities, careers, and social expectations of those tasked with sustaining them [8, 14]. In parallel, software maintenance research has revealed how organizational "common knowledge" is collaboratively produced and maintained, with breakdowns exposing the layered complexity of technical infrastructures [51]. These insights challenge instrumental or linear views of repair by foregrounding its interpretive, affective, and distributive dimensions.

Our study builds on this foundation by focusing on transit operators' dual role as maintainers of technological systems and customer-facing service providers. These operators frequently encounter and mitigate breakdowns, embodying "repair-as- maintenance" while navigating the limits of "repair-as-transformation" [28]. Unlike studies centered on maintenance staff or repair specialists, we explore how transit operators balance immediate repair needs with broader operational and passenger management responsibilities. This work contributes to ongoing discussions in HCI and CSCW by highlighting the intersection of technical breakdowns, infrastructural aging, and the lived practices of repair within dynamic, safety-critical environments. Through this lens, we extend the study of repair and maintenance to address the everyday practices that sustain transit systems under conditions of recurrent failure.

4 METHODS

This paper builds upon a larger study around the daily experiences of transit bus operators to understand how potential future technologies and automation will impact their work. To arrive at the analysis featured in this paper, our research team partnered with two international transit labor unions, the Transport Workers Union and the Amalgamated Transit Union, to develop and conduct a diary study [52] with North American transit operators over the course of one year, from Spring 2023 - Spring 2024. We chose the diary study method to collect data that would give a longitudinal perspective on transit operations, given that each day new situations arise and patterns may exist depending on the time of day, week, or year. The diary study method also allows for operators to document situations that occur soon after they experience them, documenting details that could be lost over time. The longitudinal data collection also allowed our team to learn about adaptations or changes in work that may occur over time due to different situations. Lastly, working with the transit labor unions, we learned that some operators keep a work diary, thus, the method would likely be either familiar or acceptable to the participants. To supplement the diary study data and collect more information, we also conducted semi-structured interviews with operators who agreed, asking follow-up questions based on their diary entries. In this paper, we focus on operators' entries and interviews surrounding the tools, technology, and equipment that impact their work.

4.1 Participants

With the support of our union partners, 155 operators signed up for our study, 93 of whom submitted entries. Operators came from major regions of the U.S. and Canada representing urban, suburban and rural municipalities. Due to the sensitive nature of having operators describe their day-to-day work, we did not collect detailed demographic information, however, our participants are generally representative of the overall bus operator population regarding race, gender, and age. The participants pool includes operators with varying years of experience, ranging between 0-48 years across the 68 operators who responded to this question. The majority of participants were from the U.S. as Canada represents a smaller market.

4.2 Diary Study and Interview Procedures

Participants completed the diary study via a digital Qualtrics questionnaire that allowed them to either write or record a video response to four questions. Each diary entry asked operators about 1) assisting passengers, 2) noteworthy situations, 3) the impact of tools, technology, and equipment, and 4) any other things they would like to communicate with our research team. The diary study was designed to be answered at the end of an operator's work day. Participants chose to receive either text message or email reminders to complete a diary entry. Participants selected what days and times to receive these reminders during an onboarding questionnaire that collected basic information about the participant and provided a short guide on completing diary entries. The four diary questions were intended to be answered within 15 minutes. Operators were compensated weekly with a gift card valued at $7.50 for each entry they submitted.

Participants were asked to complete 30 entries over 60 days, however, not all participants completed 30 entries due to the time commitment and extenuating circumstances at their jobs. We invited participants who had submitted entries and were enrolled for at least 60 days to participate in the follow-up interview, with 47 agreeing. To inform each interview, our research team reviewed the participant's diary entries and compiled a list of specific follow-up questions. We also asked a set of background questions to understand the operator's daily work, experience, and vehicle. Interviews were conducted over video conference and recorded with the participant's permission. During the interview, one research team member led while another listened and took notes. Interviews lasted 90 minutes on average, with some being conducted over a few days due to participants' time constraints and their eagerness to describe their work and experiences in detail. One interview was conducted via written communication over email at the request of the participant. Participants were compensated with a gift card at a rate of $30 per hour after completing the interview.

4.3 Data Analysis

Overall, the data includes over 2000 diary entries answering the four daily questions either as written answers or participant recorded videos and over 100 hours of interview audio recordings. Video-recorded diary entry audio and interview audio were machine-transcribed and later reviewed by our team and updated for accuracy. Text from the diary entries was reviewed in an ongoing manner to prepare for interviews and to provide updates to our transit union partners during bi-monthly meetings. All text-based data was then uploaded to Atlas.ti, a qualitative coding tool. The data were analyzed using a grounded theory approach [11]. Emerging themes were discussed and reviewed during weekly research team meetings. This paper focuses on themes relating to the technologies bus operators reported using and their impact on their work and operations experiences. These include firsthand reports of how different technologies impact service and safety, how operators respond to technical breakdowns and issues through adaptation and problem solving, and operators' thoughts on future training, maintenance, and operator-informed systems design.

5 FINDINGS

Our findings reveal the everyday breakdowns that bus operators experience on the road. While minor issues are frequent, more severe problems that leave buses inoperable are not uncommon. These range from small annoyances that can distract operators, such as flashing dashboard lights, to radio malfunction, to dramatic engine fires. There are *many* mechanical systems and digital technologies that can go awry. We detail their importance to maintaining smooth service and accessibility while also revealing the challenges that come with their failure. In doing so, we point to on-the-ground workarounds bus operators develop to patch over being left to their own devices.

Many bus operators pride themselves on being skilled professionals who can resourcefully and dynamically handle challenging situations. This was readily apparent with John, who compared himself to the fix-it genius of the 1980s self-titled TV series "MacGyver." Supervisors and other drivers alike turn to him for help on mechanical issues. Before becoming a bus operator he was a tow truck operator and he regularly helped out drivers who needed a lift or a small repair. He took pride in troubleshooting issues to help get folks on their way. He took this knowledge with him when he began his career in transit, carrying zip ties and duct tape in his work bag and feeling comfortable fixing small issues without asking for help from the mechanics in the yard. Lots of our participants had prior background in jobs where some mechanical knowledge comes in handy, as truckers, delivery workers, and more. But this is certainly not all drivers. Others were weary about taking on maintenance tasks and worried about role creep. They argue that doing the incredibly intensive work of safe driving and providing quality service should be enough. For them it was also about professionalism and dignity, being provided with a safe work environment and tools they need for success.

Transit workers pointed to the systemic causes of disrepair and too often feeling pushed to drive in unsafe conditions. Many suggested that they do not have adequate time to inspect vehicles during their pre-trip and are encouraged to just keep moving instead of sending a bus back into the yard. Others suggest how damage goes unreported by operators because of time constraints or fear of being blamed or penalized. Our participants also expressed sympathy

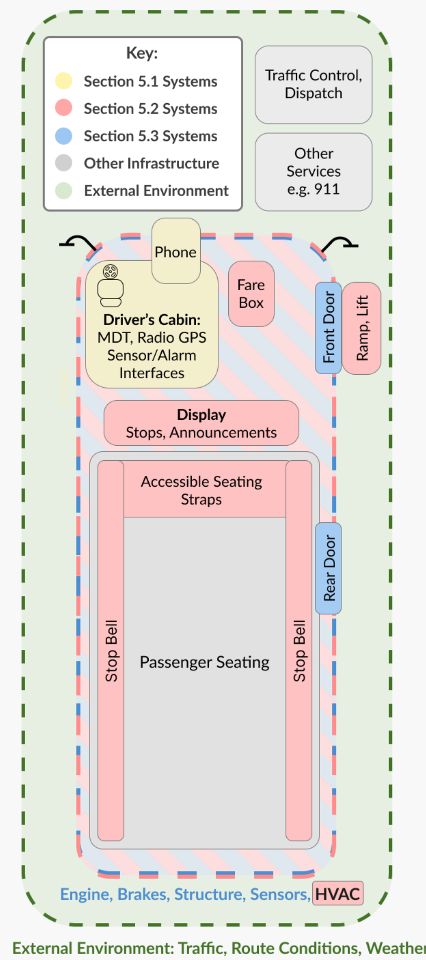

Figure 1: Generalized bus diagram illustrating the approximate spatial layout of systems described in the Findings. This generalized layout is not to scale and is not intended as an exact depiction of any particular vehicle model.

with and respect for their mechanics. But at many agencies they are understaffed and under-resourced. This leads to needed repairs taking longer and the in-practice minimum vehicle safe standard being lowered. Due to explicit federal regulations, this same dynamic would not be tolerated in other transportation industries such as the commercial airline industry. And, while this is changing, others expressed concern that procurement was not bringing in new buses fast enough to replace an aging fleet. Over a decade, buses can go through lots of wear and tear traversing poorly maintained roads and hazardous weather conditions. Together, these circumstances produce a normalized state of disrepair. We now turn to the tools and technologies bus operators utilize and worker accounts of what goes wrong.

5.1 Operator Communication Technologies

Effective communication technologies are the backbone of modern transit operations, enabling operators to navigate complex routes, coordinate with control centers, and respond to both routine and emergency situations. Tools such as mobile data terminals, bus radios, GPS systems, and, in some cases, personal cell phones play vital roles in ensuring efficient service and passenger safety. However, while these technologies offer significant benefits—streamlining schedules, improving situational awareness, and facilitating real-time updates—they are also prone to failures and design flaws that can disrupt operations. This section examines the critical functions, challenges, and operator experiences associated with these communication tools, highlighting the ways in which they shape the day-to-day realities of transit work.

5.1.1 Mobile Data Terminals. Mobile Data Terminals (MDTs) are essential for communication and operational updates in the transit system. These devices integrate with GPS, radios, and fareboxes, linking operators to transit infrastructure, including transit operations control centers. MDTs provide key functions such as delivering alerts about weather, road conditions, accidents, detours, and emergency situations. They also offer preemptive notifications about banned passengers, lost individuals, or those requiring assistance. Operators rely on MDTs to monitor schedules, track stops, and adjust their pace. Even experienced drivers appreciate the confirmation provided by MDTs for stops and scheduled arrival times. Additionally, MDTs help operators communicate with other buses, report when they have an overload of passengers, coordinate passenger transfers from one line to another, and support automated systems like stop announcements and route displays. MDTs also alert operators to potential mechanical malfunctions. Ryan noted that when the MDT functions well, it "definitely makes our job easier. Especially for new operators." Carlos emphasized that MDTs are "such a relief to have," helping them stay on schedule, keep passengers happy, and ensure safety. Andrew appreciated the MDT's feature of automatically scrolling through a list of stops as the bus passes them. Many operators also value how the timely alerts allow them to provide more comfortable, safe, and reliable service; for instance, Andrew adjusted their driving in response to a warning about steel plates in the road in order to increase passenger comfort.

Despite these advantages, we identified 35 operators who documented issues with their MDT in their diary entries. One issue was MDT system outages, often referred to as "freezing" or "going out," which operators attributed to aging hardware, weather conditions, or understaffed maintenance teams. Debbie mentioned their MDTs "are not working a lot of the time" and described how they followed training protocol by rejecting Control's command to "carry on" and instead exchanged buses. Kyler stated their MDT "impedes our job," mentioning broken promises about the deployment of more efficient electronic logbooks. Even when MDTs are operational, they may have slow boot times or connectivity issues, requiring repeated logins—a "nerve-wracking" process while driving. For example, George described their MDT taking "15 minutes to start every morning," the entire duration allotted for pre-trip inspections.

MDT malfunctions can compromise critical functions, such as accurate time and route displays or emergency alerts, leading to problems like incorrect stop announcements, ADA compliance issues, and passenger confusion. In response, operators rely on manual workarounds, often with support from control staff, such as re-entering data, using watches or paper schedules to track time and routes, and making verbal stop announcements. While these methods are necessary, they are inconvenient, error-prone, and introduce safety risks due to driver distractions. In more extreme cases, MDT failures may require slowing down, stopping, or even exchanging buses, further disrupting schedules. These challenges are particularly severe during emergencies, especially when a viable backup system is unavailable. Deja described how the failure of the "Request to Talk" button during a shift forced them to use their personal cell phone to contact dispatch about a threatening passenger. Without the phone, the operator felt that they would have been unable to contact dispatch and potentially could have faced assault.

Although MDTs are vital to operation, poorly designed interfaces can also hinder their benefits. Some operators found that alerts became distracting and intrusive. John described the onboard technology as "too annoying," citing an example where a control supervisor repeatedly sent messages about rain and traffic situations. Joyce likewise recalled receiving "multiple weather-related text messages," which were difficult to read and manually acknowledge as required while driving, forcing the operator to take their eyes off the road. Operators also noted syncing issues with MDTs during daylight savings or when deviating from regular routes. While time and schedule tracking is useful, operators reported stress caused by interfaces that highlight being behind schedule, sometimes displaying the delay in red. One senior driver expressed frustration with the design, stating that it "bothers me that it's been designed that way, and it bothers me that some people are really, really stressed with that… I don't think that whoever designed it thought that the little square would stress people."

5.1.2 Bus Radios. In addition to MDTs, bus radios are critical tools for communication, allowing real-time coordination, situational awareness, and emergency responses. Operators use radios to receive detour instructions, traffic updates, and mechanical reports; adjust schedules and routes; and share information with other operators. Rosa, who has ulcerative colitis, emphasized the importance of open communication for bathroom-related schedule changes, explaining, "If I'm taking a lot longer than just a few minutes, I will call them and say, 'Hey, listen, I'm in the washroom. This is where I am. I just need a few extra minutes.'" Radios also provide situational updates on environmental and infrastructure issues, such as road closures, accidents, and hazardous weather. For example, Steve recounted using the radio to report icy road conditions and warn other drivers. Radios also help manage passenger logistics, such as coordinating transfers, handling overcrowded buses, and assisting when buses break down.

However, radio systems face connectivity and reliability challenges. Operators reported instances of driving entire shifts without communication with dispatch due to radio failures. Operators noted these failures seem linked to outdated technology and buses, though even newer buses also experience issues. Communication can also become distorted or inaudible due to signal loss and static. Dorthy noted, "When I was out in the far end of the city, all I heard on an all-call was static. This is an everyday occurrence." In fallback modes, where communication is limited to a public broadcast channel, operators lose direct contact with dispatch. Tamika explained how fallback mode means "you can hear everybody's conversation over the radio," which can lead to confusion over who dispatch might be responding to.

5.1.3 GPS Integration. Operators also described how radio and GPS issues can compound each other. Ryan explained that when GPS becomes unsynced, control must call to establish bus status, which is "frustrating when mixed with our radio issues...whether or not control can hear us through our headsets." Operators reported GPS-related challenges similar to personal vehicles, such as geolocation and routing errors, but with added bus-specific constraints like avoiding residential areas. John noted GPS systems "guide cars and don't account for large vehicles," recounting a time they avoided "a side street that you had no business taking a bus down." Joyce stated such errors can get "people in big doo doo with one wrong turn." Noah relates how these issues are worsened by external factors like road conditions, e.g., broken-down cars, construction barriers, and highway pylons. Operators also described limited GPS functionality—lacking real-time traffic updates, turn-by-turn navigation, detour integration, and detailed street-level information. Chloe highlighted that while experienced operators rely less on GPS, it can assist with "nooks and crannies or some road closures." Bethany used GPS primarily for schedule and head sign updates rather than navigation. However, robust GPS becomes vital under challenging conditions. For example, Miles noted the difficulty of memorizing up to nine detours and 19 routes during "construction season," compounded by short winter daylight hours, and John described using GPS to find an exit in thick fog.

5.1.4 Cell Phones as Stopgap. Cell phones have emerged as an alternative during breakdowns of communication or navigation technologies, with 33 operators in our diary study describing cell phone use. Rosa described a representative experience of having to call from their cell phone because they "only had one bus this week where my radio was working." Beyond addressing direct technological failures, operators use their cell phones' ability to access–in timely and responsive ways–real-time information and communication to assist passengers, verify information, and respond to emergencies. Calvin described using their cell phone to help a passenger with a wheelchair transfer, stating, "I quickly realized he needed a different bus, but didn't immediately know which, so got off the bus and appropriately used my cell phone to find out for him." Several operators also described asking passengers who need language assistance to speak into language apps on their phone–though they note this behavior is not allowed. John lamented, "We could be more helpful if we were allowed to use our cell phones to look up addresses that customers are searching for," since MDTs often do not offer GPS navigation.

Operators also spoke of using phone apps for weather updates, real-time traffic data, and communication with colleagues about route changes and detours. Shannel used phone navigation to facilitate their bus exchange, while Joyce described saving "about half an hour" by using a traffic app to reroute, expressing frustration with the "15-20 minute" delay in traffic updates from control. Cell phones were also critical in emergencies, acting as fallback options during radio breakdowns and being regarded as more dependable than radios. Sophia and Vivian likened contacting control to "a luck of the draw" or "50-50 chance," with Bridgette recalling how they called 911 instead of transit police for a passenger emergency where "every second counts." Cell phones were also used to document dangerous passenger behavior. However, restrictions on phone use created tension. Operators faced challenges when unable to leave their seats or when cell signals were weak, and disciplinary policies penalized phone use. Despite these discretionary service-related uses of mobile phones, transit agencies may enforce zero-tolerance policies or blanket bans, to avoid liability and comply with legislation against distracted driving [43] and NTSB recommendations to disallow both hand-held and hands-free mobile phone use [21]—even when the vehicle is temporarily stationary (e.g., at a bus stop, while idling). Hailey noted month-long suspensions for phone use, while John criticized the reliance on outdated MDTs and handsets, contrasting them with personal devices that offered "more detailed and accessible resources." They described these policies as "unfair," reflecting systemic gaps where operators strove to meet passenger needs but lacked adequately maintained or integrated tools.

5.2 Passenger-Facing Technologies

Malfunctioning passenger-facing technologies directly shape operator labor. Included in this category are fare machines, announcement systems, stop signals, HVAC, and accessibility tools. These sites of hardware and software malfunctions, poor design choices, and cascading failures increase operator cognitive and emotional burden, force operators into additional roles as mediators, and present bodily risks for passengers and operators alike.

5.2.1 Communication Systems. Announcement, display, and bell systems support passengers—particularly those with visual or hearing impairments—by delivering real-time information in accessible formats. For operators, these systems ease cognitive demands by offloading routine communication and minimizing passenger confusion. Calvin noted, "Four riders with visual impairments boarded my bus at the same stop, and so I was glad that my overhead announcer was working properly to keep them informed of the bus location... We are able to manually announce the stops as well, but it is nice to have that variable, and distraction, removed from our list of things we have to focus on."

Breakdowns in communication systems create significant challenges by forcing operators to provide manual input, increasing their cognitive load and the risk of conflict with passengers. Amelia reported, "too often, the bell chimes when NOT pushed, then won't chime when the passengers push it," describing how this malfunction, coupled with the Stop Requested sign being positioned behind the driver, resulted in them being yelled at and blamed for missing a stop. The problem lasted for 8 hours. These failures lead to unnecessary stress, delays, and, at times, strained interactions between operators and passengers when the system's broken affordances mismatch riders' expectations.

5.2.2 Fare Payment Systems. Fare payment systems encompass cash, tap-enabled cards, mobile apps, and machine-issued tickets, performing essential functions like processing payments and printing transfers. Many operators noted liking these systems relative to older methods (a notable departure from Pritchard et al.'s findings [47]), but also described fareboxes rejecting wrinkled bills, failing to process tap payments, or going offline entirely. We identified 44 operators who documented problems with their fare equipment in their diary entries. For instance, Carlos described how a farebox first stopped accepting tap cards (versus bills/coins) and eventually froze—delaying their second trip and prompting them to let passengers ride for free to keep service moving.

Design and placement flaws exacerbate these challenges. To address confusion caused by a malfunctioning, passenger-facing card reader, Owen placed a garbage pail in front of it as a signal. Amelia recounted a situation where a farebox, left full for a week, nearly led to a conflict when a customer attempted to take money from it. Brian explained how QR scanning can fail due to environmental factors like bright sunlight and passenger difficulties with proper phone alignment or screen brightness.

These failures are not just technical but behavioral—with operators fielding confusion from passengers unfamiliar with tap-to-pay rules (e.g. out-of-town passengers), delayed charges, or lack of change. Operators often mitigate these challenges by troubleshooting issues themselves, providing free rides to prevent delays or conflict, and offering guidance to passengers on system use–preserving trust, continuity, and service. For instance, Oliver assisted a passenger confused about the underpayment status of their tap card and offered a free ride, hoping their small action helped the individual better navigate the system. Yet, failures in fare payment systems can lead to delays, inaccessible payment methods, passenger frustration, and even violence—fare disputes are a leading cause of conflicts between passengers and operators [42].

5.2.3 HVAC System Failures and Passenger Experience. We identified 36 operators who reported HVAC (Heating, Ventilation, and Air Conditioning) issues on their buses in their diary entries. Gabriel described having functional air conditioning only "ten out of 30 days," despite rarely being assigned the same bus. They attributed this to their company's financial struggles, with "not enough buses to replace the fleet… a lot of breakdowns," and "running with a skeleton crew" due to COVID-related absenteeism.

Notably, HVAC performance also influenced passenger behavior. Operators noted that in hot weather, some passengers rode the bus to escape the heat, while others chose buses based on functioning air conditioning or heating; operators likewise mentioned opting to manage buses with other malfunctions if they had functioning air conditioning or heat. Subpar HVAC systems could force an otherwise functional bus out of service, impacting passenger loads, workload, and system delays. Even when the bus remained in service, both operators and passengers faced discomfort. Miles described the AC not working during a heat wave, Steve described having no heat on their bus in 11° F weather, while Samir described having an achy body after enduring an unheated bus. Julia highlighted how layover area regulations against idling led to 15–25 minute waits for passengers in the cold, compounding the issue.

Operators often faced passenger complaints over temperature control, despite having little control over HVAC systems. John explained how unseasonably warm weather could make buses radiate heat, and passengers wrongly believed operators controlled the temperature, sometimes accusing them of making the bus intentionally uncomfortable. John clarified, "Heat is generally under the bus hood. It is not accessible to the bus operator." Seasonal temperature swings further heightened tensions, with John noting, "Waiting for a bus patiently in the cold does not put smiles on people's faces." These dynamics highlighted the disproportionate burden operators bore for system shortcomings—extending findings about misattribution of blame in other aspects of bus operations [23] and other human-robot systems [18].

5.2.4 Accessibility Equipment Failures. While accessibility tools like ramps, lifts, and wheelchair straps are meant to enable equitable transit, operators' accounts reveal a persistent gap between design assumptions and operational reality. We identified 28 operators who documented problems with their accessibility equipment in their diary entries. Operators frequently reported facing failures like stuck ramps and straps, compounded by design flaws that poorly accommodated diverse mobility devices or required manual intervention. Calvin found it "frustrating" and "embarrassing" when a passenger couldn't board due to equipment failure. Phebie called for wider lifts and doorways, noting "there's no room for error," while William recounted a wheelchair user nearly tipping off a ramp.

The equipment failures described by operators often undermined passenger autonomy while shifting the challenge onto operators to use their expertise to balance passenger needs, safety, and accountability. Andrew described a passenger unable to secure their wheelchair due to stuck straps, and Rachel criticized a locking strap design that prevented users from strapping in independently, saying, "They hate it. I don't blame them." These issues also increased risks for operators. Daphne noted, "If straps are not secure and a customer falls, that's on the bus operator." Randy and Andrew described breaking policy by leaving their seat to assist passengers with ramps that were too steep or narrow, citing risks of injury or unsafe traffic conditions. Noah wrestled with helping passengers without straining themselves, and Amelia highlighted dangers of exiting the bus in traffic to assist riders.

Even functional equipment caused delays due to slow operation or inconsistent designs. Andrew noted a new harness system that delayed scheduling when, as Benjamin summarized, "Seconds mattered." Delays often cascaded, with Noah explaining how, "Getting stuck behind buses deploying their ramp caused delays." When failures occurred, operators often troubleshot creatively. Miles, for example, used "creative mechanical maneuvers" to address a ramp failure in preparation for a hospital run. These accounts show that maintaining accessibility is often sustained through the adaptive and relational labor of operators rather than resilient infrastructure.

5.3 Bus Mechanics and Operations

In contrast to high-level discussions of bus automation or electrification, operators' accounts reveal the ongoing fragility of physical systems—including engines, doors, operator controls, sensors, and current deployments of new battery-electric buses. These failures of mechanical degradation and poor system integration not only disrupt operations and undermine efficiency, safety, and service;

but also shift the burden of maintaining functionality onto operators. When mechanical endurance doesn't adequately reside within existing infrastructure, operators must assess, adapt, and triage in motion. Notable across this section are the unique urgency, lack of alternatives, and bodily risk presented by mechanical breakdowns. The acuity of these incidents demand at times high-stakes decision-making that differs from the slower accumulation of strain discussed in other sections.

5.3.1 Engine, Braking, and Safety Risks. Transit operators noted facing persistent mechanical issues, including engine failure, coolant leaks, and sudden shutdowns, which critically jeopardized safety and operations. We identified 45 operators who documented a bus breakdown or needed to exchange their bus in their diary entries. Randy recalled weeks where "half of the days I've worked, I've driven a bus off the lot that I needed to swap out and call back in for some particular mechanical issue." Bus swaps may fail to resolve issues—such as when Andrew received a replacement bus with a broken radio after returning one with faulty alarms. In another case, Parm transferred passengers twice during a rainstorm due to a coolant problem and foggy windshields, saying, "It was exhausting to jump from one bus to another."

Operators further reported having to adapt to braking and performance issues in older buses. Benjamin recounted compensating for fading brakes on an aging bus by creating extra stopping space, slowing schedules. Emma, considering peak morning hours, handled poor braking by adaptively putting the bus into lower gear and continuing the route, stating, "If I felt I was dangerous, I would [have] stopped driving and had a coach change." Even after reporting issues, operators described managing until help arrived. Bethany described driving cautiously after reporting faulty brakes and a non-working horn: "I kept the bus in service and just took my time and used extreme caution until [a replacement] arrived."

Critically, mechanical problems can escalate into hazardous situations. One alarming incident involved Kyler, who documented an engine fire and reported, "My transit authority encourages us to put out the fire, putting us at risk!" Andrew highlighted another concern, recalling that the first bus they attempted to use had a jammed fire extinguisher box, emphasizing the critical importance of equipment readiness in emergencies. Benjamin reported driving a bus that lost the ability to accelerate and began rolling backward on hills. George described a bus that "died on me on the freeway," while Nadia described maneuvering to the side of the road after a coolant leak caused their bus to fail. These incidents strain operators' interactions with passengers. Hannah explained, "When things break down and it's not the norm for passengers, you can tell they panic… asking lots of questions about timing points and [if] the bus is still continuing."

Proper resolution in cases of mechanical breakdown was a persistent concern among operators. Bridgette recounted being instructed to park a bus back with the fleet despite unresolved transmission warnings after attempted repair by maintenance staff. Similarly, Tamika described regular issues with dashboard warnings, stating, "Maintenance came out, checked it, did what they did. It continued throughout the day. Of course, they wanted me to continue to roll." These failures abruptly shift operators from routine service into emergency decision-making and improvised system management—without the same level of structure or support common in other high-reliability transportation contexts.

5.3.2 Structural Defects, Door Issues, and Operational Strain. Operators consistently reported structural and material defects in buses that compromise safety, functionality, and comfort for both passengers and drivers. Joyce described driving with a windshield crack that stretched "from one side to the other"—explaining how windshield problems were especially common in double-decker buses, perhaps due to improper fitting. When the issue was reported, Control Center instructed them to keep driving because no replacement buses were available. John recounted how during rainy weather, their "bus leaked like Niagara Falls! Water was dripping out of the radio and onto my hands and legs." Shannel described how their "rear door never wanted to close," requiring them to "pop the parking brake and put the bus in neutral," a tedious workaround that delayed schedules and went unreported. Jessica highlighted how the back door on 60-foot buses "took an extra 30 seconds to close," accumulated into significant operational delays. Similarly, Andrew recounted an "issue with my backdoor opening and closing" that required transferring passengers onto another bus, exacerbating construction delays.

Operators described triaging these failures based on urgency, safety, and passenger needs–making decisions about whether to troubleshoot independently versus seeking assistance to manage service disruptions and operational expectations. Phebie shared how stuck front doors required a supervisor's help, delaying their trip and adding strain on other buses. Rachel detailed the "tricks we used, turning the air valve above the door off and on, restarting the bus, even kicking the hinge," to fix door malfunctions. They spent 1.5 hours catching up after losing 10 minutes to these efforts, emphasizing how "no one wanted to bring a bus to their relief late and make them start the work already down on time. Very bad form."

The consequences of these systemic issues extend beyond discomfort into safety. Andrew described poles from the ceiling of their bus sticking out over passenger seating. Emma mentioned how during a pre-trip, they "noticed axle lug nuts missing off the tire" and had to get a new bus. However, not all issues may be identifiable during pre-trip: Patricia gave examples of how hitting potholes in the road caused windshield and farebox malfunctions, how issues with mirrors may not be apparent until operation, and how mechanical stress from passenger use may damage equipment en route, such as the bell cord. Bridgette illustrated this with an account of being assigned a bus with dented panels, compromised locks, and broken hinges. When they refused to drive it, a supervisor attempted a makeshift repair using zip ties and scissors, dismissing concerns by stating, "This bus been out here all day." Reflecting on this, the operator stated, "This should not be a supervisor's job to assess a bus," underscoring systemic lapses in safety oversight and accountability.

5.3.3 Sensor Systems and Alarms. Though sensor and alarm failures may not entail the same immediate threat of bodily harm as issues delineated above, they may compromise operators' situational awareness or ability to respond to real mechanical risk. Several operators noted recurring sensor malfunctions in particular vehicle models. John noted that “double deckers are notorious for having sensor troubles, where it'll tell you that an engine compartment door's open, or a fuel cap door's open.” Joyce mentioned that “one of the unpleasant sensors is the doors in the back for the engine… if the sensor is the slightest bit dirty, it will come off on your dash… it's a flashing light with an audible alarm because it's a WARNING WARNING WARNING.” Randy relates how they mistakenly set off an alarm, due to its proximity to windshield wipers knobs, causing passengers to start “screaming and freaking out” while they pulled through a major intersection during rainy weather. Claire described how the introduction of a new fluid monitoring device to their old bus (409,000 miles) broke the electrical system on the bus. Andrew described how the newer buses at their garage generally seemed to have lots of different sensor issues, like alarms that buzzed all day. In response, Andrew said that they “kind of learn to ignore it" and internalize “that one isn't real. They told me it's not real…'” Similarly, Oliver mentioned learning from experience when it's safe to reset the bus to clear weather-induced false alerts and continue driving. As with other unreliable systems, operators have found ways to adapt; however, the normalization of faulty sensor systems may be particularly dangerous by undermining operators' ability to detect and respond to genuine threats.

5.3.4 Challenges with Electric Buses. Electric buses, increasingly introduced to transit fleets, offer a case study in the deployment of new technologies in existing bus infrastructure. Operator experience suggests that new electric buses, despite promises of sustainability and innovation, frequently introduce maintenance and performance challenges that mirror or intensify those of existing fleets. Operators surfaced a variety of issues around electric bus design, maintenance, and operational performance, which operators attribute to poor design decisions, fleet integration, and lack of maintenance, in part driven by staffing shortages. Of the 13 operators who mentioned operating electric vehicles in their diary entries, 12 surfaced operational problems. These failures highlight missed opportunities for collaborative, operator-informed design that could improve efficiency, safety, and the experience of both passengers and drivers—while supporting more durable and sustainable transitions, progress, and continued operations. As Randy summed up, “the people that are creating these technologies…. Are like, kind of contorting people into them… they've never used it before.”

Operators surfaced various maintenance and design issues analogous to the kinds they encounter with non-electric buses—leaving operators to address dysfunction. Mia described an “endless maintenance issue" on a new electric bus with persistent alarms and electrical warnings, which ultimately required removing the bus from service and reporting to maintenance. At times, operators employed their expertise to attempt fixes while managing the consequences. Caleb restarted their bus to clear a beeping shutdown warning, delaying their departure. David described a battery electric bus where “when you hit the brake, the air system that controls the pressure for the braking system would leak.” They called Control, who told them to continue despite the operator's protest about the high possibility of an accident. David managed to get back safely to the yard and the mechanics by figuring out a way to “engage the pedal” to “lock the wheels and lock the motors” so “air wouldn't leak out the back axles.” However, not all troubleshooting attempts may work: Nancee recounted how, after a routine shutdown during a malfunction, a new electric bus unexpectedly took off with passengers onboard–hitting four cars in the process.

Other times, reporting to maintenance for assistance may not solve the issue either. Tamika described issues with the “check engine, stop engine, check system” that continued throughout the day despite maintenance coming out for an inspection and problems with electrical buses “shutting down for no reason.” Randy surfaced compounding maintenance issues resulting from integrating new buses into fleets with existing maintenance backlogs. Their agency has “a bunch of new electric buses you know, which are nice,” but “on the maintenance… they're dealing with the same thing… they're short staffed, and they're dealing with such a high volume of trying to keep these buses operational, but they're pretty beat up.” Vivian called for “bringing training in-house… [so] these mechanics can know how to fix these new [articulated and electric] buses,” but surfaced that there's “the shortage of employees everywhere.”

Among mechanical issues, operators primarily surfaced concerns around charge/range issues and their consequences—elevating how innovation may outpace the infrastructural and human capacity required to sustain it. Andrew said they were “assigned an electric bus for the 2nd part of my shift today; none of the electric buses that I could have driven were charged enough. Which made me waste time going through all the different buses.” Rachel worried their charge levels would “run so low I would have to road call the bus. (Have OPS send me a different one)." Parm worried about increased electrification of fleets without the “kind of infrastructure that would support these electric buses. Just because they have to be charged at every end, I was running at least half an hour late causing inconvenience not only to the passengers but my fellow operator.” Mia echoed, “they keep adding these rapid transit routes... they can't even charge the [electric] buses.”

Like non-electric buses, electric vehicles are vulnerable to environmental conditions—yet these challenges expose underlying design assumptions misaligned with actual environmental demands. Several operators reported challenges during inclement weather. Tamika, for instance, stated that electric buses at their garage “have issues every time it rains really hard.” Amelia mentioned that their electric bus “doesn't detect water” in a city that “floods really easily.” Jose, working in a city with FEMA high-risk flooding zones, explained that “for electric vehicles, if there's a problem with the battery, the bus just won't move. The battery is supposed to be sealed, but since it's underneath the bus, if you encounter flooding, you'd better hope it's completely sealed, or you'll get stuck.” Debbie questioned the decision to purchase and use electric buses “that don't work… in a -35 [degree] winter city” compared to diesel buses, while David reported that “in the morning my fully electric bus did not have a heater.” These accounts highlight operator experiences of how weather-related issues, particularly flooding and extreme cold, can significantly affect the performance and reliability of electric buses. Overall, operator experiences suggest that the environmental complexities of different regions should be taken into account when designing and implementing new technologies for buses.

6 DISCUSSION

The preceding sections detail a transit system at the brink—where breakdowns in communication, fare payment, accessibility tools, and bus mechanics are not exceptional but routine. In the midst of this instability, it is bus operators who hold the system together. Their diary entries and interviews reveal not only the frequency and severity of technical failures but also the adaptive practices that keep transit running in the absence of reliable infrastructure or adequate support. This section reflects on the broader implications of these findings for technology design, maintenance, and public sector innovation. Specifically, we explore how operator responses to failure challenge dominant logics of automation and innovation that assume seamless integration, and instead point toward a need for design that supports infrastructural endurance, repairability, and worker-informed adaptation. By situating operators as both users and sustainers of transit technologies, we offer a reframing of resilience—less as a property of technology alone, and more as a product of human labor and organizational conditions.

6.1 Designing for Infrastructural Endurance

As forms of infrastructure, transportation systems are not merely built and left to function; they require constant attention to prevent failure and to manage breakdowns when they occur. From traffic management systems to safety protocols, layers of expertise and oversight form the backbone of these networks. Yet, as operators' accounts reveal, the endurance of transit technologies is too often maintained through a patchwork of temporary fixes and individual improvisation rather than robust systemic strategies. While the public often takes transportation systems' reliability for granted, the reality is far more precarious. The corrosion, fatigue, and breakdown of infrastructure exposes its vulnerability, with each failure accumulating "accretions"—evidence of ongoing repairs, expansions, and adaptations [4]. These processes of decay and renewal are essential for infrastructural endurance, yet they remain largely invisible [34].

Bus operators' lived experiences bring the instability of infrastructure into sharp relief. Operators' adaptive strategies in response to malfunctions—using personal cell phones during radio failures or deploying manual solutions for inadequate wheelchair ramps—underscore their critical role in sustaining transit systems. These responses illustrate a broader truth about infrastructure: its functionality often hinges not only on the systems themselves but also on the human labor that supports them [41, 68]. This work is not easy. Constantly having to respond to failures places a considerable mental burden on operators. This burden compounds the complexity of their already demanding tasks and becomes a psychosocial hazard, contributing to job stress and fatigue [65, 66].

Operators navigate infrastructure that is simultaneously an "engine and barrier for change" [59]. On one hand, technologies like MDTs provide critical tools for managing transit. On the other, their frequent malfunctions add layers of complexity, with operators forced to absorb the operational strain. This tension mirrors broader systemic challenges: while investments often prioritize new technologies, the existing systems they depend on are neglected, undermining both current operations and future innovations [25]. Furthermore, new technologies can interact in unexpected ways with existing systems and human processes, potentially leading to degradation in service or stress for operators, similar to previous findings by Pritchard et al. around location-based services [46] and digital payment systems [47]. However, where Pritchard et al. emphasize concerns from drivers about surveillance and increased managerial control [46], we find that bus operators often feel abandoned to deal with a normalized state of disrepair.

These accounts complicate calls for more robust or repairable technologies. While our findings suggest that designing for repairability could alleviate some of the friction operators currently face, they also reveal a deeper ambiguity: who is expected to carry out these repairs? Many operators do not view maintenance as part of their job mandate, nor are they trained or compensated accordingly. Calls for repairability and system longevity must therefore be accompanied by commitments to appropriate labor arrangements. Without investment in maintenance teams, training, and institutional support, "repairable" design risks becoming a hollow gesture—offloading responsibility onto workers already stretched thin. Thus, when we advocate for infrastructural endurance, we are not simply arguing for reduced technological obsolescence or the durability of materials alone. We are calling for greater alignment between design practices and labor conditions—ensuring that resilient systems are backed by resilient institutions. Endurance requires not only hardware that can last, but also care infrastructures that can sustain both systems and workers over time.

However, these insights are frequently overlooked in favor of experimenting with unproven models. The push to introduce automation [3], for example, proceeds without addressing the structural breakdowns in legacy systems. This approach risks exacerbating the very vulnerabilities it seeks to solve. Instead, understanding transportation infrastructure as a process rather than a product shifts attention to the second-order systems essential for its endurance. The expertise required to monitor, maintain, and repair transit systems forms an often-invisible layer of resilience. Yet, as operators' experiences demonstrate, this resilience is increasingly strained by understaffed maintenance teams, aging fleets, and a lack of investment in foundational systems [19, 25]. What, instead, if we took seriously the duty to uphold existing infrastructures? By prioritizing repairability and attending to the breakdowns revealed by operators, we could foster innovations grounded in the realities of transit operations. Designing resilient transit systems is necessarily about ensuring the well-being of those who operate them.

6.2 From Ad Hoc Solutions to Resilient Design

Focusing on the temporality of transit infrastructure—recognizing that even the most well-designed systems inevitably experience wear and breakdown—opens up new ways to understand the importance of maintenance and repair. Operators' accounts reveal persistent gaps in system design, pointing to opportunities where small, targeted improvements could greatly enhance a system's ability to cope with stress. Their workaround practices—taping handwritten destination signs, using personal phones during radio failures, assisting passengers with malfunctioning fare or ramp systems—demonstrate not passive acceptance, but skilled adaptation. Despite policy prohibitions, many operators rely on personal devices to access information, locate detours, assist passengers, or contact dispatch. These accounts show how operators stitch together fragmented or failing systems in real time, echoing Vertesi's notion of "seams" in infrastructure that must be negotiated and aligned through human labor [67].

Aging infrastructure then contains not only liabilities, but wisdom. Operators develop rich, embodied heuristics for navigating faulty equipment and inconsistent service. Their situated knowledge, often dismissed as informal or idiosyncratic, is in fact a critical asset for designing with infrastructure [62, 67]. Supporting operators' situated knowledge means treating their improvisations as design resources [64]. By tracing these adjustments, designers can identify intervention points that resonate with existing practices rather than impose top-down solutions.

We frame this capacity as resilient design: the practice of enabling systems to adapt, recover, and continue functioning amid disruption. Unlike robustness, which aims to eliminate failure altogether, resilience embraces failure as a given and emphasizes how sociotechnical systems respond and reorganize. Designing for resilience means building tools that support rather than obstruct this labor. For example, fallback communication channels, modular hardware, or operator-ready signage kits could formalize improvisational strategies without overburdening drivers.

But resilience is not an unqualified good. It can be weaponized to justify underinvestment—what Dekker calls a "drift into failure," where systems survive only because frontline workers continually stretch themselves to compensate [16]. Many operators describe working in a normalized state of disrepair, where nothing is fully broken, but few systems work reliably. In this context, resilience risks becoming a euphemism for neglect. Crucially, the burdens of resilience are also uneven. What might feel like a minor inconvenience to dispatch may impose chronic stress on a driver navigating inclement weather, vehicle defects, and unpredictable passenger needs. This asymmetry calls for participatory design processes that take labor dynamics seriously. Incorporating operator expertise is not only a matter of better design, but of accountability.

Our findings also suggest that resilience is inseparable from sustainability. While municipalities adopt electric buses under climate mandates, operators report that these transitions often stall amid insufficient charging infrastructure, poor weather tolerance, and limited mechanic training. Sustainable transit, then, is not just about propulsion systems or emissions reductions—it requires sustainable working conditions and robust maintenance support.

This view aligns with ongoing DIS conversations about designing with, rather than replacing, infrastructure [58]. Especially in public transit, where redesigns are incremental and rarely comprehensive, engaging with legacy systems enables repair, extension, and co-adaptation. Resilient design, therefore, is not a technical patch or a universal fix. It is a relational practice-a commitment to aligning technologies with institutional care, labor protections, and long-term investment. Attending to breakdown not just as failure but as a site of ingenuity opens the door to more grounded and enduring forms of innovation.

7 CONCLUSION

This research sheds light on the crucial, yet often overlooked, role of bus operators in sustaining transit systems amidst technological and mechanical failures. By centering operators' experiences, we have sought to expose the vulnerabilities within existing transit infrastructure, where breakdowns across a variety of digital and physical operator-facing, passenger-facing, and bus mechanical systems compromise safety, efficiency, and worker well-being. Operators' adaptive strategies, such as developing creative workarounds for malfunctioning equipment, underscore their resilience but also reveal systemic gaps in technology design and maintenance. As the transit industry accelerates its adoption of new technologies, including electrification and driver-assistance systems, our findings highlight the importance of integrating operator insights into design and implementation processes. Neglecting foundational systems and the lived realities of frontline workers risks amplifying existing challenges and undermining the potential of new innovations. We call for a recalibration of priorities in transportation planning and computing research. Rather than viewing aging infrastructures as obstacles to be replaced, we should recognize their potential as foundations for adaptive and inclusive innovation. The lessons of infrastructural endurance invite us to envision a future where repairability is central to transit design. By attending to the breakdowns revealed through operators' accounts, we can prioritize systems that are not only functional but resilient, and acknowledge the critical labor of those who sustain these systems.

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References

[1] 2023. "Bus of the Future" Redesign of Transit Bus Operator Compartment to Improve Safety, Operational Efficiency, and Passenger Accessibility Program. https://www.transit.dot.gov/sites/fta.dot.gov/files/2023-07/External-Presentation-BCP-Bus-of-the-Future-Listening-Session.pdf Accessed: 2025-01-19.

[2] Federal Transit Administration. 2007. Useful Life of Transit Buses and Vans. https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/Useful_Life_of_Buses_Final_Report_4-26-07_rv1.pdf

[3] Hunter Akridge, Bonnie Fan, Alice Xiaodi Tang, Chinar Mehta, Nikolas Martelaro, and Sarah E Fox. 2024. "The bus is nothing without us": Making Visible the Labor of Bus Operators amid the Ongoing Push Towards Transit Automation. In *Proceedings of the CHI Conference on Human Factors in Computing Systems*. 1–16.

[4] Nikhil Anand. 2015. Accretion. https://culanth.org/fieldsights/accretion Society for Cultural Anthropology, Accessed: 2025-01-19.

[5] Ashratuz Zavin Asha, Sharifa Sultana, Helen Ai He, and Ehud Sharlin. 2024. "Shotitwo First!": Unraveling Global South Women's Challenges in Public Transport to Inform Autonomous Vehicle Design. In *Proceedings of the 2024 ACM Designing Interactive Systems Conference*. 3193–3209.

[6] American Public Transportation Association. 2023. Transit Workforce Shortage Synthesis Report.

[7] Shiri Azenkot, Sanjana Prasain, Alan Borning, Emily Fortuna, Richard E. Ladner, and Jacob O. Wobbrock. 2011. Enhancing independence and safety for blind and deaf-blind public transit riders. In *Proceedings of the SIGCHI Conference on Human*

Factors in Computing Systems (CHI '11). Association for Computing Machinery, New York, NY, USA, 3247–3256. doi:10.1145/1978942.1979424

[8] Andrew Barry. 2015. Discussion: Infrastructural Times. Society for Cultural Anthropology Fieldsights. https://culanth.org/fieldsights/discussion-infrastructural-times Accessed: 2025-01-19.

[9] Cynthia Bennett, Emily Ackerman, Bonnie Fan, Jeffrey Bigham, Patrick Carrington, and Sarah Fox. 2021. Accessibility and the crowded sidewalk: Micromobility's impact on public space. In *Proceedings of the 2021 ACM Designing Interactive Systems Conference*. 365–380.

[10] Kelly Blynn and John Attanucci. 2019. Accelerating bus electrification: A mixed methods analysis of barriers and drivers to scaling transit fleet electrification. *Transportation Research Record* 2673, 8 (2019), 577–587.

[11] Kathy Charmaz. 2006. *Constructing grounded theory: A practical guide through qualitative analysis*. sage.

[12] Jason Clayworth. 2025. Des Moines transit scraps entire electric bus fleet. *Axios Des Moines* (8 apr 2025). https://www.axios.com/local/des-moines/2025/04/08/desmoines-transit-scraps-electric-bus-fleet Accessed on 2025-04-17.

[13] Marisa Leavitt Cohn. 2016. Convivial decay: Entangled lifetimes in a geriatric infrastructure. In *Proceedings of the 19th ACM conference on computer-supported cooperative work & social computing*. 1511–1523.

[14] Marisa Leavitt Cohn. 2019. Keeping software present: Software as a timely object for STS studies of the digital. *DigitalSTS: A field guide for science & technology studies* (2019), 423–446.

[15] Michael Crumb. 2025. DART scraps electric bus program. *Business Record* (April 2025). URL: https://www.businessrecord.com/dart-scraps-electric-bus-program/ (accessed: 2025-04-22).

[16] Sidney Dekker. 2016. *Drift into failure: From hunting broken components to understanding complex systems*. CRC press.

[17] Henrik Detjen, Irawan Nurhas, and Stefan Geisler. 2021. Attitudes towards autonomous public transportation. In *13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 62–66.

[18] Madeleine Clare Elish. 2019. Moral crumple zones: Cautionary tales in human-robot interaction (pre-print). *Engaging Science, Technology, and Society (pre-print)* (2019).

[19] Chris Van Eyken. 2022. Developing Transit Talent Pipelines. https://transitcenter.org/publication/developing-transit-talent-pipelines/ The author thanks Stephanie Lotshaw, Mary Buchanan, Midori Valdivia, Patricia Greenfield, David Stephen, Douglas Nevins, Andrew Gena, Eliseo Acosta, Brian Sherlock, David Roscow, Julian Guiterrez Joseph Mestas, Rich Diaz, Avninder Khaira, Craig Cipriano, Jess Guerra, James Hall, and Laurel Paget-Seekins for their contributions. Accessed: 2025-01-19.

[20] Juan F. Maestre, Tawanna Dillahunt, Alec Andrew Theisz, Megan Furness, Vaishnav Kameswaran, Tiffany Veinot, and Patrick C. Shih. 2021. Examining mobility among people living with HIV in rural areas. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. 1–17.

[21] Federal Motor Carrier Safety Administration. 2012. Mobile Phone Restrictions Fact Sheet. https://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/Mobile_Phone_Rule_Fact_Sheet.pdf. Accessed April 20, 2025.

[22] Federal Transit Administration. 2025. 49 U.S.C. §5339(c). https://www.transit.dot.gov/lowno Infrastructure Investment and Jobs Act (IIJA) §30018, IIJA Division J, Low or No Emission Grant Program.

[23] Mark D Fleming. 2016. Mass transit workers and neoliberal time discipline in San Francisco. *American Anthropologist* 118, 4 (2016), 784–795.

[24] Lukas A Flohr, Martina Schuß, Dieter P Wallach, Antonio Krüger, and Andreas Riener. 2024. Designing for passengers' information needs on fellow travelers: A comparison of day and night rides in shared automated vehicles. *Applied Ergonomics* 116 (2024), 104198.

[25] Yonah Freemark and Lindiwe Rennert. 2023. Surmounting the Fiscal Cliff. https://www.urban.org/research/publication/surmounting-fiscal-cliff Accessed: 2025-01-19.

[26] Jon Froehlich, Tawanna Dillahunt, Predrag Klasnja, Jennifer Mankoff, Sunny Consolvo, Beverly Harrison, and James A. Landay. 2009. UbiGreen: investigating a mobile tool for tracking and supporting green transportation habits. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, Boston MA USA, 1043–1052. doi:10.1145/1518701.1518861

[27] Michael Glotz-Richter and Hendrik Koch. 2016. Electrification of public transport in cities (Horizon 2020 ELIPTIC Project). *Transportation Research Procedia* 14 (2016), 2614–2619.

[28] Christopher R Henke and Benjamin Sims. 2020. *Repairing infrastructures: the maintenance of materiality and power*. Mit Press.

[29] Erik Hollnagel and David D. Woods. 2005. *Joint Cognitive Systems: Foundations of Cognitive Systems Engineering*. CRC Press.

[30] Erik Hollnagel, David D. Woods, and Nancy Leveson. 2006. *Resilience Engineering: Concepts and Precepts*. Ashgate Publishing.

[31] Lara Houston, Steven J Jackson, Daniela K Rosner, Syed Ishtiaque Ahmed, Meg Young, and Laewoo Kang. 2016. Values in repair. In *Proceedings of the 2016 CHI conference on human factors in computing systems*. 1403–1414.

[32] Jinuk Hwang, Wei Li, Laura Stough, Chanam Lee, and Katherine Turnbull. 2020. A focus group study on the potential of autonomous vehicles as a viable transportation option: Perspectives from people with disabilities and public transit agencies. *Transportation research part F: traffic psychology and behaviour* 70 (2020), 260–274.

[33] Steven J Jackson. 2014. Rethinking repair. (2014).

[34] Steven J. Jackson. 2016. Speed, Time, Infrastructure: Temporalities of Breakdown, Maintenance, and Repair. In *The Sociology of Speed: Digital, Organizational, and Social Temporalities*. Oxford University Press. doi:10.1093/acprof:oso/9780198782858.003.0012 arXiv:https://academic.oup.com/book/0/chapter/157284502/chapter-ag-pdf/44943992/book_9939_section_157284502.ag.pdf

[35] Ju Yeon Jung, Tom Steinberger, John L King, and Mark S Ackerman. 2021. Negotiating Repairedness: How Artifacts Under Repair Become Contingently Stabilized. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW2 (2021), 1–29.

[36] Miltos Kyriakidis, Joost CF de Winter, Neville Stanton, Thierry Bellet, Bart van Arem, Karel Brookhuis, Marieke H Martens, Klaus Bengler, Jan Andersson, Natasha Merat, et al. 2019. A human factors perspective on automated driving. *Theoretical issues in ergonomics science* 20, 3 (2019), 223–249.

[37] Hsinju Lee, Fang-Hsin Hsu, Wei-Ko Li, Jie Tsai, Ying-Yu Chen, and Yung-Ju Chang. 2023. Get Distracted or Missed the Stop? Investigating Public Transit Passengers' Travel-Based Multitasking Behaviors, Motives, and Challenges. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems*. ACM, Hamburg Germany, 1–14. doi:10.1145/3544548.3581391

[38] Carina Manger, Anna Preiwisch, Chiara Gambirasio, Simon Golks, Martina Schuß, and Andreas Riener. 2023. We're in This Together: Exploring Explanation Needs and Methods in Shared Automated Shuttle Buses. In *Proceedings of the 22nd International Conference on Mobile and Ubiquitous Multimedia*. 145–151.

[39] Nikolas Martelaro, Sarah E Fox, Jodi Forlizzi, Raj Rajkumar, Chris Hendrickson, and Stan Caldwell. 2022. How to Make Sense of Bus Transit Automation? Considerations for policy makers on the future of human-automation teaming in the transit workforce. *Traffic21: A transportation research institute of Carnegie Mellon University, Pittsburgh, PA* (2022).

[40] Sofia S Martinez and Constantine Samaras. 2024. Electrification of transit buses in the United States reduces greenhouse gas emissions. *Environmental Science & Technology* 58, 9 (2024), 4137–4144.

[41] Shannon Mattern. 2018. Maintenance and Care. *Places Journal* (November 2018). https://placesjournal.org/article/maintenance-and-care/?msclkid=7ef26afed03911eca225af3c1d3b52f0&cn-reloaded=1 Accessed: 2025-01-19.

[42] Yuko J. Nakanishi and William C. Fleming. 2011. *TCRP Synthesis 93: Practices to Protect Bus Operators from Passenger Assault*. Technical Report. Transit Cooperative Research Program (TCRP). Consultants: Yuko J. Nakanishi, Nakanishi Research and Consulting, LLC; William C. Fleming, Massachusetts Bay Transportation Authority Police.

[43] National Transportation Safety Board. 2010. *Highway Accident Report: Multivehicle Collision, Interstate 44 Eastbound, Gray Summit, Missouri, August 5, 2010*. Technical Report NTSB/HAR-11/03, PB2011-916203. National Transportation Safety Board. https://www.ntsb.gov/investigations/AccidentReports/Reports/HAR1103.pdf Accessed April 20, 2025.

[44] Charles Perrow. 1984. *Normal Accidents: Living with High-Risk Technologies*. Princeton University Press.

[45] Washington Post. 2023. *Electric buses get billions in federal aid. A top maker just went bankrupt.* https://www.washingtonpost.com/transportation/2023/08/12/proterra-bankruptcy-electric-buses/

[46] Gary Pritchard, John Vines, Pam Briggs, Lisa Thomas, and Patrick Olivier. 2014. Digitally driven: how location based services impact the work practices of London bus drivers. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. 3617–3626.

[47] Gary Pritchard, John Vines, and Patrick Olivier. 2015. Your money's no good here: The elimination of cash payment on London buses. In *Proceedings of the 33rd annual ACM conference on human factors in computing systems*. 907–916.

[48] Gary W Pritchard, Pam Briggs, John Vines, and Patrick Olivier. 2015. How to drive a London bus: Measuring performance in a mobile and remote workplace. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. 1885–1894.

[49] Jens Rasmussen. 1997. Risk management in a dynamic society: a modelling problem. *Safety science* 27, 2-3 (1997), 183–213.

[50] Lindiwe Rennert. 2023. Assaults on Transit Workers Have Tripled in the Past 15 Years. Income Inequality and Societal Tensions Have Contributed. https://www.urban.org/urban-wire/assaults-transit-workers-have-tripled-past-15-years-income-inequality-and-societal Accessed: 2025-01-19.

[51] David Ribes and Thomas A Finholt. 2009. The long now of infrastructure: Articulating tensions in development. (2009).

[52] John Rieman. 1993. The diary study: a workplace-oriented research tool to guide laboratory efforts. In *Proceedings of the INTERACT'93 and CHI'93 conference on Human factors in computing systems*. 321–326.

[53] Alice Rollwagen, Martina Schuß, and Andreas Riener. 2023. Enhancing Accessibility for Diverse User Groups in Automated Shuttle Buses: Implications from a

User Enactment Study. In *Adjunct Proceedings of the 15th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 77–82.

[54] Oscar J. Romero, Alexander Haig, Lynn Kirabo, Qian Yang, John Zimmerman, Anthony Tomasic, and Aaron Steinfeld. 2020. A Long-Term Evaluation of Adaptive Interface Design for Mobile Transit Information. In *22nd International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, Oldenburg Germany, 1–11. doi:10.1145/3379503.3403536

[55] Daniela K Rosner, Steven J Jackson, Garnet Hertz, Lara Houston, and Nimmi Rangaswamy. 2013. Reclaiming repair: Maintenance and mending as methods for design. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*. 3311–3314.

[56] Martina Schuß, Chantal Himmels, and Andreas Riener. 2023. Development of a Perceived Security Scale for Shared Automated Vehicles (PSSAV) and its Validation in Colombia and Germany. In *Proceedings of the 15th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 52–62.

[57] Martina Schuß, Carina Manger, Andreas Löcken, and Andreas Riener. 2022. You'll never ride alone: Insights into women's security needs in shared automated vehicles. In *Proceedings of the 14th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*. 13–23.

[58] Vishal Sharma, Neha Kumar, and Bonnie Nardi. 2023. Post-growth human–computer interaction. *ACM Transactions on Computer-Human Interaction* 31, 1 (2023), 1–37.

[59] Susan Leigh Star and Karen Ruhleder. 1994. Steps towards an ecology of infrastructure: complex problems in design and access for large-scale collaborative systems. In *Proceedings of the 1994 ACM conference on Computer supported cooperative work*. 253–264.

[60] Susan Leigh Star and Anselm Strauss. 1999. Layers of silence, arenas of voice: The ecology of visible and invisible work. *Computer supported cooperative work (CSCW)* 8 (1999), 9–30.

[61] Stephanie B Steinhardt and Steven J Jackson. 2015. Anticipation work: Cultivating vision in collective practice. In *Proceedings of the 18th ACM conference on computer supported cooperative work & social computing*. 443–453.

[62] Lucy Suchman. 1995. Making work visible. *Commun. ACM* 38, 9 (1995), 56–64.

[63] Lucy A Suchman. 1996. Supporting articulation work.

[64] Lucille Alice Suchman. 2007. *Human-machine reconfigurations: Plans and situated actions*. Cambridge university press.

[65] Jan Sundquist and Sven-Erik Johansson. 2000. High demand, low control, and impaired general health: working conditions in a sample of Swedish general practitioners. *Scandinavian journal of public health* 28, 2 (2000), 123–131.

[66] John LM Tse, Rhona Flin, and Kathryn Mearns. 2006. Bus driver well-being review: 50 years of research. *Transportation research part F: traffic psychology and behaviour* 9, 2 (2006), 89–114.

[67] Janet Vertesi. 2014. Seamful spaces: Heterogeneous infrastructures in interaction. *Science, Technology, & Human Values* 39, 2 (2014), 264–284.

[68] Steven Vogel. 2024. Maintenance and the Humanness of Infrastructure. In *Maintenance and Philosophy of Technology*. Routledge, 39–57.

[69] Jacob L Wasserman, Allie Padgett, and Keenan Ky-An Do. 2024. Transit, Belabored: Issues and Futures forCalifornia's FrontlineTransit Workforce. (2024).

[70] WLOS. 2023. *Multi-million-dollar loss for Asheville as flawed electric buses sit idle*. https://wlos.com/news/alexa/5-million-loss-for-asheville-as-flawed-electric-buses-sit-idle-interim-transportation-director-jessica-morriss-maintenance-director-john-mcdaniel-proterra

[71] Carolyn Yu, Yee Li, Tsai-Yuan Huang, Wei-An Hsieh, Shao-Yu Lee, I-Hui Yeh, Gang Ku Lin, Neng-Hao Yu, Hsien-Hui Tang, and Yung-Ju Chang. 2020. BusMyFriend: Designing a bus reservation service for people with visual impairments in Taipei. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference*. 91–96.