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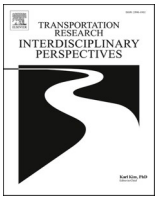

Equity and exclusion issues in cashless fare payment systems for public transportation

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ABSTRACT

Many transit agencies in the United States plan to automate their fare collection and limit–or even eliminate–the use of cash fares, with the goals of expediting boarding, collecting data, and lowering costs. Yet about 10% of US adults lack a bank account or credit card, and many rely on restrictive cellphone data plans or do not have access to the internet or a smartphone. These riders will find it difficult to access transit in the future. This paper examines transit users' experiences with fare technologies using a survey of riders in three cities. Our analysis reveals which riders are most at risk of being excluded, and how mitigation strategies could work to overcome barriers to cash-less transit. We find that a significant number of riders (~30%) currently use cash on-board buses. If on-board cash fares were to be removed, a significant share of these riders appear able to switch to other options, though many imagine they will continue to use cash in some way (e.g. at retail or ticket vending machines); a small number claim they would no longer be able to ride transit if on-board cash fares were removed. Older and lower-income riders are more at risk of exclusion as they often lack access to smartphones or the internet. A significant number rely on less dependable internet sources, such as public Wi-Fi, potentially inhibiting some from using smartphone and internet-based payment systems. Findings suggest approaches to reduce the number of riders excluded from transit during fare technology adoption.

1. Introduction

Rapidly-evolving payment technologies have motivated public transit agencies in the United States to adopt new fare payment systems (e.g. open payments and mobile ticketing applications) over the coming decade. New payment methods in transportation are far from isolated to transit; emerging autonomous, electric-powered, connected and shared mobility technologies and services – broadly classified as "smart mobility" systems – also rely heavily on these emerging payment systems. Such technological advances will likely streamline operations and make transit more convenient for many travelers. At the same time, however, travelers who cannot adopt these new payment technologies may be left behind. Previous research has examined equity implications of transit fare structures (Brown, 2018b; Farber et al., 2014; Nuworsoo et al., 2009), and barriers to technology-enabled modes like bikeshare and ride-hailing (Golub et al., 2019; Shirgaokar, 2020; Howland et al., 2017). Yet we know little about the intersection of technology and transit fares, particularly the potential equity and exclusion implications of replacing cash fares with technology-enabled transit fares.

This study explores, in the United States context, the challenges facing transit riders who lack access to pieces of this new payment "ecosystem" and potential solutions to ensure that a transition to cash-less transit fares does not exclude riders. The project asks: who is most at risk of being excluded by the transition to new fare payment systems and how would riders pay transit fares if cash payment options were reduced or eliminated? We answer these questions using intercept surveys of 2,303 US transit riders in Portland-Gresham, OR, Eugene, OR, and Denver, CO.

In the following sections, we explore existing research on emerging fare payment systems, as well as research on disparities in access to the

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various pieces of the new payment ecosystem, including credit and banking, Internet and smartphones. We then present qualitative and quantitative analyses used to investigate this topic, and conclude with a discussion of results and implications for policy and planning.

2. Prior research on fare payments and equity

Prior reviews of new fare payment systems identified at least two emerging models of fare collection. The first is referred to as *open payment systems*, where agencies accept payment via contactless bank cards at the gates in rail stations and upon boarding buses. This means that transit riders do not have to purchase a ticket or load a transit-only stored-value card before riding. Instead, the costs of their trips are billed to them via their debit card, credit card or other electronic payment account (Brakewood and Kocur, 2011; Wallischeck et al., 2015).

The second model of new fare payments is called *mobile ticketing*. Mobile ticketing systems enable riders to purchase tickets through an application (app) on their smartphones with a credit card, debit card, or other electronic payment. Agencies then have several validation options, such as visually inspecting the smartphone's app ticketing screen or scanning the app's ticketing barcode with a hand-held device (Brakewood et al., 2014; Georggi et al., 2017; Rahman et al., 2016).

The convergence of these two fare payment models has begun, where near field communications (NFC) technology on mobile phones can be used to "tap" smartphones (or similar devices like fitness trackers) at station gates or upon boarding buses to pay fares via *mobile wallets* (smartphone payment accounts linked to a credit card) (Wallischeck et al., 2015). Common examples include Apple Pay, Google Pay, Samsung Pay, Garmin Pay and Fitbit Pay (Marshall, 2019; Altstadt, 2019). Moreover, truly "open" payment systems have the flexibility to accept other forms of payment beyond contactless credit/debit cards and mobile wallets, which could include payment media such as contactless prepaid cards.

Adopting new fare payment technologies is expected to benefit both transit riders and agencies in terms of more flexible fares (Brakewood, 2010), lower fare collections costs, improved trip data, reduced dwell time, and improved integration between different agencies and systems (Brakewood, 2010; CH2M Hill, 2017). Beside these benefits, these new technologies allow agencies to introduce "fare capping" (where fares cap at the maximum for rides within a given period such as a day, week or month).

2.1. Trends towards the elimination of cash

Many merchants in the United States have sought to reduce cash collection and increasingly rely on various forms of electronic payments; however, this trend brings particular challenges for transit agencies that have diverse constituencies, especially equity concerns. Transit agencies planning to reduce cash acceptance were implementing a phased approach until the Covid-19 pandemic urged many to quickly eliminate cash-on-board payment. Before the pandemic, agencies such as DART (Dallas, Texas) partnered with PayNearMe to enable users to purchase transit passes using cash (while honoring fare capping protocols) at any PayNearMe network retailers such as 7-Eleven, ACE Cash Express, and Family Dollar (PayNearMe, 2016). TriMet in Portland, OR was gradually minimizing cash fares as they introduced their electronic fare system Hop Fastpass, which was a contactless physical card, but is also an app in their smartphone wallet. TriMet transit riders were able to pay for their fares using contactless credit/debit cards and shortly thereafter, Apple Pay, Google Pay, and Samsung Pay (Altstadt, 2019). Washington Metropolitan Area Transit Authority explored the effect of cashless fare payment on bus speeds through a study on Bus Route 79 (WMATA, 2019; Nelson, 2018). Perhaps the two most relevant examples of transit agencies going "cashless" occurred in 2021: the Big Blue Bus in Santa Monica, California conducted a 6-month long, system-wide cashless pilot program, and the Greater Dayton Regional Transit Authority (RTA) in Dayton, Ohio implemented a permanent cashless system on their bus system in late 2021 (Brakewood, 2022). More details on these industry examples and other relevant case studies - including a detailed discussion of advantages and challenges to introducing cashless systems - can be found in a forthcoming Transit Cooperative Research Program Synthesis (Brakewood, 2022). Even with the growing number of emerging fare collection systems and cash-collection workarounds through retail, few agencies are likely to end cash collection on board buses in the next decade (Brakewood, 2022).

2.2. Challenges to eliminating cash from fare payment systems

Transit agencies transitioning to cashless payment systems face several challenges. The first of course is the significant investment in new technologies, including investments in the back-end finance and revenue flow systems as well as new fare readers, ticket vending machines (TVMs) and other fare verification tools. Social equity issues, the focus of this study, are also significant. Transit agencies are concerned about meeting and exceeding civil rights and environmental justice directives both in rider engagement in these transitions, and also in the substantive ways riders benefit or are burdened by the significant changes. While this study focuses on these latter issues, we do not want to understate the importance of engagement and involvement as a key component of equity oriented practice. The next sections chronicle some of the key equity issues in new technology systems, which rely on direct linkages to banking and credit, along with Internet and smartphone access.

2.2.1. Underbanked and unbanked riders

The first obstacle to transitioning to cashless transit fares is how to serve unbanked and underbanked users, who have little or no access to banking services. The Federal Deposit Insurance Corporation (FDIC) defines *unbanked* households as lacking access to both a checking and savings account (Apaam et al., 2018). It defines *underbanked* households as households, though they have a checking or savings account, they have also used an alternative financial services product (in the previous 12 months) such as money orders, check cashing, international remittances, payday loans, refund anticipation loans, rent-to-own services, pawn shop loans, or auto title loans.

The FDIC national surveys of unbanked and underbanked households showed that the share of households which are unbanked nationwide has declined from 8.2% in 2011 to 5.4% in 2019 (FDIC, 2020, p. 12). The same study showed banking access is not equal across demographic groups. The FDIC concluded that unbanked rates were higher among lower-income households; less-educated households; Black, Hispanic, American Indian or Alaska Native households, disabled households, and households that have a more volatile income. Banking access also varied by age groups, with older adults more likely to be fully banked. The 2019 FDIC survey also asked about the reasons why unbanked households did not have a bank account. About half of unbanked households stated that they "Do not have enough money to keep in an account", which was the most common reason. The second most common reason was that they "don't trust banks", which account for almost one-third of unbanked households. The FDIC survey also found that use of Alternative Financial Services is much higher among unbanked households than banked households (FDIC, 2020, pp. 16–17).

Disparities in banking access are also found among transit riders. An older survey of 2,375 Chicago Transit Authority (CTA) riders showed that 80% were banked. However, similar to the nationwide trends, the study showed banked rates were significantly lower for lower income, younger and Black and Hispanic transit users (Brakewood, 2010, p. 73).

2.2.2. Digital divide

In addition to formal bank and credit access, new fare payment technologies often require access to smartphones, cell plans with data capabilities, and internet. A nationwide survey shows that, as of 2019,

81% of U.S. adults have access to smartphones (up from only 35% in 2011) (Pew, 2019). For transit riders specifically, research has shown that smartphone ownership for transit riders were similar or higher than the nationwide average for four out of the five agencies investigated (Windmiller et al., 2014). Smartphone ownership also varies by demographic group. One of the greatest disparities is around age, with only 53% for those 65 years old or older owning smartphones. Additionally, only 71% of people with annual incomes less than $30,000 own smartphones (Pew, 2019). No significant disparities in smartphone ownership levels exist by race and ethnicity. Similar disparities in smartphone ownership were found in a study of NICE bus users in Nassau County (Long Island, New York) (Sion et al., 2016) and in Saint Louis, Missouri (Windmiller et al., 2014).

There are also well known disparities in the availability of internet service; however, overall access to the internet is relatively high. For example, 79.9% of households report having internet access at home (FDIC, 2020, p. 26) while Pew (Pew, 2019) reported 73% of households having broadband at home. Pew research (Pew, 2019) has also found that 37% of U.S. adults say they mostly use a smartphone when accessing the internet, and younger adults are more likely to reach for their phones when going online with 58% of 18-to 29-year-olds saying they mostly go online through a smartphone. This means that access to smartphone data plans and/or freely available WiFi is increasingly important.

The transportation literature has recognized the challenges that both digital and banking divide pose for the transition to new mobility systems more broadly (Dinning and Weisenberger, 2017; Schaller, 2016; Kodransky and Lewenstein, 2014; Brakewood and Kocur, 2011; Brown, 2019; Brown, 2018a). The work of Brakewood is most focused on these issues for transit payments and specifically those of transit operators (Brakewood, 2022), and the other work addresses access to TNCs, taxis, and bikeshare (Gehrke, et al., 2018; King and Saldarriaga, 2017; Howland et al., 2017). Several studies also highlight the importance of age in technological literacy, creating additional challenges to the transition to cashless (Shaheen et al., 2017; Shirgaokar, 2020). In related research by Brakewood (Brakewood et al, 2020), a survey of bus riders in Tallahassee, Florida assessed the benefits and problems experienced when using a mobile fare payment app. On that survey from Florida, the most commonly reported issue was a low or dead phone battery; approximately 29% of the study participants experienced this at least once during the period of this study (Brakewood et al, 2020p. 62). However, none of these prior studies specifically address the fare payment needs of more vulnerable transit riders - through surveys and/or focus groups - as transit operators move toward new fare payment systems and consider eliminating cash collection.

3. Research questions and design

The brief overview of existing literature highlighted some potential obstacles for the transition to cashless transit payment including access to formal banking, credit resources, and smartphone access and Internet availability, and long with technological literacy. In light of these potential barriers, this project asks: who is most at risk of being excluded by the transition to new fare payment systems and how would riders pay transit fares if cash payment options were reduced or eliminated? The project uses a Title VI framework (US legal code which dictates how transportation projects or plans should be evaluated for how they affect, positively or negatively, different population groups, with a focus on understanding disparities for traditionally marginalized communities) to guide analyses comparing demographic groups to understand how differing access to payment resources and current payment behaviors could lead to disparities in access to emerging new fare payment systems.

To answer our research questions, we focused on three regions: Portland-Gresham, OR, Eugene, OR, and Denver, CO. These three regions were selected for two primary reasons: 1) the transit agencies serving these regions (TriMet, Lane Transit District, and Regional Transportation District, respectively) are each considering eliminating cash fare payments and partnered with university researchers in order to fully understand the potential equity implication of such a policy shift. And second, the three regions, while not representative of all agencies or cities, provide some geographical variation (west and mountain regions) and metropolitan area size and transit operation diversity (see Table 1). Compared to the two larger metro areas, Eugene is a smaller metropolitan area revolving heavily around the University of Oregon. While student riders are important there, they are not the focus of our work there as they have transit passes issued through the university. Therefore, we focused our study on non-student riders.

We first conducted three focus groups. Two focus groups were conducted in Portland, OR (n = 9, n = 11) and one was conducted in Eugene, OR (n = 12). Participants were recruited via outreach with local organizations, primarily non-profit organizations related to transportation justice (e.g. Bus Riders Union), and housing and food services (e.g. Meals on Wheels, various subsidized housing and shelter organizations). Focus groups lasted one hour and participants were provided food, on-site childcare, and a $25 Visa gift card. Translation services (Spanish) were also provided during one focus group. Focus group discussions were recorded and designed to cover several important

Table 1
Basic operating dimensions of case study regions.

	Lane County Transit District (Eugene, Oregon)	Denver Regional Transportation District	Tri-County Metro Transportation (TriMet) (Portland-Gresham, Oregon)
Urbanized Area Population	247,421	2,374,203	1,849,898
Service district population	302,200	2,920,000	1,551,531
Annual Boardings (Unlinked) (million/year)	10.7	104.8	97
Transit modes available	Bus, BRT	Bus, LRT	Bus, LRT
Vehicles Operated in Max Service periods	Bus-89, BRT-18	Bus-1043, LRT-172	Bus-670, LRT-145
Transit Trip Purpose1			
Commuting to work	36%	17%	71%
School/college	37%	6%	7%
Medical	3%	3%	3%
Entertainment, recreation	4%	45%	4%
Store, shopping	8%	7%	4%
Other	13%	21%	11%
Fare payment options			
Mobile App	Not available during survey period	RTD mobile app	Hop mobile app
Fastpass	Not available during survey period	MyRide card	Hop card
Mobile wallet/ credit card (E.g. Apple pay)	No	No	Yes
Cash on board	Yes	Yes	Yes
Purchase/reload Fastpasses online	Yes	Yes	Yes
Purchase/reload Fastpasses by phone	Yes	No	Yes

Sources: 2018 National Transit Database, 2019 RTD Customer Satisfaction Survey, 2015 LTD Origin and Destination Study, 2016 Trimet at a Glance.

dimensions of technology access and transportation challenges: age, income and English language proficiency. Complete focus group guides are included in Appendix A.

Focus group discussions were analyzed for themes related to barriers to accessing new fare payment technologies. Discussions revealed a wide range of barriers to transitioning to computer and phone-based payment systems, including both access to phones and Internet, as well as anxiety around risk and tracking. Focus group findings, in conjunction with the literature, informed a subsequent three-city transit rider intercept survey conducted between July and September 2019; we conducted the transit rider intercept surveys in Portland-Gresham, OR; Eugene, OR; and Denver, CO. Table 1 shows basic transit operating parameters from the three regions.

The intercept surveys aimed to capture a more systematic understanding of challenges faced by a sample of transit riders in the three regions. The surveys focused on current fare payment behavior, access to banking, Internet and smartphone resources, and potential fare payment behavior in the absence of cash options. Demographic information was also collected in order to perform an equity analysis. The full survey questionnaire is included in Appendix B. Survey sampling strategies varied based on local context, differed by region, but in general we sought to oversample low-income riders who may depend on cash payments. In Portland-Gresham, we intercepted riders at major transit stations and bus stops in the eastern part of the region, which has lower median household incomes compared to the western region. In Denver, we worked with a Regional Transportation District (RTD) planner to identify stops where lower income riders and riders use or transfer from buses. In Eugene, due to low ridership density overall, we identified busy transit stations and key transfer points. Surveys were conducted between the morning peak and lunchtime and again during peak afternoon hours. Surveyors were instructed to approach everyone in the station or waiting area until riders departed. Surveys were administered in both English and Spanish via paper survey that were completed independently by riders following invitation to participate from the research team. Survey data were later input into an online database. Transit riders who did not wish to complete the survey at the moment were provided a written envelope and pre-stamped envelope to return the survey by mail. No incentives were given for participation. In total, 2,303 riders completed intercept surveys across the three regions.

3.1. Survey sample demographics

Table 2 summarizes survey rider demographic characteristics alongside recent ridership data for each of the three regions. We created a "composite" sample of riders by weighting responses from each regions by their respective transit system's annual boardings. While the three cities do not represent of the full range of transit agencies operating across the US, they do include a smaller (Portland-Gresham, OR) and medium-sized metro area (Denver, CO) along with a small university town (Eugene, OR); as a result, the composite profile may be useful as a rough proxy for a range of regions throughout the country.

Using survey data, we created categorical age, race/ethnicity and income groups to create simpler comparison groups with sufficient sample sizes. Demographic groupings also enabled us to explore questions of disparities along the dimensions typically used in "Title VI" analyses of transportation disparities. Millennials are those under 35 years old, Generation X is 35 to 55 and Boomers are those over 55. Non-Hispanic Whites (NHW) include respondents who selected white as their race and either selected "not Hispanic" or skipped the Hispanic question. Low-income includes riders earning household incomes below $50,000 per year. We used this threshold partly out of convenience, being a round number and used by the census bureau in tabulated reporting, but also because it is around the income levels which qualify for housing subsidies in the major metros in the United States (being close to 60% to 80% of area median income). Many survey respondents declined to answer some demographic questions and are included as a missing category for comparison. Comparing our sample to recent agency data, we observe differences between our sample and the ridership demographics in each region. Missing data for income likewise present challenges in comparing our sample with the agency data. For race/ethnicity, we oversampled riders of color relative to the broader transit rider population. Our samples in Denver and Portland – Gresham are younger than agency data, while older than for Eugene. The latter is likely because in Eugene, the University was not in session during the survey data collection period.

In the following sections, we present the results for questions pertaining to riders' current fare payment methods, access to banking and Internet, phone data limitations, comfort using new payment practices, and future payment practices were cash fares unavailable. We present the results in four ways: 1) overall results for the three regions and the composite ridership; 2) by city and income group; 3) by city and race/ethnicity; and 4) by city and age group. We used chi-square statistical tests to confirm if differences between the groups (between cities in Table 3, and then between demographic groups separately for each city in Appendix C Tables AC1, AC2 and AC3) were statistically different at a 0.05 level. In those tables, bold numbers show that the groups being

Table 2
Demographic breakdown of survey sample compared to recent ridership surveys.

	Denver	Denver RTD 2019 Survey	Eugene	Eugene LTD 2015 Survey	Gresham/Portland	TriMet 2018 Survey	Composite
N	514		1240		549		NA
Race/Ethnicity group (share (%)):							
Missing	10		11		17		13
NHW	36	62	63	82	44	78	41
POC	54	38	26	18	40	22	46
Age Group (share (%)):							
Boomer (Over 55 years)	14	34	21	14	16	29	15
Generation X (35 to 55 years)	26	37	25	20	26	39	26
Millennial (Under 35 years)	46	27	40	66	41	33	43
Missing	14		14		18		16
Income Group (share (%)):							
Higher Income ($50 k+/year)	19	70	7	17	15	74	17
Low Income (<50 k/year)	44	30	60	83	43	26	44
Missing	36		33		42		39
Gender (share (%)):							
(blank)	8		7		12		10
Female	35	49	45	51	37	53	36
Male	56	50	45	49	48	46	52
Non-Binary / Third Gender	0	1	2		1	1	1
Prefer not to say	1		1		1		1

Sources: 2019 RTD Customer Satisfaction Survey, Lane Transit District 2015 Origin-Destination Study, and TriMet 2018 Attitude and Awareness Survey.

Table 3
Overall breakdown of survey results.

	Denver	Eugene	Gresham/ Portland	Composite
N	514	1240	549	
Share (%) of riders with current fare payment practice:				
Employer provided	**27**	**35**	**16**	22
Social service provider	**6**	**0**	**8**	7
Cash on bus	**33**	**29**	**24**	29
Cash at TVMs	**29**	**19**	**25**	27
Cash at retail/agency	**19**	**15**	**13**	16
Apple/Android Pay	NA	NA	6	6
Credit/debit at TVM	**21**	**10**	**15**	18
Smartphone app	**23**	**5**	**31**	26
Credit/debit at retail/agency	13	14	11	12
Share (%) of riders lacking access to banking and internet:				
Unbanked (No savings, checking, credit, debit accounts)	**6**	**4**	**9**	7
Lacks smartphone	**12**	**19**	**14**	13
No Internet	6	8	6	6
Only Wi-Fi for internet	**28**	**38**	**28**	29
Share (%) of riders experiencing phone data limitations:				
No data use on phone	**11**	**14**	**13**	12
Somewhat or very concerned about data limits	**19**	**26**	**21**	20
Share (%) of riders completely or somewhat uncomfortable using the following payment practices:				
Website - One Time Payment	**26**	**30**	**21**	24
Website - Recurring payments	**36**	**45**	**29**	33
Smartphone - Recurring payments	**32**	**NA**	**25**	28
Purchase by phone	**NA**	**49**	**40**	40
Share (%) of current cash-on-board users who will switch to the following practices:				
Some form of Credit/Debit (Online, Phone, etc.)	33	36	39	35
Some form of Cash (TVM, Retail, etc.)	**43**	**63**	**35**	41
Unable to Ride	**22**	**13**	**23**	22

Notes: Bolded numbers show statistically significant differences between the three cities at the 0.05 level; Chi-squared test.

compared within each city (for example, low and high-income) are significantly different.

4. Results

To discuss the results, we present an overall table of descriptive comparisons between the different regions, followed by three "equity analyses" comparing descriptive tabulations by income, race/ethnicity, and age. Those data tables are in Appendix C.

Table 3 shows that nearly 30% of composite transit riders pay for transit on board with cash. Cash use at ticket vending machines (TVMs) and retail outlets is also substantial (42%), and significantly higher than for credit and debit use at these outlets (30%).

Rates of smartphone (87%), banking, and credit card (93%) access are similar to those of the general population statistics presented earlier. While few people cite a complete lack of Internet connectivity (6%), more than one-quarter (29%) claim they rely solely on public Wi-Fi for Internet access through their phone. Another 12% own a mobile phone but do not access data on it, and one in five (20%) of riders report concerns about reaching phone data limits. Together, these data suggest substantial challenges, even for those with smartphones, to reliably pay for transit via a smartphone.

Between 20 and 40% of riders reported being "somewhat" or "completely" uncomfortable using new fare payment tools such as websites and smartphones. This corresponds to focus group discussions, in which many riders expressed discomfort storing financial information in websites or on their phones. Finally, for current riders who pay cash on board, we asked them what they might do if cash were eliminated. Nearly one-quarter (22%) claim they would not be able to ride at all; other riders state that they would either use other cash options (e.g. load a transit card with cash at a ticket vending machine) (41%) or use credit or debit cards (35%).

Technology access also varied across the three cities. Survey respondents from Eugene had lower access to Internet and banking resources, were less comfortable with new fare payment approaches, and disproportionately reported relying on cash even after cash-on-board options were removed. The other two major metros were similar on these issues.

4.1. Equity analysis by income

As mentioned above, equity analysis tables are included in Appendix C. Table AC1 presents results broken down by income group, where "Low-Income" (Low) includes respondents who earn incomes below $50,000 per year, and Higher Income was those who earned above $50,000 per year; because we had a high degree of income non-response, we also present separate results for those missing income information (Miss.). Focusing on the composite analysis, clear differences exist in fare payment practices between the different income groups. A greater share of higher income riders have employer-provided passes (33 vs 21%) and pay by credit or debit (25 vs 19%) or smart phone app (36 vs 27%) compared to low-income riders. A significantly lower share also uses some form of cash to pay for transit; for example, about one-third (32%) of low-income riders use cash on board transit compared to 16% of higher-income riders.

Banking and internet access among both income groups was high, although the composite analysis shows significantly lower access to banking and internet for low-income respondents compared to higher-income riders. Just 1% of higher-income respondents, for example, were unbanked compared to 7% of low-income respondents. A relatively high share of both higher-income and low-income respondents relied solely on Wi-Fi for Internet access (18 and 32%, respectively); differences between income groups within each city followed composite patterns. Interestingly, higher income riders in Eugene had significantly lower access to smartphones than respondents in the other cities. While for the overall dataset the age-income correlation was positive but weak (0.067, significant at a 0.05 level), the correlation was stronger in Eugene (0.111). This may influence the association between income and smartphone ownership. One possible explanation for this is that Eugene is a small metropolitan area whose economy revolves heavily around the University of Oregon; the positive effect between age and income may therefore relate to the disproportionate presence of university students in Eugene who earn relatively lower-incomes compared to young adults employed full time. The age-income correlation in Eugene poses challenges, as higher income riders may have better access to technology, but less proficiency in using it because of an age effect.

Riders across both income groups voiced concerns about phone data limits spanned income groups (about 20% of riders). At the same time, a greater proportion of low income respondents did not use data on their phones at all compared to higher-income respondents (14 vs 2%, respectively). A larger share of low income respondents also reported being uncomfortable using new payment systems relative to higher income respondents, although this may also relate to respondent age.

Finally, the analysis of payment behavior if cash-on-board options were eliminated showed that a greater proportion of higher income groups report that they would transition to some form of credit or debit based payment, while a higher share of low income groups claimed they would continue to use cash (e.g. at a retail location or ticket vending machine) or be unable to ride at all.

4.2. Equity analysis by race and ethnicity

In this analysis, we break out responses into Non-Hispanic white riders and riders of color (Table AC2). Non-Hispanic white riders are respondents who identified as white and who either selected "Not Hispanic" or skipped the Hispanic ethnicity question in the survey questionnaire. Riders of color are those who identified as Hispanic and/or

any racial category other than white. The "missing" group (13% of total respondents) declined to answer the race question.

The differences between groups here are less stark than those between income groups, which corroborates some of the findings from other studies of digital/banking divide (e.g. Apaam, 2018; Pew, 2019). A greater share of riders of color pay with cash both on board (35 vs 24%) and at TVMs (32 vs 24%) compared to Non-Hispanic white riders. Otherwise, the differences are fairly small or statistically insignificant. Indeed, riders of color have slightly higher (though statistically insignificant) access to smartphones and Internet relative to Non-Hispanic white riders. Levels of discomfort using new fare payment systems is nearly identical between the two rider groups and future payment differences were not statistically significant, although equity issues by race/ethnicity often varied by city.

4.3. Equity analysis by age

In this analysis, we break out responses into three groups by age: Millennials are those under 35 years old, Generation X are ages 35 to 55 and Boomers are those over 55 years old; we also include a "missing" category for those who declined to report age. Results are shown in Table AC3. A greater proportion of Millennials paid for their transit fare both with cash and with smartphone applications, although these differences were not statistically significant across age groups). A higher share of Millennials also purchased transit fares at retail locations, compared to the two other age groups. Conversely, a greater share of Boomer respondents used retail options and a smaller number used smartphone applications. Generation X respondents' fare practices typically fell between the two groups. The three groups were identical in personal access to banking and credit resources (other than the missing group). Almost one third of Boomer respondents lack access to a smartphone, significantly more than the other groups. Similarly, a far smaller share of older adults had access to the Internet, use data on their phones, or were concerned about reaching phone data limits. A higher share of older adults were less comfortable using new payment systems, and between 23 and 40% of riders across all age groups reported discomfort purchasing fares by phone. Finally, a higher proportion of older respondents claimed that they would remain more reliant on cash and be unable to ride if cash-on-board payment options were eliminated.

5. Factors PREDICTING CASH-ON-BOARD USE

Alongside tabulations of survey responses presented in the previous sections, we can also use modeling techniques to understand the relative contribution of different factors to predicting whether someone will face the challenge of making the transition to cashless. We decided that this was best captured by understanding factors that predicted whether someone is a current user of cash-on-board payment. We focus on cash-on-board as it is likely the first place where cash payment would be eliminated, and it is those riders which would experience the greatest inconvenience and disruption.

5.1. Binary logistic regression

Given our focus on those riders most vulnerable to changes in fare policy, we used choice models to predict the use of cash-on-board payment. A series of binary logistic regression models were run to predict current cash-on-board payment, versus all other payment types. Models included various combinations of demographic and digital and banking access and other survey response variables. Generally, candidate models' goodness of fit were disappointingly low as missing variables in some of the responses, especially age, income and race/ethnicity plagued the models. Table 4 presents results from one of the better models for the overall dataset and shows that access to credit cards and comfort with new fare payment systems significantly reduce the use of cash-on-board, while higher incomes, better phone data plans and higher frequency of ridership also predicted lower cash-on-board payment. Interestingly, age, smartphone access and race/ethnicity do not seem to correlate with cash-on-board use. Higher riding frequency predicted lower cash use as it perhaps becomes more worth the effort of switching to new payment systems when you are riding and paying more often.

Looking at the city-specific regressions in Table 4, results were slightly different for each city. Portland followed the overall findings from the full regression. For Denver, several of the variables (comfort using new payment systems, phone data limits, and ridership frequency) were not statistically significant in predicting cash use. For Eugene, many of the variables from the overall regression were not significant, while reliance on public Wi-Fi and being a rider of color increase the likelihood of paying cash-on-board.

Because of the low model fit, we ran an additional "Factor" analysis to verify the regression modeling results for the overall dataset. Factor analysis reveals patterns in the data and enables researchers to distill datasets with a large number of variables into a few "types" based on strong relationships among the variables. In this case, we can reduce the large number of survey responses representing each rider into several rider "types" using this technique. This can help us understand which variables were commonly correlated with cash-on-board payment behavior. The analysis revealed four significantly common rider types among those surveyed (accounting for 56.2% of the total variance in the data). The results of the analysis are shown in Appendix D, where significant relationships (absolute value of correlation scores higher than 0.3) are highlighted in the bolded numbers.

The first rider type revealed was older than average and more likely non-Hispanic white, but this was not correlated with payment type. The second rider type revealed did not ride very much and was higher than average income and had good access to Internet. This second rider type did not correlate with payment behavior. The third rider type had good

Table 4
Binary regression to predict current payment using cash-on-board.

Variable	Overall *Odds Ratio*	Sig.	Denver *Odds Ratio*	Sig.	Portland *Odds Ratio*	Sig.	Eugene *Odds Ratio*	Sig.
Rides per month	0.97	**0.077***	0.99	0.660	0.95	**0.035***	0.93	**0.0001*****
Smartphone ownership (Y/N)	0.92	0.855	0.69	0.592	1.28	0.695	0.92	0.805
Phone data limits not a concern (Y/N)	0.68	**0.098***	0.72	0.285	0.53	**0.072***	0.91	0.659
Only use public Wi-Fi (Y/N)	1.23	0.396	0.91	0.772	1.57	0.236	1.94	**0.001*****
Credit card access (Y/N)	0.40	**0.0001*****	0.47	**0.018***	0.31	**0.001*****	0.54	**0.005*****
Ave comfort with online/phone payment score (1–4)*	0.77	**0.01*****	0.84	0.174	0.69	**0.032**	1.13	0.267
Age	1.00	0.669	1.00	0.849	1.00	0.795	1.00	0.975
Income ($/year)	0.99	**0.049***	0.99	**0.059***	0.99	**0.082***	1.00	0.98
Non-Hispanic White (Y/N)	0.75	0.21	0.97	0.922	0.72	0.336	0.60	**0.024***
Constant	4.86	**0.035***	4.17	0.172	7.04	**0.088***	1.97	0.281
Nagelkerke R^2	*0.151*		*0.131*		*0.216*		*0.119*	

Significance levels: 0.01 = **A*****, 0.1 = **A***. *Average of scores on four questions about comfort using few fare payment systems. For Yes/No variables, the NO is the reference category.

access to credit cards and high comfort using new fare payment systems and had lower than average likelihood of using cash-on-board payment systems. This third rider type corroborates the findings of the regression analysis. The fourth rider type had high access to smartphone and good phone data plans, but this did not correlate with any particular payment behavior.

6. Discussion

Before we explore the wider implications of the results, we want to consider some of the limitations of the study. First, we examine three metro areas in the US. Although these three regions offer relative diversity in terms of location (mountain, west), size, and transit operations, they do not reflect the wide range of cities and transportation operations both in the US and internationally. Therefore, findings from this study may not be generalizable to other agencies and locations. Second, survey findings are limited by the times and places riders were intercepted. We purposefully did not intercept riders in the late night off-peak periods due to both safety concerns for fieldworkers and because of the need to maximize the survey responses from our staffing budget. Our sample therefore omits riders who use the transit systems during off-peak hours, a higher share of whom are likely lower income compared to those who ride transit during peak hours (Brown, 2018b).

Even considering these limitations, results from this study show that transit riders have on average, similar rates of access to smartphones and internet–and in some ways are even better equipped to adopt for new fare payment systems–compared to the general population (Apaam, 2018; Pew, 2019). Still, our investigation reveals some substantial barriers and disparities among current transit riders with important implications for new fare payment technology adoption. Several important conclusions and concerns emanate from the results and analysis presented here.

First, a significant number of riders (~30%) still rely heavily on paying cash-on-board buses. Those who currently pay cash-on-board appear able to switch to other cash and non-cash options, though a significant number anticipate continuing to rely only on cash; a small number of riders claim they would no longer be able to access transit Access to new fare payments depends largely on technology adoption. Overall, we find that smartphone ownership is high (over 80%) for all groups, other than Boomers, a lower share of whom owned a smartphone or had access to the internet. A small but significant number (~20%), however, are concerned about reaching phone data limits and nearly one-third of riders (~30%) depend on nontraditional sources such as public Wi-Fi for Internet connectivity. Model results show that higher-incomes, access to credit cards, and comfort using new fare payment systems are associated with lower reliance on cash-on-board fare payment. Yet even when riders have access to all the tools needed to use new fare payment technologies, some continue to report unease with using payment systems requiring credit information to be stored or input into websites or phones.

Interestingly, some of these disparities differed from city to city, though systematic differences were unclear. A greater share of survey respondents from Eugene reported earning lower incomes, did not have access to Internet and banking resources, were less comfortable with new fare payment approaches, and reported continuing to rely on cash even after cash-on-board options were removed. These may reflect the smaller size town, where riders are more likely transit dependent than in the major metros, where transit offers advantages for riders with other travel options. The two larger metros were more similar in many aspects of this analysis. Observed differences across context emphasizes the potential limited generalizability of these research findings and the possibility that local conditions and patterns may differ substantially from national averages. Therefore, planners and policymakers should consider undertaking local survey work to understand local rider issues prior to fare technology transitions.

Model results suggest that credit card access and greater comfort using emerging new payment systems (either on-line or through a smartphone) predicted significantly lower cash-on-board use, controlling for other factors such as income, smartphone access, and transit use frequency, among others. While public transit agencies may have difficulty improving access to credit cards, outreach and training programs could increase riders' comfort using new and digital payment systems. Education could also highlight ways to continue to employ cash fares even were cash removed from on board buses; agencies could, for example, highlight transit stations or retail locations that allow riders to load cash on board fare cards or transit apps. Cash acceptance through retail networks or on TVMs may still be necessary for the medium term as a large share of transit riders report that they plan to pay fares in cash even if not on board vehicles. This is consistent with the findings of other new research from the Transit Cooperative Research Program on cashless fare collection systems that concluded that "one of the most critical elements in preparing for cashless fare collection systems is to provide customers with convenient alternative options to pay cash, including a robust retail sales network and ticket vending machines" (Brakewood, 2022 p. 3). Model results also showed that more frequent transit use predicted less reliance on cash. Agencies should therefore recognize that occasional users (tourists, sports games attendees etc.) represent an important segment of transit riders that may have limited information on fare payment, particularly if cash is removed. Therefore, agencies could consider specific efforts to reach these populations such as communicating information at airports, train stations, at major transit centers, and at large events such as concerts or sports games.

Concern over phone data limits moderately predicted cash-on-board payment, controlling for other factors. Free public Wi-Fi near transit stops and stations could therefore improve app-based fare access for riders who are dependent on Wi-Fi hotspots, especially at stops that may be far from stores, libraries or cafes which offer free internet access.

This research highlighted a number of potential barriers to adopting new fare technologies while ensuring access for marginalized riders. Findings also revealed, however, that in addition to likely experiencing barriers to new fare technologies, many focus group respondents were unfamiliar with the technologies and many focus group and survey respondents reported concerns about adopting new fare technologies. In particular, riders voiced concerns about privacy while using apps (e.g. tracking) and the relative security of paying for transit fares over the internet and via apps. These hesitations suggest that even while many riders may have access to technology and banking resources, they may be uncomfortable or unfamiliar with new technologies in a fare payment setting, which could inhibit or deter adoption. Therefore agencies considering introducing new fare payment systems should engage in outreach, education, and training to improve overall adaptation, which was also a key finding of related TCRP research on cashless fare collection systems (Brakewood, 2022).

CRediT authorship contribution statement

Aaron Golub: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Anne Brown:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Candace Brakewood:** Conceptualization, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **John MacArthur:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Sangwan Lee:** Data curation, Formal analysis. **Abubakr Ziedan:** Data curation, Formal analysis, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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