A Comparative Analysis of Vanpool and Single Occupant Commuters’ Self-reported Stress Level Before and After the Commute

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ABSTRACT

The purpose of this study was to examine commuter behavior to determine if those that use a vanpool (VP) to commute to and from work experience a different level of stress than their single-occupant vehicle (SOV) counterparts. In this study, survey respondents provided their personally perceived level of stress both before and after their commute on a scale between one and ten. Qualitative analysis of the change reported as a number, was followed by statistical analysis by applying confidence intervals to infer the probable range of median values for each data set. The average within each dataset was used to determine the change. Overall, the aggregated data revealed that the vanpool set experienced a 21% lower rate of self-reported stress than their single occupant vehicle counterparts specific to the commute. The results provide insight into the effects of stress when choosing a vanpool as a primary commute mode by using SOV commuters as a control group. Additional data from one of the participating employer sites provided enhanced understanding of other metrics that could contribute to overall wellness or personal satisfaction. Analysis of the data revealed additional behavioral insights between the commuter modes including reduced absenteeism for the vanpool participants. This information can help people understand motivating factors that may alter commute mode choice based on a desire to lower stress. It may also assist employers in understanding the kind of value these types of services bring to their employee base. Both provide implications for enhancing MaaS options and perhaps increasing its adoption to a wider audience.

KEYWORDS Vanpool, Carpool, Single-Occupant Vehicle, Mobility as a Service (MaaS), Commute
Purpose

Mobility as a Service (MaaS) is steadily gaining popularity as a concept in the provision of transportation service. However, forms of MaaS have been around for decades. For instance, vanpools began in the 1970's and are groups of commuters who live and work in generally the same area and choose to commute as a group in a passenger vehicle. In many cases this can be an informal grouping of colleagues traveling in a personal vehicle. In the U.S. the majority use this service in a purchased transportation model from a private provider. Participants pay a fee and the private provider offers varying levels of service, and at a minimum, provides the vehicle for a monthly fee to the group. The purpose of this study was to examine behavioral observations of two specific commute modes to determine if those that use a vanpool (VP) to commute to and from work experience a different level of stress than their single-occupant vehicle (SOV) counterparts. This was intended to bring the concept of psychographics, how people think and feel, to commuter-focused research. In this study, survey respondents provided their personally perceived level of stress both before and after their commute on a scale between one and ten. Qualitative analysis of the change reported as a number, was followed by statistical analysis by applying confidence intervals to infer the probable range of median values for each data set, which was used to measure the change. A separate study was conducted with one of the original participating worksites to determine the nexus between vanpool participation and workplace attendance.

Methodology

The processes used to design the survey and implementation tools took into consideration the confidentiality and expectation of privacy for respondents as evidenced in the Informed Consent procedure. For the survey, respondents were instructed on the Merriam-Webster definition of stress as “a physical, chemical, or emotional factor that causes bodily or mental tension and may be a factor in disease causation” (1) to use as a baseline to gauge their self-assessment. Then, each participant was asked “based on that, what is your level of stress for today’s commute?” All statistic methodologies used measure the change in stress as reported from before the commute and after.

Aggregated Data

There were three sites where the survey was performed, and each produced individual data outcomes. To determine the overall results for this study, the aggregate data files were compiled by including all data, without regard to site, into a single file and then analyzed. The data was separated only by commute mode and time of day. These aggregated files included only information for the VP (Vanpool) and SOV (Single Occupant Vehicle), all separated into morning and evening and before- and after-commute. For the purposes of this study the equation to determine the difference in stress between modes is:

\[
\begin{align*}
|V_{BP} - V_{PA}| &= \Delta \text{Stress} \\
|SO_{VB} - SO_{VA}| &= \Delta \text{Stress}
\end{align*}
\]

VPB is vanpool [before] and VPA is vanpool [after], while SOVB is single occupant vehicle [before] and SOVA is Single Occupant Vehicle [after]. The subtraction for the delta calculations is always before-commute self-assessed stress minus after-commute self-assessed stress.
To understand the results, a negative delta means that stress increased. A positive delta means stress decreased. Hence, an increase in stress produces a negative value.

The equation for determining the overall difference in stress level is:

\[
\text{<Stress - >Stress / <Stress} = \Delta \text{ (expressed as a percent)}
\]

(2)

Such that:

If the >Stress is also [B] then the \( \Delta \) is lower stress

(3)

If the > Stress is also [A] then the \( \Delta \) is higher stress

To support the summary findings the data is:

<table>
<thead>
<tr>
<th>VPB</th>
<th>VPA</th>
<th>SOVB</th>
<th>SOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.64</td>
<td>3.47</td>
<td>3.25</td>
<td>3.88</td>
</tr>
</tbody>
</table>

\[\text{|VPB – VPA| / VPB} = .046 \text{ (5\%) lower stress}\]

\[\text{|SOVA – SOVB| / SOVA} = .16 \text{ (16\%) higher stress}\]

The VP is a 5\% decrease
The SOV is a 16\% increase

RESEARCH METHODOLOGY

The survey was designed to deliver initial vanpool data that can be the foundation for future research. The questions that were sent to participants in order of appearance in the survey are:

1. I commuted today: (Yes / No)
2. For the commute today I was a: (vanpooler, single occupant driver, other)
3. For the work-to-home (or home-to-work, depending on time of day) my level of stress is: (choose 1-10)
4. Gender: (Male or Female)
5. Age: (One of six choices based on generation)
6. My one-way trip in miles is: (one of five options based on distance)
7. For this trip I was a: (Driver, Rider)
8. Do you have any suggestions on the survey experience or thoughts you would like to share from your participation that would be helpful for the researcher to know?

For question one, if respondents did not commute that day, they defaulted to the end of the survey. There is no follow-up question for why they did not commute that day, because it is not pertinent to the data desired for this study. For future research is important to note there could be many reasons for not commuting, which could range from sick, off work, or even working from home; which is commonly referred to as teleworking.

Respondents who answered anything other than vanpool or SOV for question two were also taken to the end of the survey to ensure responses were limited to only those two modes. Between questions two and three, additional information was given to the respondents to define a common methodology for judging their self-perceived stress level (the definition of stress from the dictionary as referenced above). Questions three and four both relied on the simple understanding of the definition of stress as it applies to this research. Additionally, lay language was added to increase understanding. The phrase “in other words, stress is a
factor in your daily experience that causes you tension or anxiety and could make you sick” followed the dictionary’s definition of the word. Then, each participant was asked “based on that, what is your level of stress for today’s commute?”

The respondents could then move to question three which had two parts: an indication of their level of stress before they left home, and an indication of their level of stress after they arrived at work, or vice-versa, depending on whether the survey was administered to morning or evening commuters. Questions four and five were general demographic information—age and gender. Question six asked for the one-way mileage and seven questioned whether they were a driver or rider. Question eight allowed for free form responses and feedback on the survey itself, and yielded interesting information that may be helpful in future surveys but is not included in this study. The scope of this research was limited to the before-and-after self-reported stress levels of vanpool and SOV commuters. Before analysis, the survey information was wiped of all personally identifiable information (PII), including IP address, e-mail information, etc.

SURVEY METHODOLOGY

It is recognized that there can be many factors that affect stress during the commute time. These factors could include traffic, knowledge of impending events later in the day, workload, concerns at home, etc. The purpose of this survey structure was to determine, even with all of those factors, does the commute mode choice impact stress level. All statistic methodologies used are to measure the change in stress from before the commute and after. Under this methodology the reasons for being stressed are not of concern. Most of the stresses experienced by an individual would be experienced regardless of commute choice; for instance: both SOV drivers and vanpool commuters experience traffic, although to different levels and in different ways.

All participants were given the same definition of stress each day to provide an equal frame of reference for how to define stress over their day. Each survey was administered for a full 14 days. Given the self-reporting nature of the data, it could be argued that there are individuals that would rate stress significantly different in either direction than others. To minimize the impact of individual bias several sites were used, creating a large sample size. The longitudinal nature of the study was designed to minimize any potential for bias in the data due to these potential individual differences.

Using a Scale of One to Ten

There are many ways to measure stress. Hospitals use a numeric rating scale during triage of incoming patients as a methodology for assessing patient symptoms. The ten-point scale is used in multiple settings in addition to hospitals, including by the American Psychological Association (APA) in their annual report, “Stress in America”™. For this annual study, the scale allows respondents to report their individually perceived levels of stress in different aspects of their lives on a scale of one (little or no stress) to 10 (a great deal of stress). Findings within the “Stress in America” report support the rationale of utilizing individually perceived levels of stress to be used as an appropriate measurement tool, as reinforced over the long term of the reports as reported annually, and across the nation from 2007-2014. Further, the APA stress report found that when comparing East, Midwest, West and South regions, Americans report similar levels and sources of stress. Regardless of where they live, Americans’ experiences with stress appear to be similar (2) (Figure 1).
This would indicate that the realized levels of commute-specific stress could mimic potential findings in other areas of the U.S. Confirmation of comparable levels would be further justified in future research, to see whether results are replicated across other areas of the U.S.

There is a broad space that different individuals can use to determine their individually conceptualized levels of stress. It is common knowledge that there are individuals with inherently higher or lower levels of tolerance. The longitudinal nature of this study maximizes the likelihood for statistically-valid data while minimizing the potential for bias in the individual self-reporting.

Findings

There were 5,515 individual responses received, including 70% SOV and 16% VP commuters. Over the term of the study, vanpool commuters reported a 21% difference in stress than the SOV commuters. Breaking down that number, vanpoolers reported a 5% decrease in stress, while the SOV commuters reported a 16% increase in stress.

On average, vanpool commuters had a slightly higher level of stress than their SOV counterparts before the commute. However, by the end of the commute the same group reported a lower level of stress than its original score, and a significantly lower reported level of stress than the SOV commuters. The evening commute vanpool participants showed a higher stress level before the commute compared to the SOV participants, which actually lowered after the commute. Conversely, the SOV commuters stated a lower level of stress than the vanpool commuters before their commute, and experienced a higher level of stress at the end of their commute.

Implications

The only category of commuter that resulted in less stress after their commute was the evening vanpool group. This could be an important behavioral marker to note; the vanpool group was able to start their evening at home with lower stress, which could be beneficial to the individual; further research is required to understand why. All other categories showed an increase in stress after the commute.
The many questions raised as a result of this study, such as “will other modes of transportation reflect similar reductions?” etc. reaffirm a need for ongoing research in commuter decision processes. This study provides a unique perspective into potential (even unrealized) motivating factors for vanpoolers as well as single occupant drivers.

BACKGROUND

Vanpools are commonly defined as a group of volunteer commuters who live and work in the same general area and agree to participate in a ridesharing arrangement. In the U.S. most vanpools qualify as public transportation. Public transportation is defined by Congress as regular, continuing, shared-ride, surface transportation service that is open to the general public or open to a segment of the general public defined by age, disability, or low income (3). Vanpools, by federal definition, must have seating for a minimum of seven and a maximum of fifteen passengers including the driver. The driver cannot receive any compensation for driving, but the participants can reduce their individual commuting costs by sharing expenses.

Vanpooling is one of the fastest growing modes of commuter transportation in the U.S. Unlike other modes of transportation, vanpools saw a retention of ridership even after fuel prices fell following the sharp spike in prices in 2007 as indicated by data in the National Transit Database (Figure 2).

![Change in Unlinked Trips 1998-2008](image)

**FIGURE 2:** Increase in vanpool trips compared to other modes of transit. Source data taken from FTA, National Transit Database (2013)

This level of retention might be attributable to a realization of commuters’ cost savings over time, or to a better quality of life due to the commute shift, among possible reasons. The retention rate of vanpoolers over time is another reason why studying motivating factors behind commute choice could reveal important information regarding increasing vanpool use. It may also provide useful behavioral markers for other modes of service entering into the Mobility as a Service marketplace.
WHY IS THIS IMPORTANT?

Transportation currently accounts for 71% of total U.S. petroleum use, and 33% of the nation’s total carbon emissions (4). Identifying ways to remove potential barriers that prevent individuals from altering their commute behavior could increase participation. Increasing use of public transportation options could have the potential to lower the need for petroleum and reduce U.S. greenhouse gas emissions. This study attempts to gain a better understanding of one aspect—stress—as a possible motivating factor in mode shift, which is the decision by an individual to utilize an alternative form of transportation instead of using a single-occupant personal vehicle for travel. Understanding behavioral factors may enhance adoption of MaaS products overall, especially if used as a motivator for users.

This study attempts to measure stress as a result of the commute, with the commute itself being the only difference independent of mode choice. Not all stress is bad. Stress can be beneficial for some people, under the right circumstances. But, long-term, ongoing high stress levels have been known to cause medical issues. The World Health Organization (WHO) Global Burden of Disease Survey estimates that by the year 2020, depression and anxiety disorders, including stress-related mental and health conditions, will be highly prevalent and will be second only to ischemic heart disease in the scope of disabilities experienced by sufferers (5).

Insurance companies should have a stake in understanding whether a person’s commute choice affects their overall health, given the link between stress and health. Casualty and Insurance Edition of Best’s Review estimates that $150 billion of revenue is lost to stress annually in lost productivity, absenteeism, poor decision-making, stress related mental illness, and substance abuse (6). Understanding how stress is impacted by the commute is an important step in minimizing a person’s exposure to stress specific to commute mode choice.

Data collected for this research includes surveys administered to companies that have employee access to vanpool service in addition to other forms of public transportation. Focusing on commutes in different areas of the State of California allowed the study to compare commutes that shared similar issues (congestion, suburban-to-urban and urban-to-urban routes, weather conditions, etc.).

A similar study from the University of California Los Angeles (UCLA) was conducted in 2015. In that study, the researchers interviewed a selection of the institution’s vanpool participants to reveal their perceived benefits of using a vanpool. The study included respondent information from recorded statements and determined that riders in every group indicated that participating in the van was a source of dramatic reduction in stress (7). This study’s findings concur with those statements through statistical analysis. These perceptions can account for outcomes from earlier research specific to vanpools where an EPA study found that over 90% of all employees who have participated in vanpools intend to stay in them (8). It could benefit the MaaS industry to understand why satisfaction of utilizing this mode leads to a desire to continue with that behavior.

RESEARCH ADMINISTRATION

For each individual site, an informed consent letter was sent to the population one week in advance of the first survey being sent. This allowed for proper review of the consent page, and an opportunity to ask the research team questions. The surveys began the following Monday and were sent at five a.m. and five p.m. each day for the 14 day period.
Survey Research Tools

After the survey questions were developed, a crosscheck was performed to ensure the questions were appropriate to the intended outcomes, and to make sure they were easily understood by the average commuter. The survey medium was the Qualtrics™ online platform that was chosen instead of a mobile based survey tool because all of the employers participating gave permission to allow employees to use the internet during their work day to complete the survey. Each employer site was provided with a set timeline to expect survey participation.

Survey Implementation

This research was limited to employers in the State of California. To set an accurate baseline, it was important to ensure the respondents are experiencing approximately the same issues during their commute. California commutes are universally congested, especially in the cities—specifically the employment centers where the research was targeted. The surveys were performed electronically at employers in the cities of San Mateo, Los Angeles, and San Francisco, California. Locations were chosen based on the willingness for cooperation by an in-house administrator; population size (medium and large employee sets); and existing vanpool users.

The sites that received the surveys included: Los Angeles World Airports™ (LAWA), LinkedIn™, and Intuit™. These sites each met the criteria for a willing site administrator, and all have existing vanpool participation. Each of these locations is within a city in the State of California.

Analysis Tools

Upon completion, each individual survey was downloaded from its submission date, and aggregated according to survey type (morning or evening). Once the individual site information was inserted into individual Excel™ spreadsheets, descriptive statistic information was derived utilizing the Excel add-in. The descriptive statistic data was then used to perform confidence intervals which are described in detail later.

Understanding the Results

Each of the individual result sets had a total number of people who signed up during the informed consent period. However, on any given day, fewer than the total number of people that registered actually submitted their survey information. It is also important to note that an individual could take a vanpool one way and a bus the other way, or any other number of choices based on their daily routines. Each day respondents were asked to proceed with their surveys only if they actually commuted by one of the selected modes. This means if they used any other mode (such as bus, carpool, etc.), that information is not logged in this dataset because these respondents were taken to the end of the survey. The ability to choose “other” is also why the totals for percentage of SOV and vanpool vs. the total number of responses do not add up to 100%.

Additionally, it is acknowledged that stress levels may differ based on the roles of drivers and riders, trip length, and between gender and age groups. When all SOV driver stress ratings were aggregated, there is no substantial difference between the reported changes in the male and female SOVs. Although male drivers start with a lower reported average stress level of 3.09 versus the female average of 3.22, both show a 21% increase in stress after the commute. However, there are substantial differences in the vanpool groups’ reporting of stress based on role and gender. Male vanpool drivers reported increased stress levels of 18% after the commute compared to just 3% increase in stress reported by female vanpool drivers. Conversely,
male vanpool riders reported a 13% decrease in post-commute stress, while female vanpool riders only experienced a 5% reduction in stress. The delta between male SOVs and male vanpool riders is a 34% difference in stress level, while the delta between female SOVs and vanpool riders is 26%. From these findings, it would appear that the male SOVs may experience a greater benefit in stress reduction by changing modes. The group with the highest stress levels both before and after the commute was female vanpool drivers, who reported 4.33 before the commute and 4.45 after the commute, an increase of 3%. The group with the lowest reported stress level before the commute was male SOVs at 3.09, while the group with the lowest reported stress level after the commute was male vanpool riders at 2.87.

The trip length significantly affected reported stress levels of all groups. Female SOVs showed the greatest delta in stress level by distance with an increase of 3.31 between the group traveling 25 or less miles (-0.51) and the group traveling 50-69 miles (-3.81). This is an increase of 655%. Male vanpool drivers showed the highest percentage increase in stress by distance of 967% difference between those traveling 0-25 miles (-0.9) and those traveling 50-69 miles (-0.91). The groups least affected by trip distance were male and female vanpool riders. Those traveling 70 or more miles actually showed an improvement in stress levels, indicating that the longer drive may have a calming effect, or could indicate an acceptance of the task at hand more than the shorter distances may experience. Further research is recommended to explain this unique outcome.

On any given day the number of respondents fluctuated based on the mode choice they used that day. For purposes of comparing the data, the average number of respondents was used for the length of the study for the morning report, and separately for the evening report. There is potential for bias in the data because the total number of responses on any given day will differ, affecting the sample. However, as a way to minimize this issue, the survey was administered for a total of 14 days as a way to increase the likelihood that individual responses would be repeated a number of times and maximize the opportunity for highly reliable data.

Each site observed a significant drop in the number of total respondents for both the vanpool and SOV categories on weekends. The drop in responses was common at each site. If the data were analyzed in that manner there would be weighted bias in the outcome of the individuals who did log any data on those days. In order to keep the dataset more reliable, the Saturday and Sunday responses were removed entirely, and instead analysis was performed only on days one through five of each survey week. Many work locations have schedules that operate seven days a week, and therefore all weekday as well as weekend data was intended to be included. Future follow-on research could identify in advance if a seven-day schedule is common before requiring those dates in the response set. All outcomes list days one through ten for surveys, which correlate to Monday through Friday of both weeks studied.

Individual Site Information

Los Angeles World Airports™

Los Angeles World Airports (LAWA) was the first survey administration site. One hundred eighty-seven employees signed up during the informed consent period. LAWAs employees were highly engaged throughout the process. On average, there was a total of 88 responses in the morning and 84 responses in the evening. The percentage of vanpool responses in this total was 25% on average for both the morning and evening. The percentage of SOV responses was 68% in the morning and 69% in the evening. Overall, the percentage of responses was the same from the morning to the evening. During survey analysis, LAWA was able to confirm the percentage of the sample of SOV and vanpool participants was consistent with their population.
In cooperation with this research, LAWA provided additional data to enhance the overall outcomes. The additional data is specific to LAWA only, and provides insight into metrics that are significant to them as an employer. Though this data did not come from the originating research, the outcomes provided by LAWA are included here because it pertains to the same population that the research sample was derived from. The additional analysis focused on how vanpool participation relates to attendance. Specifically this company has an annual award program for employees who are able to achieve Good or Perfect Attendance. These awards include a certificate of achievement placed in the employee’s personnel file and a small cash reward. Good Attendance requires an employee to have 3 or less unscheduled days off during the year, while Perfect Attendance allows for no unscheduled days off.

LAWA collected Vanpool participation and attendance data at Los Angeles International (LAX) Airport for 6 years from 2010-2015. During those years 14-15% of LAX employees were participating in the Vanpool Program, and 17-20% of employees achieving Good or Perfect Attendance ratings were vanpoolers. This showed a correlation between vanpooling and attendance at an average of 3.4% higher than non-vanpool commuters over these six years.

During this period, 25.5% to 31.7% of vanpoolers achieved good or perfect attendance ratings each year at an average of 28.6% of vanpool participants per year. For comparison, 23.4% of employees in all travel modes and 23.3% of solo drivers achieved this honor, showing that vanpoolers earned attendance awards at a rate 5.4% higher than the general population.

Additional research should be conducted in this area to determine the exact reasons for the correlation between vanpool participation and improved attendance. It would be beneficial for companies to quantify this data further, perhaps by calculating loss of revenue due to employee absence. It could be an important metric for the business case behind offering Mobility as a Service options in that paying for some level of service could offset losses due to absenteeism, or realized savings in healthcare costs due to lower stress levels as indicated in the overall findings.

During the informed consent period, 130 individuals signed up. A daily average of 42 individual responses were registered. Of the morning responses, an average of 8% of the total responses were from vanpoolers, whereas 66% were SOV commuters. The evening commutes registered similar data: 9% of the total were vanpoolers and 63% were SOV commuters. The much smaller ratio of SOV to vanpool responses could be cause for concern. A discussion with the site administrator confirmed that the ratio of vanpool to SOV commuters was representative of their overall population.

During the informed consent period, 204 individuals signed up to participate. Initially, the sample size reflected a mix of 12% vanpoolers to 88% SOV commuters. The site administrator was contacted and confirmed that it was appropriate sample size. By the close, surveys averaged 66 respondents per day. Of the daily responses, 10% were vanpoolers, and 76% were SOV drivers, making the overall averages representative of the population of the chosen site, as confirmed by the site administrator.
SUMMARY FINDINGS

Confidence intervals (CI) estimate the mean of the dataset using the desired level of confidence coefficient, which in the case was chosen to be 95% (CI95). After performing several confidence interval analyses and reviewing the descriptive statistics (as well as other statistical tools) the data analysis outcomes support the conjecture from the Mobility as a Service industry that vanpools do in fact lower stress. Each statistical tool answered specific questions relating to the data itself, and including CI for paired data, independent means assuming population variances, and proportions. There were 5,515 individual responses received, including the morning and evening commutes. In all, 1,986 individual surveys were analyzed for the morning commute and 1,813 individual surveys analyzed for the evening commute. The respondents included 70% SOV and 16% VP commuters (Figure 3).

![Pie Chart Reflecting the Percentage of Respondents by Commute Type](image)

**Figure 3:** Percentage of respondents grouped by type of commute mode.

These averages are consistent with the anticipated average SOV versus vanpool commuter as reported by each survey location chosen. The formal conclusion of this study is that SOV commuters have higher levels of stress than VP commuters after the commute in both the morning and the evening. The resulting data did not show a normal distribution, however, the vanpool data is consistently to the left of the SOV data. Since the data was not normally distributed non-parametric tests (Wilcoxon Rank Sum Tests) were run in addition to the parametric confidence intervals. The non-parametric results reflected p-values that were near zero which indicate that the original parametric method was appropriate, as well as simpler to express in the findings. All confidence intervals assume the samples reflect the population. There is no indication that they do not. The findings suggest a link between choice of commute mode and overall average stress level.

Over the term of the study, vanpool commuters reported 21% less stress than the SOV commuters on a daily basis. Breaking down that number, vanpoolers reported a 5% decrease in stress, while the SOV commuters reported a 16% increase in stress, which is a combined total of a 21% difference.

On average, vanpool commuters were shown to have a slightly higher (though not statistically significant) level of stress than their SOV counterparts before the commute. However, by the end of the commute the same group reported a statistically significant lower level of stress than its original score, and a significantly lower reported level of stress than the SOV commuter group. The evening commute vanpool participants showed a (statistically significant) higher stress level before the commute compared to the SOV participants,
which actually lowered after the commute. Conversely, the SOV commuters stated a lower level of stress than the vanpool commuters before their commute, and experienced a higher level of stress at the end of their commute (Figure 4).

These findings support the outcomes from the confidence intervals and show a correlation between the data, with the only change occurring over the period of time being the commute itself. These findings support a relationship between commute choice and stress level. The data reveals a logical association between commute and stress levels, with vanpoolers experiencing lower levels of overall stress compared to single-occupant drivers as a result of their commute choice.

Confidence Intervals (CI)

The first methodology applied to the dataset (CI paired data) was used to determine whether there is a statistical difference between each mode-specific user group before and after their commute, with respect to both the morning and evening commute. The same people assessed themselves before and after the commute, therefore allowing for a degree of control over the variability of the results. For the morning commute, VP equaled no statistical difference between average stress levels before and after. The level of stress experienced before the commute remained the same at the end of the commute. SOV equaled on average (.69-1.04)CI95 more stress on the scale after the commute than before. For the evening results both modes showed a change before and after in slightly different ways. VP = an average (.25 to .74)CI95 change reporting less stress upon arriving home than when leaving work. The commute appears to play a role in the reduction of stress when using a vanpool. SOV = an average (.25 to .54)CI95 increase in stress after arriving home than when leaving work. Hence, the commute for the SOV group had a higher post-commute stress level, while the VP group experienced lower levels.

The second methodology applied to the dataset (CI independent means with different variances) was used to determine if there was a statistical difference between VP and SOV with respect to the delta in stress levels.
before and after their respective commutes. It acknowledges that there will be an expected change in stress for either method, but answers whether one mode has a greater level of change over another. The morning results show average stress levels were greater (.4 to 1.0)CI95 for SOV than for VP. Though both methods indicated an average increase in stress, the SOV commutes produced a greater differential. As in method one, method two reflected major differences in the evening data. Average stress level changes were greater (.66 to 1.18)CI95 for SOV than VP. Both indicated an average increase, but the SOV mode produced a greater differential in stress. Interestingly, the VP mode reported that on average, the VP commuters ended their commute with lower stress than when starting. This reiterated previous findings.

The third methodology applied to the dataset (CI independent means with different variances) compared the actual self-assessed test scores rather than the changes in stress levels between VP and SOV. This measured the statistical difference between “before” commute for both VP and SOV. It would indicate whether there is one group that is inherently more prone to stress than the other, hence any differences that could be attributed to lifestyle rather than the commute. For the morning results there was no statistical differences before the commute between VP and SOV. Both types had the same initial stress. After the commute the SOV has between a (.14 and .88)CI95 greater average self-assessed stress level than the VP counterparts. For the evening commute the “before” level of stress comparing the modes showed that VP showed a (.18 to 1.00) CI95 average higher stress level. This result is counterintuitive. A possible explanation could include anxiety of the impending commute to be sure they get to the van on time for departure. Further research would be necessary to explain this higher stress level at the end of their day. The “after” commute data reflects no statistical difference between the modes. This may appear strange, however there are reasonable explanations to explain this result. The first findings show a higher initial stress level for VP that appears to be overcome by the commute itself. The higher initial result appears to either mitigate stress for the VP while increasing for the SOV as the commute progresses. Looking back on the data from the second methodology applied, it appears as though a combination of decreased stress for the VP and an increase in stress for the SOV produces the result. It should be noted that the average difference for VP shows a .52 differential decrease in stress between the start and finish for VP. Conversely, there is an average .40 differential increase in stress for the SO commuter. Vanpool is the only group to show an actual decrease in stress level as a result of the commute.

The fourth methodology applied to the dataset (CI proportions) asked what the differential in proportion between VP and SOV was, with respect to the before- and after-commute delta of the stress level. No additional stress or a reduction in stress would be data of importance. Only the delta with respect to no change, or reduction from pre- as well as post-commute is counted to determine the proportion between the two groups. Morning results show an average of (18 to 55%)CI95 VP users had either no change in stress or reduced stress compared to their SOV counterparts. For the evening, there is an average of (47 to 85% CI95) VP users who had either no change of reduced stress levels compared to the SOV.

The fifth methodology applied to the dataset (CI proportions) ignores any difference between the morning and evening commutes, and determines the overall difference in proportion between VP and SOV with respect to commute stress. This is a combination of all the differential data. A negative score means that stress increased. A positive score means that stress decreased. A zero score means there was no change. The positive and zero scores were counted for the VP and SOV groups using 60 as a divisor (total count). On average, between (37 to 66%)CI95 VP users had no change in stress or reduced stress compared to their SOV counterparts.
Performing five different confidence intervals was a way to ensure the individual actions were replicating results of the overall findings. The mean identified through the descriptive statistics was then used to compare the high level findings and reflect the actual reduction (as observed in the vanpool results) with the increased stress level (as observed in the SOV results).

OVERALL OBSERVATIONS

The evening commuters appeared to be better with regard to stress than the morning commuters. Future research should focus on explaining a commuter’s ability to handle stress at the end of their day better than at the beginning of it. The only category of commuter that resulted in less stress after their commute was the evening vanpool group. This could be an important behavioral marker to note; the vanpool group was able to start their evening at home with lower stress, which could be beneficial to the individual; further research is required to understand why. All other categories showed an increase in stress after the commute. It is important to note that in the morning although both categories reported an increase, the vanpool group’s increase was minimal. Other than the “within VP and SOV CI,” all other applied methodologies were conducted assuming unequal population variances. In order for the outcomes to have broader applicability, future research should expand to areas outside of California to determine if the outcomes are consistent.

Healthy Stress Levels

The American Psychological Association “Stress in America” study shows that in 2014 the Average American level of stress is 4.9 on a scale of 1-10. The level of stress that those same individuals felt on average would be a healthy level of stress is 3.7 (9) This would require a reduction of 1.2 points, a 24% reduction of their stress level, to achieve what respondents perceive to be a healthy amount of stress. What combination of changes would account for that much change to achieve the targeted stress level? It would appear that there is an opportunity to assist in identifying ways that the average American could reduce their levels of stress. Utilization of vanpools or SOVs appears to be a contributing factor to either an increase or decrease in stress level. Further research is necessary to identify if these results can be replicated against other modes of transportation. As an overall goal of making healthy choices, determining a commute choice that supports stress reduction would be a good strategy.

Closing Remarks

A study performed by the Transportation Research Board (TRB) from the United States determined that both demographic variables and attitudinal factors are important and significant in explaining mode-choice behavior (10). The many questions raised as a result of this study, such as “what other contributing factors could explain the difference in stress before and after the commute?” or “will other modes of transportation reflect similar reductions?” etc. reaffirm a need for ongoing research in commuter decision processes. Future research should account for additional perspectives including a study on stress before joining a rideshare arrangement and then measured afterward. Such future research if commissioned by a governmental agency could diversify the dataset by including more regions of the U.S. and Internationally. Understanding the underlying factors that allow certain individuals to choose one transportation mode over another can assist the field of MaaS in making educated choices for their service networks. This study provides a unique perspective into potential (perhaps even unrealized) motivating factors for vanpoolers as well as single occupant drivers.
REFERENCES


Can we Design Mobility Services accounting for Complexity and Social Justice?

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ABSTRACT

Recent convergent development of sensing, computation, and communication technology is enabling the advent of self-driving vehicle (SDV) technology. Moreover, general advances in digitalization and smartphone use are enabling the advent of mobility services, exemplified in a Mobility as a Service (MaaS) concept. Considering the potential societally-wide disruption stemming from SDV technology and MaaS, a need arises for simultaneously considering the development of mobility technologies and services. In the spirit of Value Sensitive Design, as socio-technical systems, mobility system design has to account for underlying behavioural aspects alongside the technological interdependencies. Moreover, in the spirit of liberal theory of justice, mobility system design has to account for how advantages and disadvantages will be distributed among users. The objective of this research is to provide a proof of concept for possibility of such a design approach. The basis for this research is a version of Priority System (PS), developed as integrated mobility and traffic management framework. Based on the explicit formulation of complexity and social justice requirements, PS provides an opportunity for the user to select a Priority Level for her trip, in addition to destination and route. Moreover, PS includes a scheme of non-monetary Mobility Credits, and has a direct relations for SDV control at the intersection, route, and network level. In addition to elaborating PS, in order to evaluate the prosed concept, we have used a web-based experimentation with human subjects interacting with a version of PS. Thus, this paper focuses on development of web-based experimentation for allowing user interaction with PS. In addition, this paper will present the information collected from web-based experiment. Findings include in-depth insights into human decision-making within the proposed mobility management framework. In addition, the paper presents a summary of respondents’ comments related to proposed management framework and technology in general. Finally, the paper presents a summary of results, conclusions, and recommendations for further research, emphasizing upon the need for understanding human decision-making and potential in using web-based environment for further participatory development of both SDV and MaaS technology.

KEYWORDS Self-Driving Vehicles, Mobility as a Service, Traffic Control, Social Justice, Web-Based Experiment, Value Sensitive Design
INTRODUCTION

With the ongoing development of self-driving vehicle (SDV) technology [1, 2], there is a range of questions that emerges too. Considering that in the last stage of development, SDVs will be able to perform all safety-critical driving functions and monitor roadway conditions for an entire trip, the current vision is that user’s responsibility will be limited solely to destination and navigation input [3]. As a result, SDV technology could improve traffic safety [4], improve the mobility of people unable to drive [5], mitigate the environmental impacts of automotive transportation [5], and increase operating capabilities from road infrastructure [6]. With the simultaneous development of SDV technology, we also see a range of efforts in development of Mobility-as-a-Service concept and technology. However, the vision for these mobility technologies primarily focuses on potential benefits (e.g., [6]), underestimating the complexity of technological evolution. One important point that technology designers might not be aware is that, as other technologies [7-9], transportation technology evokes and influences user’s behavior. In addition, focusing on assessing how efficiently technology achieves its operational goals, might neglect how responsive technology is to social, moral, and political values [10, 11]. Considering that both SDV and MaaS technology are in their foundational stages of development, this is a crucial stage allowing us to rethink some fundamental premises and develop a sustainable technology – technology that can fulfill our current needs but not restrict the needs of the future generations [12, 13]. With this in mind, the approach presented here will be analogous to the Value Sensitive Design approach [14-16].

The core value taken into consideration in this research is social justice. In essence, social justice refers to the structure that determines how advantages and disadvantages from certain technology are distributed in a society [17]. We have based our consideration of social justice upon a theory proposed by John Rawls [18]. Consequently, mobility management framework has been developed as a version of Priority System (PS). This PS allows the user to select a Priority Level (PL) for their trip with SDV. A general ideas is that each vehicle is supposed to use their PL and in communication with other SDVs at an intersection, can determine who receives the right-of-way. Although there have been several previous research efforts for developing traffic control mechanism for SDVs (e.g., [19-21]), this is the first attempt to enable end-user responsibility in the management process.

Considering that initial development of PS is presented in a different paper, this paper will focus on web-based experimentation for allowing user interaction with PS. In addition, this paper will present the information collected from web-based experiment to develop simulation scenarios and consequently evaluate PS operation at an isolated intersection. First, we will present our methodological approach, followed by details of the web-experiment development. In addition, this paper will present results from web-based experiment. Finally, the paper will present a summary of respondents’ comments, followed by conclusions.
METHODOLOGY

Priority System

As argued elsewhere [22], mobility management technology in general directly affects following universal and fundamental human rights [23]:

1. right to life,
2. right to freedom of movement, and
3. right to equal access to public service.

Considering that these rights are universal and fundamental for every human being, as prerequisite for carrying out life’s plans, it becomes an imperative for mobility management technology not to promote an unjust distribution of restrictions to these rights. This is why an underlying framework of social justice within mobility technology is an important point to consider. Consequently, there is a relation to a management objective, and in this case we relate it to travel time or delay per user.

John Rawls has developed his theory based on the principles of liberty and equality. Essentially, Rawls’ framework is arranged to protect the inviolability of the user and maximize the benefits of the least advantaged in the complete scheme of equally shared by all [24]. Rawls’ principles have been used to structure a framework for development of new technology. Considering that the inviolability of the user is the most important point in this framework, this can be translated as emphasizing the distribution of delay among individuals, and not solely emphasizing upon the total delay for an approach, an intersection, or the whole transport system. In order to protect the inviolability of the user, management principles are developed to allow for greater responsibility of end-user in the management process. Enhancing end-user responsibility is envisioned to emphasize long-term and large-scale cooperation for the mutual advantage of individual user, and to support a just structure. In addition, such a mobility management framework has to account for complexity of human behavior, especially in the context of preventing user usurpation. Thus, we have primarily focused on human tendency to cooperate [25], especially in cases with reciprocity [26, 27], because people care about outcome for other people and greater social goals [28, 29], if they perceive that other people cooperate [30], if there is reputation building [30] or sanctioning system [25].

At this current stage of development, within PS, a user can select a PL for each trip, in integer value from one to four. These PL is then used to determine the right-of-way between SDVs approaching intersection, where SDV with the higher PL has the right-of-way over the SDV with lower PL. Consequently, PS is similar to the priority queuing principles [31], where a user is selected for service if it is the member of the highest priority class. However, the users within a class are selected upon FIFO principle. For example, one person would assign “very high priority” one day, due to the emergency that trip has (e.g., trip to the hospital). The other person for the same day would assign “low priority” since the trip has leisure as a purpose. In the case when these two vehicles approach the same intersection at approximately similar amount of time, the vehicle with “very high priority” would be the first one to receive right-of-way, relative to the vehicle with “low priority”. The users in this situation might have respectively inverse roles in other situation, and would achieve the respectively inverse result. This is underlying an agreement between vehicles in a system of cooperative production – person A will yield to person B today when person B needs right-of-way, under agreement that person B will yield person A tomorrow, when person A needs right-of-way.
However, in order to avoid user usurpation of the PS, there has been developed a system of non-monetary Mobility Credits (₡). In the initial assignment, each user should receive identical amount of 20 ₡. Spending/gaining of ₡ relates only through PL selection, with uniform rules for all users (Table 1). In addition, there is a ₡ ceiling, being a maximum number of ₡ that individual user can have. In addition to these rules, there is a series of other rules proposed elsewhere. Considering that this is the initial development stage, the research team has decided to implement the simplest version of PS to potentially obtain greater insight about a potential range of issues. Details on the control framework model are presented in [32-35].

**Table 1: Initial ₡ system in relation to Priority Levels**

<table>
<thead>
<tr>
<th>PL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>₡</td>
<td>+2</td>
<td>0</td>
<td>-2</td>
<td>-10</td>
</tr>
</tbody>
</table>

Methodological Approach

For the research approach, the research team has decided to use web-based experiment. Web-based experiment is selected because of faster speed, lower cost, greater external validity, the ability to experiment around the clock, high degree of automation of the experiment leading to low maintenance costs and limited experimenter effects, and wider samples than in person experiment [36]. Moreover, comparison of web-based experiments with in person surveys have showed similar results [37]. For example, Gosling et al. found that internet samples are relatively diverse with respect to gender, socio-economic status, geographic region and age; that findings were not adversely affected by non-serious or repeat responders; that findings are consistent with those from traditional methods [38]. Similarly, Meyerson and Tryon conducted a study to evaluate the psychometric equivalence of online research, and concluded that data gathered was reliable, valid and reasonably representative, as well as noting that the process of gathering data was cost effective and efficient [39]. However, there are comparisons which have shown differences. Dandurand, Shultz and Onishi found that online participants were less accurate in their performance of tasks than lab-based participants completed their task less accurately than their lab-based participants, they attributed it to the possibility that online participants may have been simultaneously working on other things or have been distracted while completing the task [40]. With this in mind, the design of this web experiment will specifically focus on attracting and maintaining attention of the participant.

**WEB-BASED EXPERIMENTATION**

Experiment Setup and Development

For user experiment, research team has decided to develop a custom website (approved by Institutional Review Board VT IRB 14-542). The purpose of web-experiment was to collect information on user decision-making within PS, and opinions related to PS. Experiment was anonymous and subjects had to be over 18 years old to participate. In total, the experiment was developed not to require more than 10 to 15 minutes of time commitment. Since it is web-based, experiment can be performed at any location with Internet connection. Information from the experiment was collected in a database on a secure server. In addition, the website is stored on external service with Secure Sockets Layer (SSL) encryption. Hyperlink for experiment was distributed via Virginia Tech news, listservs, and using LinkedIn website, mostly on groups related to transportation or autonomous vehicles. In addition to root page, where subjects starts the experimental process, there were five more pages: consent, info, experiment, exit, and contact page.
As already mentioned, web-based experiment provides respondent with autonomy and convenience for participating. However, previous research recommends that other elements are incorporated (e.g., shortness of experiment, shortening loading times, interesting content, emphasizing contribution, etc.) [41]. Recommendation is that website needs to have aesthetic quality, convey trust in online entity, has interactive elements, simplified instructions and extroverted writing style. Moreover, design needs to take into consideration elements such as font size, color, ability for normal reading, expected location of the content, etc. [42]. These design elements were implemented throughout the website pages. Finally, the user can enter a raffle for a chance to win a $50 gift card or can provide their name and approximate location for a list of contributors that will be publically listed on the experiment’s website. The diagram of web-page structure and diagram of user activities and decision-making steps during an experiment are presented on the left and right side of the following figure, respectively.
Figure 1: Diagram of web-page structure and diagram of user activities and decision-making steps during an experiment
• Consent page
On the first web page (top left part of Figure 2), similar to a consent form, subject was presented with information on the study purpose, who is conducting the study, expectation from the participant, risk, benefits, anonymity and confidentiality, freedom to withdraw, and contact info [43]. This page is intended to emphasize confidentiality, and to include information that will increase trust in researchers [41, 44]. Self-disclosure has been done using LinkedIn profiles from research team members to establish rapport. In addition, it was important to include information on how long the experiment will last, and that participant’s contribution will affect the design of technology [45]. Finally, participants are also asked to provide consent at the end of this web page by clicking on the button for Info page.

• Info page
After providing consent and continuing to the info page (top right part of Figure 2), subject is presented with detailed information about the operation of Priority System, and trip parameters for decision-making in the web experiment.

• Experiment page
On the third page (lower left side of Figure 2), the participant is supposed to interact with the management framework. Participant is expected to select PL based on information about his/her hypothetical trips and ₡. In addition, participant can provide information on his/her reasons for decision to select a specific PL. Subject can be involved with the experiment as long as they prefer, and as many times as they prefer. The limit of minimum 10 interactions within one experiment is set to be eligible for entering the raffle. Considering that even the design of PL selection button can affect user’s decision-making [41, 44], research team decided to use radio button since it provides the simultaneous visual overview of all PLs. In addition, PL 4 or PL 3 buttons would dynamically disappear, based on the number of available ₡. The button “Next trip” was used to provide the participant with the information about the next hypothetical trip, and to store previous PL selection and comments. In addition to this button, there is an “Exit” button, used to lead participant to an Exit page. This is preferred option, since participant can be debriefed about the experiment, and prevented from simply closing the browser tab and leaving the experiment [45].

In addition, trip parameters used in the experiment, along with their distributions and values, is presented on Table 2. Trip purpose distribution has been approximated from National Household Travel Survey for 2009 [46], taking into consideration respective frequencies between different trip purposes. Based on the interviews, time obligations are divided into three categories, as without time obligation, with time obligation, and with strict time obligation (Table 2). In addition, there were estimates of time delay per trip purpose (Table 2), which were also as time obligation approximated from previous interviews with users. For web development of experiment mechanism, research team used PHP, general-purpose scripting language [47]. Specifically, for generating random numbers, rand, a PHP function that generates random integers between certain interval [48]. Finally, every time any user follows the webpage link, new user id is assigned, thus allowing different users to anonymously participate in the experiment several times.
Table 2: The distribution of trip purpose, time obligations, and time delay

<table>
<thead>
<tr>
<th>Trip purpose</th>
<th>Distribution</th>
<th>Time obligations (uniformly random)</th>
<th>Time delay (uniformly random)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopping</td>
<td>20%</td>
<td>W/o</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/strict</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-20</td>
</tr>
<tr>
<td>Holiday</td>
<td>8%</td>
<td>W/o</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/strict</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-40</td>
</tr>
<tr>
<td>Social</td>
<td>17%</td>
<td>W/o</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/strict</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-20</td>
</tr>
<tr>
<td>Entertainment</td>
<td>5%</td>
<td>W/o</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/strict</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-15</td>
</tr>
<tr>
<td>Personal</td>
<td>19%</td>
<td>W/o</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/strict</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-15</td>
</tr>
<tr>
<td>Work/school</td>
<td>29%</td>
<td>W/o</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>W/strict</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-15</td>
</tr>
<tr>
<td>Medical</td>
<td>2%</td>
<td>N/A</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
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<td>0</td>
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<td>-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-5</td>
</tr>
</tbody>
</table>

• Exit page

After experiment page, user can reach exit page (lower right side of Figure 2). Remembering that attracting participant’s interest are crucial issue with web-based experiment, experiment design included an option for users to submit their email for a raffle after a certain number of experiment iterations, and to submit their name and approximate location for public announcement of contribution. Research team decided to use online gift-certificates so that subject can redeem their certificate without revealing their identity. In addition, on the final page of the experiment, subject will also have an option to provide his/her opinion related to Priority System, as a part of debriefing from experiment page.

• Contact page

Finally, from each web page, the user has an option to contact the research team, for questions or to report a problem [45].

Figure 2: Screen shots from consent, info, experiment, and exit page
Web-based Experiment Results

After closing the web experiment, there has been total of 266 participants. Minority of participants provided less than ten or more than 100 PL selections (maximum is 350 PL selections), with an average of 34.1 PL selections and median of 20 PL selections per participant. In reality, PS is envisioned for long-term interaction, so experiment results present only a part of the potential number of situations. Consequently, behavior of participants might be primarily short term, and relying on their imagination to consider their decision-making in specific situations. Considering that experiment results were stored in a database, research team has used SQL queries to extract and group results.

Following several figures (from Figure 3 to Figure 9) show the number of selections of each PL for different trip purpose, and varying by time obligation and expected delay. From these figures we can observe user tendency to select certain PL depending on the trip purpose, time obligation, and expected delay. One can also observe a shift from tendency to select one PL to tendency to select other PL as trip parameters change. First, one can see that user tend to select lower PL for shopping, social, entertainment, vs. holiday, personal business, work/school, and medical trip purpose. Second, one can notice that users tend to select lower PL if the estimated delay is negative vs. when estimated delay is positive. Similarly, for time obligation, users tend to select lower PLs when there is no time obligation, as opposed to trips with time obligation.
Figure 3: Number of selections of PL for shopping trip purpose, varying by time obligation and expected delay
Figure 4: Number of selections of PL for social trip purpose, varying by time obligation and expected delay
Figure 5: Number of selections of PL for entertainment/sport trip purpose, varying by time obligation and expected delay.
Figure 6: Number of selections of PL for holiday trip purpose, varying by time obligation and expected delay
Figure 7: Number of selections of PL for personal business trip purpose, varying by time obligation and expected delay
Figure 8: Number of selections of PL for work/school trip purpose, varying by time obligation and expected delay
Figure 9: Number of selections of PL for medical trip purpose, varying by expected delay

In addition, Figure 10 shows number of PL selections per PL and based on the available ₡ for the user. One can observe that most of the selections were done at 24, 22, and 20 ₡, but that users were selecting at all ₡ values. However, selection of PL 4 does not occur at below 10 ₡, and selection of PL 3 does not occur at 0 ₡. In addition, the ratio of PL selected is similar for great majority of available ₡ values, where the frequency of PL selection is inverse to PL value.

Figure 10: Number of PL selections based on Priority Credits available

Figure 11 shows examples of three types of user behavior in selecting their PL in relation to available ₡. Participant 64 is an example of risk averse user, always trying to remain around maximum ₡. Participant 7 is an example of user trying to remain above 10 ₡, as a critical value for selecting PL 4. Finally, participant 59 is an example of user that covers a wide range of ₡ values. The last type of the user tells us that there might be influence from shortness of the experimentation period, since participants might not be immediately focusing on ₡ saving.
Figure 11: Examples of PL selected in relation to Priority Credits available
Further analysis shows that, from 8311 PL selections, 392 of these selections (4.7%) were at 0 ₡. Having in mind that the framework was envisioned to deter users from reaching 0 ₡ (since user cannot select either PL 3 or PL 4 at that point), this is not a significant percentage of situations. Consequently, we can conclude that only a small percentage of participants was not assuming interaction with PS on a long-term basis. However, there is a learning process involved when users arrive to 0 ₡ in long-term system operation, that could potentially resulting in better ₡ management after the initial period. In addition, average PL selected was 1.8, while median PL selected was 2, confirming previous observation that participants mostly tend to select PL 1 and PL 2. This was the intention of the framework, thus deterring the overuse of higher PLs.

Web-based Experiment Comments

In addition to PL selection, there are comments that participants provided during PL selection, and on the Exit page. They are organized into following five groups.

1. Positive features
   • Ability for user to prioritize and use highest PL for emergency situations.
   • PS is forcing users to think about their choices and to plan ahead their time.
   • PS deters abuse (e.g., with the maximum limit for ₡, high ₡ value for PL 4).
   • Fair ₡ distribution and ability to save.

2. Potential for system failure
   • Concern from self-centered human nature and differences in evaluating different PLs that might lead to inflated sense of urgency and frequent selection of higher PLs.
   • Favoring individuals with more education, planning or management skills.
   • Remaining without ₡ but facing an emergency situation.
   • Using meaningless and short trips to accumulate ₡.
   • Alternating between assigning PL 1 and PL 3.
   • No incentive to select PL 1 once ₡ are at 24.
   • Users that do not drive much could use higher PLs more often.
   • If an area simultaneously accommodates many users with medical conditions or appointments, where users assign high PLs all the time.
   • Incentive to spend ₡ when a user has them.

3. Further development
   • Priority credits should be tied to an individual instead to a vehicle.
   • PL should be adjustable during the trip, as the need arises.
   • Highest PL should be only activated by external mechanism (e.g., calling police).
   • PL should be assigned and ₡ lost/gained based on destination and arrival time needed.
   • There should be a mechanism for post-activation verification for highest PL and for spending/gaining ₡ (e.g., medical emergency).
   • There should be a separate emergency ₡.
   • There should be different mechanism for gaining ₡ (e.g., reporting incidents, using zero emission vehicle, using active or public transportation).
• The importance of PLs should be inverse (PL 1 being the most important).
• PS should be combined with trip information service to reduce system abuse.
• There should be minimum distance or minimum amount of time SDV needs to be stationary for receiving 
₡.
• There should be maximum number of 
₡ user can gain during certain time.
• Medical emergencies should not cost 
₡ or there should be
• Low PL trip with no conflicts at an intersection should not gain 
₡.
• PL should be determined by someone who is unbiased (e.g., third party customer representative).
• User should know in advance how long it will take to travel with each PL.
• Route, speed, or road lane for SDV could be determined based selected PL.
• There should be an option for combining several PLs and their 
₡ for carpooling.
• There should be three or five PLs, without PL that does not lose or gain 
₡, or with higher max 
₡ but along with higher 
₡ loss for selecting higher PLs.
• Activation of highest PL (or separate emergency PL) should drive SDV to the nearest hospital, with fines for misuse.
• PL 4 should only be available for selection if SDV’s destination is on the predefined list (e.g., hospital).
• Gain of 
₡ for lowest PL should have higher value.
• PS should be setup differently for delivery vehicles, taxis, or infrastructure support vehicles (e.g., more 
₡, less PLs).
• Loosing and gaining 
₡ based on the number of 
₡ that user has (e.g., as 
₡ number increases, gaining less 
₡).
• People that need frequent medical care or voluntary firemen should have more starting 
₡.
• There should be monetary component related to PLs or 
₡ (e.g., either as paying, exchange for bitcoins, or as market).
• Further development will need to take into consideration local culture, values, etc.

4. User factors
• Estimated arrival at destination (e.g., depending on departure time or trip duration)
• Value of time punctuality and consequences
• Culture and habits (e.g., value of time, acceptance for being late to social events vs. doctor’s appointment, level of relationship, ability to call ahead, ability to “blame it on traffic”, understanding for repeated lateness to social events because of other obligations, acceptable arrival window for activity, dinner reservation, being always late for social events)
• Relative importance of the destination/activity (shopping low, plane important but not as emergency)
• Other people involved or in the vehicle
• Next obligation (e.g., shopping might not be important, but might become based on the next activity)
• Time available in the day
• 
₡ (e.g., being around 10 
₵ as a critical value for selecting PL 4, intention to save or gain 
₵)

5. General points
• Concern about mechanical failure, hacking, and illegal market for buying/selling priority credits
• Perception of transportation as a service and “selling” arrival on time
• Complexity of trip in time and space and relation to PLs (e.g., higher PL does not mean getting somewhere faster)
• Not losing inherent flexibility in human driving
• Getting used not to have control over the vehicle and the issue that removing a sense of agency from driver that is late can increase stress level
• People do make distinctions between different trips within the same trip purpose – holiday trip to the lake and one that involves taking a plane are not valued equally
• An opinion that an expert system would work better
• Reevaluation of travel time with impact from SDV technology
• Perception that automated vehicles will improve traffic conditions
• Need for real scenario testing and evaluation

In addition, there are several other points concluded from users comments:

• Small number of users would prefer first come, first serve principle instead of priority.
• Participants suggested that there is a need for wider diversity of activities listed in trip purposes, since an activity can significantly influence PL selection.
• There were several cases when participant’s decision-making was primarily made from individual perspective, not necessarily taking into consideration other people in traffic. Consequently, there is a need for greater emphasize on cooperation and altruism when presenting PS.
• The arrival time window (i.e., how early or how late one should arrive) highly depend on the activity.
• Low ₡ number in combination with long estimated travel time and less important activity can influence people to change their departure time.
• Some users expect that other people should plan their daily activities well, and do not support the notion that lack of planning should validate for higher PL.

CONCLUSION

In order to evaluate proposed management framework, this research has implemented a revised Priority System into a web-based experiment. Web-based experiment was developed as a series of web pages, obtaining consent, providing information, and allowing the subject to interact with PS. Provided with hypothetical trip information and his own ₡, user was supposed to select PL per trip. Results from web-experiment show us that PL selection was altruistic and PL 4 was not selected often for trip purposes different from medical. Consequently, the frequency of PL selection is inverse to PL value, confirming the intended “loss aversion” feature of PS. However, one can notice inevitable randomness in human decision-making, potentially originating from different interpretation individuals have related to trip information or the operation of PS. Moreover, the results were influenced by the short-term interaction perspective that most users had. In addition, web-experiment has provided insights into PS operation, and users have provided a range of comments related to positive features, potential for failure, further development, factors in user decision-making, and points related to SDV technology in general.

At the end, it is important to emphasize several points. Since the introduction of internal combustion engine and microprocessor technology, transportation has not faced a potential technological impact of this scale. Self-driving vehicle technology is bound to revolutionize transportation, and probably our societies as well. In our research approach, we have tried to aim beyond resolving immediate negative effects, but to take into consideration the long-term impact on society that this technology might have. First, this is specifically related
to the notion of common humanity, through our cross-generation responsibility for sustainable development of technology. Moreover, the standpoint for technological development considers that technology is a socio-technical phenomenon. Consequently, decisions related to design of technology seize to be solely technical decisions, but they tend to have direct social implications. In addition, technology is connected with political decision, and can consequently manipulate reality and favor certain social classes [49].

Following this line of thoughts, we cannot lack the conscious reflections on the morals in technology, because it shapes the context of humans as moral agents and consequently it shapes humans themselves. This research endeavor was not planned to provide a final solution, but to be used as proof that such an endeavor is possible. The long-term vision for SDV and MaaS technology will need to achieve a careful balance between the needs of multiple segments of population in the current and future generations. This result will never be accomplished without a wider discussion, including not just engineers and entrepreneurs, but general public as well. One sure point that this research has shown is the capability of web-based experimentation for redevelopment of PS or development of other approaches for anthropocentric mobility technology. In addition, online environment has a potential for providing space for reflective vision and critical conversations that could provide essential understanding of the relevant values and their function in lives of people and groups. Finally, this research has shown that there is a need for greater understanding of human decision-making and planning in relation to the proposed framework, but also in relation to trip planning taking into consideration a range of features future mobility technology might have.
REFERENCES


Abstract

This paper examines the ways in which business models for MaaS can generate sustainable value, that is, value that extends beyond the traditional ‘profit norm’ embedded in business models, and belongs to the economic, environmental and social dimensions of sustainability. We draw on the growing literature on sustainable business models to explicate a set of principles and guidelines for generating sustainable value, and address one key function of a business model that is often overlooked in this field – value capture. We then identify different ways in which MaaS business models can generate sustainable value, linked to mobility services, data-based services, environmental technology and material recirculation. We identify potential mechanisms for value capture, and discuss the implications of our findings for practitioners and future research.

KEYWORDS Mobility services, business models, value capture, sustainable development

1. Introduction

Generally, business models are increasingly recognised as a vital component of transitions towards sustainability (Bocken et al., 2014; Bocken and Short, 2016; Boons and Lüdeke-Freund, 2013a; Schaltegger et al., 2016, 2012; Stubbs and Cocklin, 2008). For example, several works have noted that new business models may unlock the economic potential of electric vehicle technology and assist in its adoption (e.g. Budde Christensen et al., 2012; Costain et al., 2012; Weiller et al., 2015), but there exists no such work on Mobility as a Service (MaaS), although it can, in principal, revolutionise the way we travel and has a huge potential to improve the sustainability of the transport system. Whilst is not presently clear which business model/s will underpin the development and adoption of Mobility as a Service, it is possible to outline the characteristics of a sustainable MaaS business model. This paper aims to address the following research question:

“What characterises MaaS business models that deliver improvements in the economic, environmental and social sustainability dimensions?

In order to address this question, we must first tackle the sticky problem of understanding how to treat MaaS as a concept that currently lacks a formal and robust definition. MaaS is often described as an alternative to private vehicle ownership that combines different types of mobility services as part of a single, seamless offering made available to users via subscription-based smartphone applications (Beutel et al., 2014; Goldman and Gorham, 2006; Sochor et al., 2015), and is also referred to using the rubrics ‘combined’ or ‘integrated’ mobility services. However, the MaaS concept can refer to different types of services, and there are several ‘things’ that can be integrated within any MaaS initiative. Also, at the current, pre-commercial phase, it makes little sense to attempt to define MaaS as the field is in a state of fluidity, with several innovative concepts being tested. Hence any pre-emptive definition would run the risk of quickly becoming redundant, especially given the current level of hype around the MaaS concept. Instead, it is better to treat MaaS in
topological terms by classifying different elements in terms of what may be integrated in a single service (Table 1).

A business model is commonly referred to as a device for creating, delivering and capturing value (Chesbrough, 2010; Johnson et al., 2008; Osterwalder and Pigneur, 2010; Teece, 2010; Zott et al., 2011; Zott and Amit, 2010). Hence in order to examine what characterises sustainable MaaS business models, it is important to consider: 1) the concept of sustainable value; and 2) the ways in which MaaS, as a topological phenomenon, can be translated into a set of business models that create, deliver and capture sustainable value. These two points underpin the structure of this paper, which consists of four sections, of which this is the first. The next section outlines the methods deployed, focusing on an integrative literature review. Section three presents our main findings, outlining a set of principled arguments regarding sustainable MaaS business models, supported by practical examples. The last section concludes with a set of implications for practitioners and further research.

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<tr>
<th>Level of integration</th>
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<td>Integration of societal goals</td>
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<td>Integration of the service offer</td>
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Table 1: Different levels of integration within MaaS and value generated. Source: Sochor et al. (2017).

2. Methodology

MaaS has been described as a concept that can deliver sustainability gains in terms of reduced congestion and transport emissions and improved accessibility. MaaS is also billed as an innovation opportunity, underpinned by the development of new business models in transport, such that it can deliver economic benefits. Until now, however, little has been done to examine how business model innovations in the MaaS field can generate sustainable value. To address this shortcoming, we performed an integrative literature review, which is defined as “a form of research that reviews, critiques, and synthesizes representative literature on a topic in an integrated way such that new frameworks and perspectives on the topic are generated” (Torraco, 2005, p. 356). Here the topic in question is related to the way in which different MaaS business models can generate sustainable value. Given that this topic is not addressed by any single literature, we elected to focus on existing literatures on business models and the related subfield of sustainable business models, together with the more general literature on mobility services. In perusing these literatures, we sought to identify and synthesise a set of key ideas, concepts and principles that can be used to address our research question (What characterises MaaS business models that deliver improvements in the economic, environmental and social sustainability dimensions?). The overall aim was to deliver a fresh and consolidated perspective on how MaaS can generate sustainable value that is useful for MaaS practitioners when designing and further refining MaaS services, and a basis for further research on this topic.
3. Sustainable business models for MaaS

Many practitioners argue that MaaS comprises a user-centric approach, suggesting that creating user value is the main aim. However, MaaS can and should aim higher than this by contributing to the development of a more sustainable transport system. Generally, mobility services such as car sharing are recognised for their sustainability attributes, in terms of better urban management; improvements in energy efficiency and urban air quality; greater use of renewable fuels; reduced congestion and improved accessibility (Greenblatt and Saxena, 2015; Greenblatt and Shaheen, 2015; Rydén and Morin, 2005). The limited evidence available suggests that MaaS can bring about more sustainable forms of travel behaviour (Karlsson et al., 2017; Karlsson et al., 2016; König et al., 2016b; Sochor et al., 2016a, 2016b, 2015a, 2015b, 2015c, 2014; Strömberg et al., 2016). Taken together, these studies indicate that MaaS has the potential to generate sustainable value that benefits more than just individual users.

Considering the ways in which MaaS can generate different types of value brings us squarely to a discussion on business models. What types of value does MaaS generate? For whom? Which actor/s are able to capture and distribute different types of value? And what characterises MaaS business models that generate sustainable value? These issues are discussed in the following sections.

3.1. What is a business model?

Generally, a business model is regarded as a device for creating and capturing value, and for delivering that value to customers (Chesbrough, 2010; Johnson et al., 2008; Osterwalder and Pigneur, 2010; Teece, 2010; Zott et al., 2011; Zott and Amit, 2010). The concept of a business model is rather new and is thus not robustly defined. However, one oft-cited definition is provided by Teece, (2010, p.179):

“A business model describes the design or architecture of the value creation, delivery and capture mechanisms employed. The essence of a business model is that it crystallizes customer needs and ability to pay, defines the manner by which the business enterprise responds to and delivers value to customers, entices customers to pay for value, and converts those payments to profit through the proper design and operation of the various elements of the value chain”.

The above definition makes it clear that traditional conceptualisations of business models consider how value is created for and delivered to customers, and how value is captured by firms. Other conceptualisations share this idea. The Osterwalder (2004) ‘canvas’, for instance, can be used to categorise different business model types, and describes nine constituent ‘building blocks’. These include: a value proposition (i.e. a product or service that is offered to customers), a customer interface, supply chain relationships, a financial model (i.e. a cost and revenue structure that distributes benefits across business model stakeholders), partners, distribution channels and other key resources and processes (Osterwalder, 2004; see also: Bocken et al., 2014; Johnson et al., 2008; Zott et al., 2011b). A broader conceptualisation, which focuses on the “total value creation for all parties involved” (i.e. suppliers, partners and customers) is offered by Zott and Amit (2010, p. 218). The latter characterise business models as ‘activity systems’, describing content (what is done), structure (how it is done) and governance (who does it).

Both the activity system approach and the Osterwalder ontology can be used to explore the network of contracts and agreements within different MaaS services, in other words how value is created, delivered and captured via value chain collaborations. Uber, for instance, relies on privately-owned assets (vehicles) that are made accessible to users via multi-sided platforms. Uber captures the value generated via provisional
fees on each transaction made via the platform. By contrast, MaaS Global and UbiGo creates value via a set of contractual arrangements with different service providers and by repackaging and bundling these services into a single offer. This value is captured via a subscription-based payment model. Yet neither the Osterwalder ontology nor the activity systems approach consider the ways in which business models generate sustainable value, that is, value for stakeholders other than the end-users of a product or service. In order to examine the way in which MaaS can generate sustainable value, we turn to the field of sustainable business models.

3.2. What is a sustainable business model?

The development of new business models is increasingly linked to sustainability (Bocken et al., 2014; Bocken and Short, 2016; Boons and Lüdeke-Freund, 2013a; Schaltegger et al., 2016, 2012; Stubbs and Cocklin, 2008). As a consequence, a body of literature on sustainable business models (SBMs) has emerged in the past decade. Similar to the work on corporate social responsibility, much work in this field has taken issue with the ‘profit normative’ orientation of business (Upward and Jones, 2016). The latter is critiqued for measuring firm success in terms of economic performance, serving a narrow set of stakeholders (i.e. shareholders). By contrast, SBMs aim to broaden the definition of value creation by integrating social and environmental performance into the fabric of business. SBMs are thus defined in terms of their ability to internalise the three sustainability dimensions into the core of business:

“A business model for sustainability helps [in] describing, analyzing, managing, and communicating (i) a company’s sustainable value proposition to its customers, and all other stakeholders, (ii) how it creates and delivers this value, (iii) and how it captures economic value while maintaining or regenerating natural, social, and economic capital beyond its organizational boundaries” (Schaltegger et al., 2016, p.4).

And:

“…a sustainable business model is one which is both sufficiently profitable and that results in a process of comparative absolute or relative reductions in environmental and socioeconomic burdens through the delivery of socially relevant products and services. Sustainability is not an absolute end-point, but rather an improvement process whereby future generations are progressively less prejudiced by contemporary practices” (Wells, 2016, p.3)

These definitions are successful in acknowledging the negative social, economic and environmental externalities of business, and note that SBMs are those which either reduce existing burdens (make things less bad) or have positive impacts (make things good). SBMs can thus be viewed as a subgroup of normative business models, referring to the set of norms that become embedded in business models through a process of institutionalisation (Randles and Laasch, 2016). A narrow view of shareholders, as profit maximisers, is what lies behind the critique of (unsustainable) business models as ‘profit normative’, as noted above. Here sustainability can be regarded as one set of norms and values among many, such that business models are pitched as capable of resolving a variety of societal issues (Randles and Laasch, 2016).

Related to the topic of sustainability norms embedded within business models, scholars have outlined a set of principles upon which to base SBMs. These include things like: resource efficiency, social relevance, longevity, localisation and engagement, ethical sourcing and work enrichment (Wells, 2016); sustainable supply chain management, the management of production and consumption phases, the equitable distribution

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1 Sometimes referred to as ‘Sustainability Business Models’ (e.g. Wells, 2016), or ‘Business Models for Sustainability’ (e.g. Abdelkafi and Täuscher, 2016).
of financial costs and revenues among involved stakeholders (Boons and Lüdeke-Freund, 2013); using a triple bottom line metric to assess performance, stakeholder engagement, environmental stewardship, and systems thinking (Stubbs and Cocklin, 2008; see also: Upward and Jones, 2016). This broad set of principles reflects the prescriptive tone taken within the SBM literature, which seeks to radically transform and reform societal structures and institutions in a broader process of transformation (Randles and Laasch, 2016).

One aspect that is overlooked in some studies from this field is that a business model is a mechanism for creating and capturing value. SBM scholars that do acknowledge the importance of value argue for a broad definition of it, as reflected in the following statement:

“…a business that contributes to sustainable development needs to create value to the whole range of stakeholders and the natural environment, beyond customers and shareholders” (Schaltegger et al., 2016, p.4).

Whilst the creation of social and environmental value is undoubtedly desirable from a sustainability perspective, the question of how firms can capture these types of value is largely left unanswered by the SBM literature. Traditionally, business models allow firms to directly capture value via sales of products or services, whose utility fulfils a customer need or want. Value capture is conducted through the market, where business models serve to assign prices to goods (products or services). Capturing value becomes much more complex when a market does not exist, rendering such goods uncommodifiable. This is arguably the case for many goods with social and environmental value, hence the economic terms ‘market failure’ and ‘externality’. Even in cases where public sector organisations create mechanisms to internalise externalities, such as subsidies for public transport, one can argue that a market exists. Hence public transport, which typically captures the social and environmental value inherent in its offering2 via ticket sales and subsidies, can be seen to have a financially viable business model. Where markets do not exist (e.g. creating social value for future generations) due to a lack of paying customers, designing financially viable SBMs becomes much more challenging.

The main challenge in capturing sustainable value is related to the concept of merit goods. A merit good is defined in terms of the private and public benefits inherent in its consumption, where the latter outweighs the former (Musgrave, 1957). In other words, the consumption of a merit good generates positive externalities (or less bad negative externalities) that are greater than private benefits perceived the individual consuming the good. An example may be the treatment of a contagious (yet not life-threatening) disease via medication, where the benefits of vaccination may be of greater benefit to the public than to the individual that is inoculated. The fact that the public benefit is greater than the private means that individuals under-consume merit goods in a free market, warranting state (or other third party) intervention. The importance of merit goods has been noted in studies on business models for shared mobility (Cohen and Kietzmann, 2014). Further, the public good aspect of public transport is what in many cases warrants support from the state coffers.

This reasoning can be used to understand the inability of firms in capturing sustainable value, due to the fact that the public benefits often outweigh those which are private. Hence we posit that for a MaaS business model to be sustainable, one cannot ignore the function of value capture. It is unlikely that any organisation (public or private) will aim to generate sustainable value if they cannot appropriate revenues directly or

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2 Public transport generates both social and environmental value, i.e. value for the collective, in terms of reduced emissions and congestion that would probably arise if it did not exist and travellers instead utilised private modes such as cars.
benefit via some other form of indirect returns (e.g. competitive advantage, market position, brands). How can firms capture such value?

There is evidence to show that environmental value can be captured indirectly. In a review of the literature on corporate environmentalism, Abdelkafi et al. (2013) argue that SBMs with environmental value propositions allow firms to enhance their brands; boost their image and reputation; attract and retain talented workers; improve resource efficiency; support higher sales volumes; reduce investment risks; attract financial capital; build trusting relationships with stakeholders; attract new customers; and promote customer loyalty. However, firms can experience difficulties in capturing environmental value, as in some cases environmentally-oriented firms demonstrate lower economic performance in comparison to firms that are not environmentally oriented (Linder et al., 2014).

There are some cases where environmental value can be captured directly as a result of paying customers that are willing to express their environmental concerns with their wallets, such as the growing market for premium electric vehicles (e.g. Tesla, Prius). However, the consumption of such goods is often also linked to individuals’ willingness to pay for products that confer a certain status or identity (e.g. the wealthy, environmentally conscious consumer). Firms can also capture the value of environmental value propositions directly by minimising waste (i.e. becoming more resource efficient), allowing for cost savings (Porter and van der Linde, 1995). Regardless of whether the value of an environmental value proposition is captured directly or indirectly, the ability to capture value is arguably dependent on the salience of environmental issues in the external business environment.

3.3. How can MaaS business models create, deliver and capture sustainable value?

In order to examine the potential for MaaS business models to generate sustainable outcomes, it is important to consider different types of MaaS services, the value they may generate, and ways in which that value may be captured. To reiterate, for a MaaS business model to be sustainable, one cannot ignore the function of value capture. Hence we now investigate ways in which MaaS business models can create, deliver and capture sustainable value.

Customer segments

Although MaaS currently lacks a robust definition, existing attempts to characterise the concept highlight some of its potential sustainability attributes. As noted in the introduction, Sochor et al. (2017) characterise MaaS in ‘topological’ terms, i.e. with reference to mobility-related services that exist at different levels of integration. Seen this way, MaaS comprises a set of different mobility-related services that can potentially generate different types of value, for private individuals and for broader publics. For example, there is evidence to suggest that a level 3 MaaS service, entailing the integration of different mobility services into a single offer: 1) is attractive to customers in terms of flexibility, convenience and cost; 2) may be a viable alternative to private car ownership; and 3) may encourage a shift towards more sustainable modes of travel such as public transport, walking and cycling (Karlsson et al., 2016; Sochor et al., 2016b, 2015b). Hence the value created by such services is delivered to:

1. Customers, who gain access to an attractive, cost effective and convenient mobility service;
2. The environment, via lower transport emissions);
3. Society, which benefits from lower congestion and improved accessibility.
Each type of value listed above can be captured by a level 3 MaaS operator via sales of the service to users. Note that the value captured by operators is redistributed to partners in the value chain. Partners must be alerted to the opportunities of collaborating in a MaaS ecosystem to overcome the tendency towards protectionism and risk aversion. That is, MaaS operators, acting as the focal organisations which capture the value generated by MaaS business models, must create an offer which allows partners (e.g. upstream transport service providers such as public transport operators and taxi firms) to expand their existing customer base. Further, MaaS operators must ensure that the value captured is distributed within the ecosystem in a manner that is just and legitimate among partners. Without this, transport service providers are unlikely to enter into partnerships as they will foresee risks of other actors cannibalising their offers, which is arguably the main reason public transport operators are currently unwilling to allow MaaS operators to resell the full range of available tickets. The upshot is that the viability of level 3 MaaS business models depends on their ability to attract customers from new market segments, namely those beyond their partners’ existing customer base. In practice, this refers to segments where customers either walk, cycle, or drive (or ride in) a privately-owned vehicle. For level 3 MaaS business models to be sustainable, however, they must also ensure shifts to more sustainable modes. The sum consequence is that the viability and sustainability of level 3 MaaS business models hinges entirely on their possibility to attract customers from the private car segment. Without this, the provision of low cost, convenient access to combined mobility services may result in shifts to modes which are less environmentally sustainable (e.g. travellers from the public transport segment may increasingly travel by car).

Similar arguments can be made for level 0 MaaS services such as station-based and free-floating car sharing initiatives. If the provision of these services does not attract users from the private car segment, then these services will likely not result in environmental sustainability improvements. However, car sharing can improve accessibility, which belongs to the social sustainability dimension. That is, users can gain access to a flexible alternative to taxis/public transport that grants better accessibility in towns and cities. Hence car sharing represents a potential trade-off between environmental sustainability and accessibility (note that this also applies to car sharing in level 3 MaaS). The trade-off between environmental sustainability and accessibility further accentuates the need for MaaS service providers to target existing and potential private car owners. Without this, the consumption of MaaS services will not result in the reduction of environmental burdens, and level 3 MaaS business models will not be feasible in the eyes of value chain actors. In other words, without targeting private car owners, the consumption of MaaS services will not generate sustainable value.

**Travel behaviour**

As noted above, while some scholars have noted that car sharing may facilitate shifts to more environmentally sustainable transport modes (e.g. Firnkorn and Müller, 2011), others have voiced concerns that modal competition may result in a shift in the opposite direction (e.g. from public transport to car sharing) (Stillwater et al., 2009). In reality, MaaS will likely facilitate modal shifts in both directions, that is, some users will shift from less-to-more environmentally sustainable modes, and others will move in the opposite direction to fulfil their accessibility needs. Hence in addition to attracting users that are currently within the private car segment, it is important that MaaS operators encourage sustainable travel behaviour by creating incentives for the utilisation of more environmentally sustainable modes and for ride sharing. In practice MaaS operators must find innovative ways to improve accessibility and promote environmentally sustainable travel behaviour, particularly in geographical contexts where public transport is sparser (e.g. rural areas). The simplest way
to create incentives is through pricing, such that more sustainable modes and ride sharing are made cheaper than less sustainable alternatives. In terms of environmental sustainability, the least pollutive mode within a level 3 MaaS service is walking, followed by cycling, public transport, car sharing and finally taxi. Pricing these modes in terms of their environmental impacts is not necessarily a challenge, as more pollutive modes are generally more expensive.

It may appear to be difficult for MaaS operators to capture the value of modes such as walking and private cycling, since they are not commodified within the business model (i.e. users do not pay to walk or use their own bicycles). However, it may be possible to increase savings if users elect to walk or cycle rather than utilise a mode that would entail a cost to MaaS operators (public transport, taxi, etc.). Similar arguments could be made for ride sharing and non-travel options such as virtual meetings. In practice, the opportunities to capture this type of value relate to the composition of payment models. Pay-as-you-go models disallow value capture, as users will only pay for their actual use, creating no incentives for MaaS operators to minimise costs. This is not the case for subscription packages, assuming users pay a lump sum for a predetermined travel allowance, and if rebates or deferrals are not provided for unused credits. In such circumstances, MaaS operators would be able to capture the value of walking and cycling in the form of cost savings. However, this type of payment model may have rebound effects if users rush to use up their credits prior to the start of a new subscription period (likely a new month). Notwithstanding, it does appear to be possible for level 3 MaaS operators to capture the value inherent in incentivising sustainable modal shifts. Aside from (or alongside) pricing, MaaS operators can create other types of incentives, through mechanisms such as nudging and gameification, that encourage sustainable travel behaviour. These types of mechanisms can be directly integrated into MaaS software applications, and value can be captured in the same manner described above.

**Data-based services**

One way in which to better understand modal choice in MaaS-based transport systems is to leverage the power of big data analytics. Willing et al. (2017) review the literature on multimodal platforms (MMPs), which refer to a range of information services that allow travellers: to compare different transport options; to make informed selections according to preferences (usually trip duration and cost); and to plan and re-plan trips en route (see also: Motta et al., 2015). Some MMPs also facilitate bookings and payments (cf. levels 1 and 2 in the Sochor et al. (2017) topology). Most MMPs provide informational services for free, and collect user data which is typically anonymised and aggregated before being put to use.

Aside from individual travellers, data analytics can be used to create value for different stakeholders in the MaaS ecosystem, including transport service providers and government or regulatory bodies. Transport service providers, for instance, can gain real-time data on customer demand, which can help to deal with tasks such as the relocation of shared cars in free-floating systems; to optimise service coverage according to geographical and temporal variations in demand; and to understand revealed user preferences regarding modal choices as a means to improve the service offer (Willing et al., 2017). This type of data is also of interest to governmental bodies such as city planners and municipalities, who are charged with the responsibility of minimising congestion and governing infrastructures such as roads and parking (Motta et al., 2015; Willing et al., 2017). Arguably, the value of big data analytics has network effects – as more data is generated the value becomes greater in terms of private and public benefits. Hence as (or if) MaaS services proliferate, the sustainable value that data analytics generates will increase. The value of data analytics is likely created by MaaS integrators, a role in the ecosystem which refers to ICT platform providers (i.e. actors that provide
access to and operate multimodal platforms) (Smith et al., 2017). The value can be captured, in principal at least, via sales or agreements with stakeholders such as transport service providers, MaaS operators, city planners, municipalities, and transport authorities. Integrators may also capture value via advertising revenues in a similar way as actors such as Google generate revenue streams, or via provisional fees for individual transactions (e.g. ticket sales).

Resource efficiency

Changes in travel behaviour in the form of modal shifts and ride sharing can reduce the environmental impacts of the transport system. These types of actions improve the resource efficiency of the transport system by reducing the number of material inputs (e.g. vehicles, road infrastructure) required to fulfil user needs. The resource efficiency of the transport system also depends on the technologies deployed within vehicles and is critical to the decarbonisation of the transport system. This can be realised by introducing environment friendly technologies such as electric vehicles into MaaS fleets. Autonomous vehicles may also have a role to play in reducing transport emissions (Greenblatt and Saxena, 2015; Greenblatt and Shaheen, 2015). Can MaaS business models generate sustainable value via the deployment of environment friendly vehicle technologies?

Generally, it is widely understood that there is a link between business models and technology. Although the two are distinctly separate concepts (Baden-Fuller and Mangematin, 2013), business models are mediating devices that capture the value of technology and deliver it to customers (e.g. Chesbrough, 2010; Chesbrough and Rosenbloom, 2002). That is, without a functioning business model, new technologies are merely inventions in need of commercialisation. A new technology is seen as useless without a complementary business model: “the inherent value of a technology is latent until it is commercialized” (Björkdahl, 2009, p. 1470). The often cited case to highlight this point is that of Xerox Corporation, whereby a new, technologically superior photocopier was developed but could not be commercialised without a radically new business model (Chesbrough and Rosenbloom, 2002). In line with this thinking, several scholars have noted that new business models can unlock the potential of electric vehicle technology and assist in its adoption (e.g. Weiller et al., 2015; Budde Christensen et al., 2012; Costain et al., 2012).

It may be possible for MaaS business models to capture the sustainable value inherent in technologies such as electric and autonomous vehicles, resulting in a more environmentally friendly, sustainable transport system. If vehicles (particularly cars) are utilised more frequently as a result of being utilised within a MaaS service, then their operational costs take a more accentuated role in determining the types of technologies deployed. In cases where market competition exists between different MaaS operators, fleet owners will be forced to compete on cost. This has two principal implications for the environmental sustainability of the vehicle fleet. The first is in the vehicles’ use phase, where incentives will exist for fleet owners to deploy vehicles with low running costs. If electric vehicles have lower running costs than fossil fuel vehicles, then fleet owners will, in principal at least, be able to capture the sustainable value inherent in electric vehicle technology in the form of cost savings. In practice, the deployment of electric vehicles depends on other factors, such as the costs of installing recharging infrastructure and the range of electric vehicles, which influences their availability. Notwithstanding, the fact that electricity is generally a lower cost fuel than petrol and diesel means that value capture may be possible. Similarly, if it can be shown that autonomous vehicles lower costs for fleet owners, then a viable business case can be put forward. In both cases, value may be captured by both fleet owners and MaaS operators, assuming the two are different actors. In addition, MaaS operators may be able
to capture the value of this type of environmental offering through indirect channels, as described in section 3.2. Further, higher utilisation rates mean that the vehicles in a MaaS system will be renewed more frequently than privately-owned vehicles, allowing for more rapid technological substitution.

In cases where it is not possible to capture value directly via cost savings, it may be possible to collect revenues via public policies that create incentives for the deployment of environmentally friendly vehicle technologies. Given their climatic benefits, several governments have created subsidies and tax exemptions for electric vehicles, for instance, and decarbonisation is increasingly enshrined as a transport policy goal. Hence in the future one may reasonable assume that governments will increasingly support environment friendly vehicle technologies via supportive and/or punitive measures (i.e. those which make the consumption of fossil fuels more expensive, such as carbon taxes).

The second implication is that cost competition between MaaS operators may result in attempts to find cost savings further upstream in the value chain. One way to achieve these types of cost savings is to prolong product (i.e. vehicle) lifespans by recirculating physical materials, akin to the principles of a circular economy. This is especially pertinent given that vehicles in a MaaS system will be utilised more than privately-owned vehicles, and thus wear out more rapidly. In a circular economy, material can be recirculated via different cycles, such as reuse, remanufacturing and recycling. Remanufacturing, for example, has been shown to simultaneously generate environmental benefits and cost savings by minimising waste in manufacturing processes (e.g. Amaya et al., 2010; Guide, 1997; Ijomah, 2009; Lindahl et al., 2006; Smith and Keoleian, 2008). The main reason that MaaS creates incentives for material recirculation is because of the development of product-service business models (i.e. those which give access to products as services), which have been cited as an key enabler of a transition to a circular economy (Linder and Williander, 2015; Tukker, 2015). Similar to the deployment of environment friendly technologies, the value of material recirculation can be captured through cost savings. However, the question of which actor captures this type of value is unclear, as new value chains are required to facilitate material recirculation (Ferguson, 2010). Hence gains in resource efficiency in the form of environmental technology and material recirculation are future-oriented business model activities that require new forms of cross-industry collaboration (Sarasini et al., 2016).

4. Discussion

This paper sought to examine the issue of what characterises MaaS business models that deliver improvements in the economic, environmental and social sustainability dimensions. To address this question, we examined the concept of a business model, noting that it is broadly understood to be a mechanism for creating, delivering and capturing value. The concept of a sustainable business model extends the definition of value to encompass benefits in each of the economic, environmental and sustainability dimensions. Based on this understanding, we then sought to identify ways in which MaaS business models can create and capture sustainable value, noting that value capture is a fundamental element of business modelling that is often overlooked in the SBM literature. We identified three types of sustainable value that MaaS business models can generate, and outlined potential mechanisms for capturing this value. Our findings are summarised in Table 2.
Table 2: Potential ways in which MaaS business models can create and capture sustainable value.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Private value</th>
<th>Public value</th>
<th>Potential mechanisms for value capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility services</td>
<td>Affordability, flexibility and convenience</td>
<td>Reduced congestion and emissions following sustainable modal shifts, Improved accessibility</td>
<td>Bundled mobility services, available to individual customers</td>
</tr>
<tr>
<td>Data-based services</td>
<td>Trip planning, booking and payment, Mobility service optimisation, Travel time savings and lower mobility costs</td>
<td>Real-time traffic management, Urban planning</td>
<td>Sales of data analytics to MaaS operators, transport service providers and public sector organisations, Provisional/brokerage fees for individual transactions, Advertising</td>
</tr>
<tr>
<td>Resource efficiency I: Environment friendly vehicle technologies</td>
<td>Lower mobility costs</td>
<td>Reduced congestion and emissions in vehicles’ use phase</td>
<td>Cost savings due to lower operational costs</td>
</tr>
<tr>
<td>Resource efficiency II: Material recirculation</td>
<td>Lower mobility costs</td>
<td>Reduced environmental impacts in vehicles’ production phase</td>
<td>Cost savings due to lower cost of vehicle production</td>
</tr>
</tbody>
</table>

4.1. Implications for MaaS practitioners

Our findings have some practical implications. One major implication is that for MaaS business models to be truly sustainable, MaaS operators must consider the different elements of sustainable value when designing new business models and when refining existing ones. In many instances, generating sustainable value is linked to details within the business model, such as targeted customer segments, the pricing of different transport modes, and the way in which different payment models influence travel behaviour. A more nuanced understanding of these factors and the way in which they influence sustainable outcomes is needed as a basis for MaaS business modelling. Also, our findings sought to outline a set of future oriented opportunities for sustainable value generation via resource efficiency gains. Realising these potentials in practice means that practitioners from different sectors must establish new forms of collaboration to facilitate the deployment of environment friendly vehicle technologies and material recirculation. These are intended more as medium- to long-term aims rather than immediate objectives. In the short term, practitioners should focus on developing business models that generate sustainable value by 1) identifying the different ways in which MaaS business models can create different types of sustainable value; 2) finding ways to capture that value, either directly in the form of revenues or indirectly in the form of other types of economic benefit; and 3) understanding potential trade-offs between, for instance, environmental sustainability and accessibility. We contend that a more nuanced understanding of how business models can generate sustainable value will not only benefit the sustainability of the transport system – it will also allow practitioners to act as advocates of MaaS in broader settings, creating legitimacy for the concept and serving to create a set of enabling conditions to allow it to flourish.
4.2. Implications for future research

The three types of sustainable value outlined in this paper are linked to the mobility and data service elements of MaaS business models, and the resource efficiency of the transport system. This is not an exhaustive list, but an initial set that may be expanded on in future studies. Further, we focused on the ways in which MaaS business models can create and capture sustainable value, obscuring other elements of business models that may potentially influence sustainability outcomes. One such function of a business model is its scalability, which can be defined as the capacity or potential for a particular business model to expand effectively and efficiently by reaching larger numbers of customers and new markets (Jolly et al., 2012). Scalability is central to the ‘innovativeness’ of MaaS business models, and may thus fall under the economic sustainability dimension. Examining scalability as a potential enabler of sustainable value delivery is an interesting way of building on this study, and may be used to compare different types of MaaS business models, according to the roles taken by private and public actors in the business ecosystem (e.g. König et al., 2016a). Finally, while the literature provides some useful guidance in terms of principles that should be embedded in sustainable business models, a more nuanced set of tailored guidelines is needed for developing and assessing the sustainability of MaaS.

5. References


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