PUREmotion: Understanding the Impact of Highway Construction on People's Wellbeing

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Abstract. Planned disruptions such as highway construction typically have negative impact on the health & wellbeing of people living in the surrounding communities due to increased air and noise pollution as well as inconveniences such road closures. Further, these communities typically tend to have low socio-economic status with high unemployment rate and limited resources (Environmental Justice Communities). The goal of this paper is to understand this impact via a smartphone app called PUREmotion providing ecological momentary assessment. We describe the deployment of PUREmotion in a four-month study with people living in the vicinity of a major construction project (C70 project) in North Denver, Colorado. The PUREmotion app is built based on the results of several focus groups and three rounds of usability study with people from these communities. We deployed the PUREmotion app over two time periods of six weeks each with about 100 community participants in each time period. In this paper, we report on our experience of these deployments and provide a detailed analysis of the data we collected to assess the impact of construction on health and wellbeing of the people. Our findings show that living near such construction projects has a direct (negative) impact on people's wellbeing due to air pollution, bad odor, increased noise, and disruptions in daily commutes.

Keywords: Sociotechnical Systems · Wellbeing · Environmental Justice

1 Introduction

The Central 70 project (C70) was a major highway construction along a 10-mile stretch of the I-70 interstate in northeast Denver. Four communities that live in the vicinity of this construction are Globeville, Elyria-Swansea, Clayton and Cole (GESC) communities. These communities have low socio-economic status with high unemployment rate and limited resources (Environmental Justice Communities), as well as a longstanding history of environmental pollution. The Social Justice Environmental Quality - Denver (SJEQ) project (*https://www.sjeqdenver.com/*) seeks to gain a greater understanding of the impacts of C70 on the health and wellbeing of the four communities, devise appropriate intervention mechanisms to alleviate any negative impacts, and provide decision-makers with valuable data concerning the potential consequences of such disruptions.

In this paper, we focus on understanding the impacts of C70 on the health and wellbeing of the people living in the vicinity of the project via the socio-technical system that we have developed. In particular, we report on the results of deploying a smartphone-based diary app called PUREmotion that we have designed and developed.PUREmotion has been created with the intention of collecting pertinent user data over a prolonged time period in order to ascertain the impact of C70 construction on the health and wellbeing of the inhabitants of four environmental justice communities. We have deployed PUREmotion to collect *just-in-time* data regarding the users' current activities, their perceptions of noise and air quality, their emotional state, any respiratory issues they are encountering, and the effects on their daily commutes. The app was deployed over two different time periods—Cohort 1: January-March 2022 and Cohort 2: May-July 2022. For each of the two cohorts, we recruited about 100 participants from the four communities. Participants were required to use the app at least once a day for 30 days during their respective cohorts. We got approval from Institutional Review Board for conducting this study.

Our research question is: To what extent does the data collected from the PUREmotion app help us understand the impact of C70 construction on the health and wellbeing of the four environmental justice communities? From our deployment of PUREmotion over the two cohorts, we collected a total of 4,565 survey entries. Our key findings include a clear relationship between poor environmental conditions (air quality, noise and odor) resulting from the construction and the level of people's happiness. Further, we found a direct positive correlation between people's level of happiness and their distance from the construction activity. As we get closer to the construction, the happiness level gets lower.

2 Literature Review

Smartphone health and well-being self-tracking has been increasingly studied in many research work recently. Methods include manual self-reporting like EMAs [10, 3], automated methods of smartphone sensors like GPS, microphone, accelerometer or meta-data [16, 15] or using a hybrid approach of both ways [9, 18]. For instance, in using manual methods, Jones et al [8] have examined the adherence to the use of self-tracking apps with patients.

Unlike the first study, Wang et al. [16] have used passive mobile phone sensing data (automated method) to predict the depression of college students. The third kind of research has combined traditional ways with opportunities that are provided by mobile phones. Both approaches have their advantages but mostly it is about awareness (in manual ways) vs efficiency (in automated ways) [12]. Choe et al suggested the usage of semi-automated self-tracking methods in building self-monitoring systems [5]. One common traditional method to assess one's current mood, Ecological Momentary Assessment (EMA), has been adopted and supplemented by smartphone capabilities (e.g. GPS) in many studies [7]. A study by Kim et al [9] was conducted to design, build and evaluate a semi-automated tracking app called OmniTrack that allowed users to track their own activity.

People have benefited from construction projects for a long time in almost all aspects of civilization. The level of advancement in the infrastructure of a country is a high indicator of its welfare and development [11]. Despite their huge benefit, their impacts on the environment and nearby communities are huge [6] as they are considered a main source of air pollution [13] in terms of CO2 emission [1]. Further, they cause other direct and indirect impacts on the environment [6] such as noise, dust, solid waste and water waste [4]. These impacts eventually impact people who live around the location of the construction project. For instance, air pollution has been shown to cause many health problems such as pulmonary and cardiovascular disease, cancer and diabetes [14]. Further, noise can cause serious hearing issues if exposed to a long period of time [2]. In addition to their impacts on people's health, they also impact their lives. For example, a study by Xue et al has shown how a subway construction project had impacted people's transportation, travel, and daily lives such as traffic jams, inconvenience to nearby residents, and impact shopping stores around [17].

3 Methodology

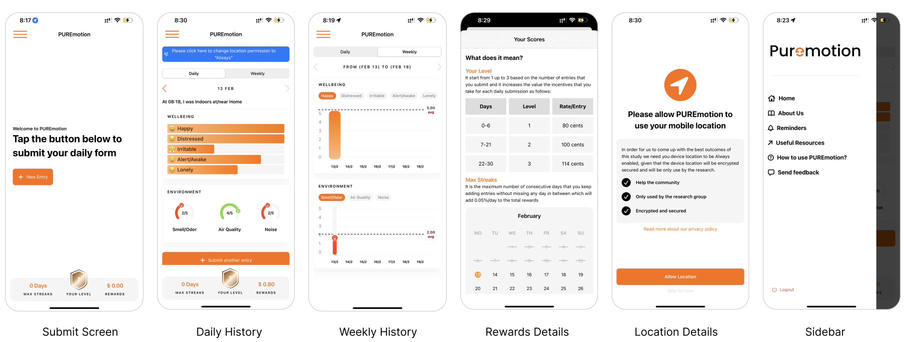

Fig. 1. Screens of other features of PUREmotion app

PUREmotion design is based on a systematic usability study that the authors conducted. This included a series of focus groups with the members of the four communities to finalize the app requirements and come up with an initial design followed by three rounds of usability testing with diverse groups of people from the four communities. The app design was revised after each round of usability testing. The app is comprised of a sequence of screens that include a set of survey questions that are presented to the user as he/she progresses in using the app (See Figure 3). In addition, PUREmotion collects the current location of the user continuously. There are survey eight questions:

1. Rate your current feelings for each of the following. Five emotional feelings (Happy, Distressed, Irritable, Alert/Awake, Lonely) are assessed here.
2. Where are you right now? (Indoors, Outdoors)
3. How many hours did you spend outside (not in a building or vehicle) in the last day (24-hours)?
4. How satisfied are you with the following qualities of your environment right now? There environmental qualities that are typically affected by construction (Smell/Odor, Air Quality, Noise) are assessed here.
5. Select all the qualities of the air with which you are not satisfied (None, Smell/Odor, Temperature, Visibility, Smokiness, Mustiness, Allergies, Dustiness)
6. How did you move around the community? (Car, Bus, Train, Bicycle, Motorcycle, Walk)
7. Considering the recent impacts of construction, how satisfied are you with your ability to move around the community?
8. Please write any additional comments below.

Questions 1, 4, and 7 allow the user to choose from a 5-point Likert scale: “1:Not at all" to“5: Completely" in Question 1 to understand the current emotional state of the user; “1: Very dissatisfied" to “5: Very satisfied" in Question 4 to assess user’s satisfaction with the perceived environmental quality; and “1: Very dissatisfied" to “5: Very satisfied" in Question 7 to assess user’s satisfaction with their transportation experiences. Question 2 presents the user with multiple places to choose from after they select either indoors or outdoors. It also allows them to select "Other" if they do not find the place that they are in. Our goal in asking people about their location, perceived environmental quality, and transportation experience is to eventually correlate the impacts of the construction project activities to their feelings reported in the first question. Questions 4 and 5 are designed to assess user’s perception of the current environmental quality around them and their level of satisfaction. Questions 6 and 7 are designed to assess how construction activities have affected users’ daily commutes.

When users submit an entry, they are able to see the entry on the main screen of the app in two forms, a daily form, and a weekly summary. The weekly summary averages the feelings and perceived environmental quality for each week. Users are able to navigate to any day or any week to see their entries. The first cohort of the research contained 89 participants, and the second cohort increased to 99 participants.

4 Results

4.1 General Statistical Analysis

We have collected a total of 4,565 data points from a total of 188 participants during the two cohorts. After cleaning the datapoints by removing entries that contain null values, we were left with 4350 entries, which is 95% of the orignal datapoints. Almost half of the users of Cohort 2 were new users, while the other half were returning from Cohort 1. The majority of the participants have submitted 31 to 40 entries in both cohorts, which is the required number for full compensation. In Cohort 2 we raised the amount of compensation from $24 to $40 but there was no significant change in the level of user engagement in the study (Total number of entries).

The daily form starts with asking users about their current feelings (Happiness, Distress, Irritability, Alert/Awake, and Loneliness). To reduce the number of personal differences among participants and make data easier to comprehend and correlated, we combined 1 and 2 as -1 (low), 3 as 0 neutral, and 4 and 5 as 1 (high). We observed that Happy and Alert/Awake feelings were higher, on average, than Irritable, Distressed and Lonely, and among the two cohorts, the average levels of feelings did not have a significant difference.

Table 1 shows the percentages of each place of the top 10 places the users were in when they submitted their entry. As we can see, most of the time people submitted their entries from their homes. We can also see that people submitted their entries from an indoor place almost 90% of the time. Further, there is an increase in the percentage of entries submitted from outdoors in Cohort 2. We attribute this increase to the fact that Cohort 1 was conducted during winter months, while Cohort 2 was conducted during summer months when people tend to spend more time outdoors. This is further confirmed by our next question.

Table 1. Entry submission place (%)

Place	Cohort 1	Cohort 2
Home Indoors	71.66	65.79
Work Indoors	8.23	10.06
Home Outdoors	3.24	9.33
Work Outdoors	1.39	2.23
Car	1.90	1.29
Walk/Bike Indoors	1.39	1.46
Busy Road/Traffic	1.54	1.29
Walk/bike Outdoors	0.51	1.33
Restaurant	1.39	0.60
Store/Retail	1.03	0.64

Table 2. Air Quality Complaints

Issue	Cohort 1 # (%)	Cohort 2 # (%)
None	850 (28.9)	660 (14.64)
Smell/Odor	558 (27.31)	760 (19.41)
Dustiness	401 (19.63)	803 (20.51)
Allergies	330 (16.15)	836 (21.35)
Temperature	309 (15.12)	554 (14.15)
Mustiness	209 (10.23)	350 (8.94)
Smokiness	135 (6.61)	319 (8.15)
Visibility	101 (4.94)	294 (7.51)
Total	2043	3916

Table 3 shows the number of hours people spent outdoors. We can see that the time spent outdoors in Cohort 2 is more than in Cohort 1. Once again, we attribute this to the fact that Cohort 1 was deployed in the winter time while Cohort 2 was deployed in summer time. Table 4 shows the levels of satisfaction with air quality, noise and odor in Cohorts 1 and Cohort 2. To be consistent, we have mapped the scale of these questions from (1 to 5) to (-1 to 1) as we did with the feelings question. While users are generally neutral in both cohorts, we notice that the level of satisfaction decreased slightly in Cohort 2. We hypothesize that the reason for this decrease in satisfaction is because users spent more time outside in Cohort 2, thus increasing their exposure to construction impacts.

Table 3. # hours spent outdoors (%)

# of Hours	Cohort 1	Cohort 2
0-1 hours	63.94	40.27
2-3 hours	26.24	39.08
4-6 hours	5.73	13.13
More than 6 hours	4.09	7.52

Table 4. Satisfaction with environmental qualities (Scale: -1 to 1)

Cohort	Air Quality (%)	Noise (%)	Smell/Order (%)
1	0.301	0.337	0.336
2	0.161	0.135	0.242

Finally, Table 2 shows that the number of people dissatisfied with different air quality features. We can see that the number of people dissatisfied with various air quality features increased significantly in Cohort 2, almost double in many cases. There were about 30 complaints per user in Cohort 1 vs 45 per user in Cohorts 2. Looking at the reports' detail we can see that Smell/Odor was the highest for Cohort 1 while allergies and dustiness in Cohort 2 are equal to smell/odor. Again, we hypothesize that one reason for this increase in Cohort 2 is that users in Cohort 2 spent more time outdoors.

Transportation The most used transportation method in both cohorts was cars. However, in Cohort 2 people walked and biked way more than in Cohort 1 and the usage of cars decreased a little. Again this can be attributed to the fact that Cohort 1 was deployed in winter while Cohort 2 was deployed in summer. The level of satisfaction for Cohort 1 is a bit higher than cohort 2. In both cohorts, users were least satisfied with driving.

4.2 Pair-wise Analysis

Table 5. Correlation between the satisfaction of environmental quality and feelings

Feelings	Correlation with							
	Air Quality		Noise		Odor		Transit	
	Cohort 1	Cohort 2	Cohort 1	Cohort 2	Cohort 1	Cohort 2	Cohort 1	Cohort 2
Happy	**0.350**	0.274	**0.288**	0.239	0.330	**0.354**	0.274	**0.305**
Distressed	-0.200	-0.138	-0.214	-0.105	-0.246	-0.204	-0.169	-0.147
Irritable	-0.149	-0.184	-0.157	-0.108	-0.159	-0.210	-0.130	-0.168
Alert/Awake	0.159	0.113	0.163	0.101	0.130	0.178	0.182	0.208
Lonely	-0.240	-0.151	-0.230	-0.141	-0.252	-0.184	-0.233	-0.250

Environmental Quality and Feelings This analysis investigates the indirect effect of construction activities on people's well-being. In particular, we look at the correlation between satisfaction with perceived environmental quality (Air Quality, Noise, Odor, and Transportation) and levels of different feelings. Table 5 summarizes these correlation values. We can see that there is a strong positive correlation between happiness levels and satisfaction with different environmental quality measures. Further, we notice that there is a strong negative correlation between the levels of negative feelings (Distressed, Irritable, and Lonely) and satisfaction with different environmental quality measures. Among different feelings, the correlation of Happiness with satisfaction with different environmental quality measures is the strongest. The analysis also shows that odor is the most correlated environmental quality and noise is the least.

These correlations provide evidence that people's wellbeing is positively correlated with their satisfaction with environmental quality. Since construction activities result in poor environmental quality, this analysis provides (indirect) evidence that construction activities are contributing to lower wellbeing of users.

Table 6. Correlation between the average feelings and the distance from construction project's Center (C), Highway (HW) and Nearet Point (NP)

Feelings	Correlation of feelings with distance from C, HW and NP								
	Cohort 1			Cohort 2			Long Term		
	C	HW	NP	C	HW	NP	C	HW	NP
Happy	0.041	0.132	0.148	0.008	0.001	0.069	0.11	0.13	**0.24**
Distressed	0.054	-0.01	0.006	0.002	0.077	-0.043	0.08	-0.05	-0.02
Irritable	0.13	0.029	0.055	0.018	0.052	-0.036	0.16	-0.01	0.01
Alert	0.073	0.123	0.131	-0.122	0.031	-0.088	-0.01	0.05	0.1
Lonely	0.023	-0.017	-0.013	0.065	0.118	0.052	0.14	0.08	0.09

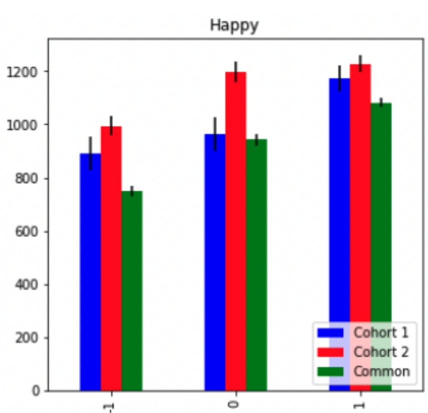

Fig. 2. Happiness vs average distance

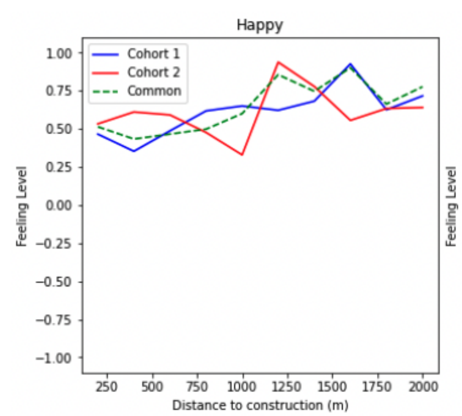

Fig. 3. Happiness vs distance of area

Location vs feelings We analyze the distance from the construction project activities and the feelings levels. We look at the entries submitted from a location point that is within 3000m of the center of construction project activities. This allows us to discount any outliers where some of the participants submitted sometimes from very far places. 81% of the data points collected are from the area within 3000m of the construction project activities.

To understand the correlation between the construction project activities and the well-being of the people in the surroundings, we have looked at the distance between the location from where the entries were submitted and the location of the construction activities. Since the construction activities were spread over a larger area along a highway and specific activities took place at different locations with in this area on different days, we first consider three different construction activity location options: (1) distance from the center of the construction (C), (2) distance from the construction highway (HW), and (3) distance from the nearest construction activity point (NP) - median GPS location of the construction activity locations.

We performed three different types of analyses: 1) PEARSON correlation between the distance from construction and the GPS location from where an entry was submitted; 2) distribution of each feeling over different distances; and 3) average area feelings, where an area consists of all locations within (i) 200 m from the construction activities, (ii) 200-400 m of construction activities, (iii) 400-600 m of construction activities, and so on.

Table 6 shows a summary of the PEARSON correlation analysis. We notice that the only clear positive correlation was between the feeling of Happy over a long term using the Nearest Point method. We believe that this is because happiness is the easiest and most accurate feeling to express, compared to the other feelings. Based on this result, we focused on the feeling of happiness and nearest point distance method for all upcoming analysis.

Figure 2 shows the relationship between the level of happiness (Y-axis) and distance (X-axis). We clearly notice that the level of happiness increases as distance increases, especially over the long term (green). We have conducted an analysis of the variance test and it showed that the means are different (p-value: Cohort 1=5.78e-09, Cohort 2: 0.002, Common: 8.189e-11). The difference among other feelings was not significantly different. Figure 3 shows that level of happiness (Y-axis) increases as the distance of the area being considered increases. However, we did not find a clear relationship for happiness and distance beyond 2000m. Both of these analysis (Figures 2 and 3) provide a direct evidence that people's wellbeing gets lower as they get closer to the construction activities.

5 Discussion

We now answer our research question: To what extent does the data collected from the PUREmotion app help us understand the impact of C70 construction on the health and wellbeing of the four economic justice communities?

We first investigated the truthfulness of the survey data and found three indicators that tell us that the data is genuine and not random. First, we asked participants in the first question to rate the level of five different feelings. Among these are feelings of happiness, distress, and irritability. We analyzed the correlation between the feeling of happiness and feelings of distress or irritability for each entry submitted. We found this correlation to be strongly negative. This would be expected and the strong negative correlation shows that the entries submitted by the users are genuine. Second, the participants were required to submit 30 entries (one per day) during the study period to receive full compensation. However, we found that more than 50% of the participants submitted more than 30 entries. This shows how motivated a large number of participants were to help us in our study goals, and thus we assume they provided truthful information. Finally, the two cohorts were conducted in the winter and spring seasons. In the second cohort, people reported more walking and biking than driving which is consistent with the expected commute medium for the season.

Our data analysis provides strong evidence that the C70 project has contributed to lower wellbeing of the people living in the vicinity. We found that the level of happiness reported by users decreased and levels of distress, irritability and loneliness reported by users increased as they get closer to the construction activity locations. We found that the average levels of positive feelings (happiness) decreased and average levels of negative feelings (distress, irritability and loneliness) increased as we moved to areas that are closer to the construction activity locations. Finally, we found a strong positive correlation between levels of happiness and satisfaction with environmental quality measures such as Air Quality, Noise, Odor, and Transportation, and negative correlation between the levels of distress, irritability and loneliness and satisfaction with these environmental quality measures, providing an indirect evidence that construction activities contributed to lower wellbeing of the people.

While our results are based on the impact of C70, the insights we gained are relevant for other large infrastructure projects. This is because the impacts of such projects in terms of poor environmental quality and road closures are similar. Further, the communities that live nearby typically tend to be environmental justice communities similar to the ones in the C70 project.

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