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Using crowd sourcing to locate and characterize conflicts for vulnerable modes

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ABSTRACT

Most agencies and decision-makers rely on crash and crash severity (property damage only, injury or fatality) data to assess transportation safety; however, in the context of public health where perceptions of safety may influence the willingness to adopt active transportation modes (e.g. bicycling and walking), pedestrian-motor vehicle and other similar conflicts types may define a better performance measure for safety assessment. In the field of transportation safety, an absolute conflict occurs when two parties' paths cross and one of the parties must undertake an evasive maneuver (e.g. change direction or stop) to avoid a crash. Other less severe conflicts where paths cross but no evasive maneuver is required may also impact public perceptions of safety especially for vulnerable modes. Most of the existing literature focuses on vehicle conflicts. While in the past several years, more research has investigated bicycle and pedestrian conflicts, most of this has focused on the intersection environment. A comprehensive analysis of conflicts appears critical. The major objective of this study is two fold: 1) Development of an innovative and cost effective conflict data collection technique to better understand the conflicts (and their severity) involving vulnerable road users (e.g. bicycle/pedestrian, bicycle/motor vehicle, and pedestrian/motor vehicle) and their severity. 2) Test the effectiveness and practicality of the approach taken and its associated crowd sourced data collection. In an endeavor to undertake these objectives, the researchers developed an android-based crowd-sourced data collection app. The crowd-source data collected using the app is compared with traditional fatality data for hot spot analysis. At the end, the app users provide feedback about the overall competency of the app interface and the performance of its features to the app developers. If widely adopted, the app will enable communities to create their own data collection efforts to identify dangerous sites within their neighborhoods. Agencies will have a valuable data source at low-cost to help inform their decision making related to bicycle and pedestrian education, encouragement, enforcement, programs, policies, and infrastructure design and planning.

1. Introduction

While public health researchers argue about the societal health benefits of active modes (de Hartog et al., 2010), the increased level of exposure of pedestrians and bicyclist to motorized-vehicle movement creates safety issues. According to the National Highway and Trasnportaiton Safety Administration's (NHTSA) National Center for Statistics and Analysis, approximately 5987 pedestrians and 840 bicyclists died in USA in 2016 (NHTSA, 2017). While this number of deaths remains unacceptable, crashes still represent random and rare events when considering exposure rates (Theofilatos et al., 2016). Moreover, this randomness may cause the observed crash data to be biased and underrepresent actual issues of safety that exist. Most agencies and decision-makers rely on this crash and crash severity (property damage only, injury or fatality) data to assess transportation safety; however, in the context of public health where perceptions of safety may influence the willingness to adopt active transportation modes (e.g. bicycling and walking), pedestrian-motorized vehicle and other similar conflicts may represent a better performance measure for safety assessment. A conflict is "an observational situation in which a vehicle [can also be a

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pedestrian or a bicyclist] and pedestrian [can also be a bicyclist or a vehicle] approach or encroach each other in space and time to such an extent that a collision is imminent if their movements remain unchanged" (Autey et al., 2012; Hydén, 1987). As such, conflicts (or near miss situations) often pose potential safety concerns for vulnerable modes such as pedestrians and bicyclists. These conflict measures can act as a surrogate of safety measures (at the sketch level -planning performance measure tool) to understand potential safety issues related to transportation infrastructure such as crosswalk, sidewalk and bike lane (Saelens and Handy, 2008; Laureshyn et al., 2016; Zheng et al., 2014; and Chin and Quek, 1997).

While, collision or crash data play a key role in modeling the pedestrian or bicycle injury risk as a function of transportation characteristics, pedestrian safety analysis using non-collision data mostly relies on traffic conflict analysis (Van Houten et al., 1997; Tourinho and Pietrantonio, 2003; Medina et al., 2008). Unfortunately, the availability of conflict data remains sparse as most near miss incidents never get reported; therefore, detailed information about the conflict that has occured may help reduce the chance of potential crash occurrence and hence requires comprehensive analysis. A recent study by Casey et al. (2016) identifies three key conflict factors that influence the seriousness of the conflict. These three factors include: a) the separation distance at the moment of conflict identification, b) the speed of the motorized vehicle or bicyclist, and c) the time available to take any evasive action to avoid eminent danger. Hence, the major objective of this study is two fold:

1) Development of an innovative and cost effective conflict data collection technique to better understand vulnerable road user conflicts (e.g. bicycle/pedestrian, bicycle/motor vehicle, and pedestrian/motor vehicle) and their severity.
2) Test the effectiveness and practicality of the approach taken and its associated crowd sourced data collection.

In an endeavor to undertake these objectives, the study adopts the method developed by Casey et al. (2016) and incorporated it into a smart phone app to capture data using crowd-sourcing to investigate the various types (the continuum) of conflicts (bicycle/pedestrian, bicycle/motor vehicle, and pedestrian/motor vehicle) experienced by pedestrians and cyclists within different types of transportation infrastructure. A crowd-sourced data collection effort may lack some of the data quality of a more formalized approach; however, the data can be gathered in a cost-effective manner while also reducing the time needed to collect the data.

The app provides the ability to geocode the location, type, and severity of conflicts experienced or observed by users. This additional information can be used by agencies and community organizations to identify and prioritize strategies for responding to potential public health (i.e. safety) concerns for bicyclists and pedestrians. The project uses user feedback and hot spot analysis to determine user comfort in using the app and evaluate the potential relationship with bike and pedestrian crashes.

2. Literature review

The Centers for Disease Control (CDC) in 2005 stated that, traffic safety is the 2nd most common barrier for children walking to school (SRTS Guide, 2019). Evidently, these crashes have deterred pedestrians and bicyclists from using an active mode of transportation more frequently, and for many years, researchers have been trying to solve the problem (Quistberg et al., 2014). Researchers have done an extensive amount of studies on pedestrian crashes (Cottrill and Thakuriah, 2010; Loukaitou-Sideris et al., 2007) or bicycle crashes (Wei and Lovegrove, 2013) or both pedestrian and bicycle crashes (Dumbaugh and Li, 2010; Siddiqui et al., 2012; and Zhang et al., 2015). But as collisions remain rare and random events, researchers have to gather several years of data to produce statistically significant estimates and discard the variations due to their stochastic nature. Moreover, the data quality of crashes remains low because of post-hoc description, witness accounts and site observations, which may underrepresent actual safety issues that exist. The Highway Safety Manual (HSM) (AASHTO, 2010) summarizes years of crash studies and proposes analytical methods to evaluate safety effectiveness and calculates crash modification factors (CMFs) for specific roadway treatments. The disadvantages associated with reliance on crash data to establish crash prediction models becomes magnified when no crash history exists at a location. Moreover, the lower exposure rates of vulnerable road users and the stochastic nature of crashes may often require research studies to gather years of crash data to obtain statistically significant estimates of the impact of safety imporvoemnt strategiesto. Furthermore, crashes related to bicyclists, pedestrians or other vulnerable road users remain scarce due to less monitoring, cost of vision based identification and lack of consistent reporting. The ethical concern of the safety analyst to wait for an accident to happen to take any preventive measure also appears to be an issue. Clearly, only using crash analysis does not adequately portray the safety challenges that pedestrians and bicyclists face in their day to day movement.

The only difference between a real crash and a near-miss as the term implies that in near-miss events the parties involved barely avoid the collisions where in a crash, they cannot. Perkins and Harris (1967) propose the concept of conflict analysis as an alternative to collision data, which in many cases are scarce, unreliable, or unsatisfactory. The perceived safety of walking or biking can only be truly observed through one's lived experience, participation, interaction and/or observation of conflict, which verifies that accidents often reflect the "tip of the iceberg" in terms of systematic risk (van der Schaaf and Lucas, 1991). According to risk management and industrial accident prevention researchers, near misses appear much more predominant than their related incidents (Heinrich, 1941; Ritwik, 2002). The series of events (e.g., braking, swerving and stopping) that occur prior to the near-miss or traffic conflicts have similarities with the series of events (e.g., braking, swerving and crashing) preceding actual crashes (Hydén, 1987). As conflicts occur more frequently, a well crafted methodology to observe conflict analysis can provide insight into the failure mechanism that leads to collisions (Autey, et al., 2012) and thus help analyzing, diagnosing and solving safety problems (van der Horst, 1990).

Conflict measures, which are developed based on the motion characteristics of vehicles, have seen wide use as a tool in identifying hazardous situations (Archer, 2005; Barcelo et al., 2003; Cunto, 2008; Garber and Gousios, 2009; Gettman and Head, 2003; Sobhani et al., 2013; Young et al., 2014). These traffic conflict techniques (TCT) have shown that including less severe events than crashes, i.e. conflicts facilitate a better understanding of the traffic safety process. The U.S Department of Transportation Conflict Technique (USDOTCT) from the Federal Highway Admiration (FHWA) categorizes various elements that induce conflicts; identifies the severity levels of each element and finds the overall grade of the severity of the conflict (Parker and Zegeer, 1989). Like the USDOTCT, the Swedish Traffic Conflicts Technique (STCT) (Hydén, 1987), and the Institute of Highways and Transportation Conflicts Technique (IHTCT) (Swain, 1987) were developed for vehicle to vehicle conflict analysis. However, some vehicle-vehicle conflict based methods were also used for motor vehicle-pedestrian conflict analysis; these include, modelling interaction between left-turning motor vehicles and pedestrians at signalized intersections (Lord, 1996), assessing the efficiency of safety regulations for vulnerable road users at intersections (Chen and Meng, 2009), and qualitative categorization of conflict types and severity (Cynecki, 1980).

A more in depth knowledge on the severity of conflicts will help in evaluating transportation infrastructure safety conditions and predicting collisions. Various conflict indicators have been established to measure the severity of an interaction by quantifying the spatial and temporal proximity of two or more road users. The main advantage of conflict indicators is their ability to capture the severity of an interaction in an objective and quantitative way (Autey et al., 2012). Therefore, Hydén (1987) proposes the Swedish Traffic Conflict Technique as an expansion of Perkins and Harris' concept, which systematically arranges the steps that must be taken in vehicle accidents. Also, a modified version of the IHTCT method was used to develop a motor vehicle-pedestrian conflict analysis method (Kaparias et al., 2010). Over the past decade, various traffic conflict risk indicators such as time-to-collision (TTC) or time-to-accident (TA), post-encroachment time (PET), unsafe density (UD), deceleration rate to avoid collision (DRAC), proportion of stopping distance (PSD), gap time (GT), comprehensive time-based measure (CTM), and rear-end collision probability (RECP) that measure the temporal and spatial proximity of involved road users have been developed (Allen et al.,1978; Hayward, 1972; Kraay et al., 1986; Johnsson et al., 2018; Minderhoud and Bovy, 2001; Zheng et al., 2014). Most of these previous studies consider traffic conflict indicators as the severity index (van der Horst and Hogema, 1993; Vogel, 2003; Sayed et al., 2013). Svensson (1998) attempted to extend time-to-collision (TTC) (Hayward, 1972) to describe the danger of a conflict situation, and found that *vehicle speeds* also represent a dominant factor. A comprehensive summary of the different indicators is provided in Brown (1994); Tarko et al. (2009) and Johnsson et al. (2018).

Various other researchers have studied the severity of conflict and identified that *time to collision, distance* and *speed of the approaching vehicle* may contribute to severity. More recently, a comprehensive study by the Transportation Research Center for Livable Communities (TRCLC) conducted by Casey et al. (2016) developed conflict analysis performance measures as a surrogate safety measure for both pedestrians and bicyclists for intersections and segments. Casey et al. (2016) defined the conflict severity category as a grade using conflict type (bicycle/pedestrian, bicycle/motor vehicle, and pedestrian/motor vehicle) and conflict characteristics (speed, distance and time) to indicate the seriousness of the conflict situation. This study adopts these key elements of conflict analysis and developes an android-based app to collect information on these variables-

a Location of the conflict
b Parties involved in the conflict (i.e., pedestrian, bicyclist, motor-vehicles)
c Overtaking or non-overtaking
d Time available to take safety measure (e.g. stop, change direction, reduce speed)
e Closest istance between the conflicting parties
f Speed of the conflicting party

Despite the fact that several studies have demonstrated the feasibility of collecting conflict data using (i) field observers (Perkins and Haris, 1967; William, 1972; Zegeer and Deen, 1978), (ii) simulation models (Persaud and Mucsi, 1995), and (iii) video-camera (Ismail et al., 2009; Autey et al., 2012), researchers (Ciro and Maurizio, 2012; Vasconcelos et al., 2014; Essa and Sayed, 2015) recognize some continuing limitations. For example, simulation models can not consider the unexpected behaviors of parties involved in a conflict. Video data collection and automated video data analysis process

- requires trained personal, equipment for video recording and tools for video processing.
- primarily made during daytime and in good weather conditions.
- Primary data collection locations are at the intersections and a lot of times vulnerable segments are missed

Hence, use of video recording and automated tools may not be cost effective. Sending field observers to conduct conflict surveys may be the most practical solution as numerous research studies confirm that people seem relatively good at comparing situation-specific cycling risks (Bill et al., 2015). Knowles et al. (2009) also find in their research that self-reported conflict reports almost accurately matches with the event and provides an 'early warning' sign of possible injury behavior such as impared driving. While conflict analysis will provide better understanding of the crash occurrence and improve safety of active mode users, the lack of an extensive database hinders its further improvement. Crowdsourcing data from users will not only reduce the cost of collecting conflict data, but it also enhances a database by collecting various level of information, which otherwise remain unreported. A crowd-sourced data collection effort may lack some of the data quality of a more formalized approach; however, the data can be gathered in a cost-effective manner while also reducing the time needed to collect the data. Crowdsourcing has also been found to be useful in transportation because it voluntarily brings together a large group of people into the same platform around a common issue (Misra et al., 2014). This data can be used by agencies and community organizations to identify and prioritize strategies for responding to potential public health concerns for bicyclists and pedestrians.

3. Method

A recent comprehensive study by the Transportation Research Center for Livable Communities (TRCLC) conducted by Casey et al. (2016) developed conflict analysis performance measures as a surrogate safety measure for both pedestrians and bicyclists for intersections and segments. Most of the time the conflicts considered for pedestrians and motorized vehicle occurs at the intersection at an angle. The global adaptation of complete streets leads to more use of shared or dedicated bike lanes. The research team considers two broad types of conflicts for both pedestrian and bicyclist interactions with the transportation infrastructure. A non-overtaking (or angled) conflict type occurs when parties (pedestrians, bicyclists, or motor vehicles) are not travelling in the same direction. An overtaking conflict occurs when both parties are traveling in the same direction; the same direction of movement limits the ability of vulnerable road users to initiate or anticipate required evasive manuevers. Frequent overtaking conflicts likely indicate the need for more education and/or a more definite separation of modes traveling at different speeds. Overtaking conflicts may become more important with the indroduction of electric scooters in many cities. Table 1 lists the three factors this study uses to measure conflict severity.

In total, the study performed by Casey et al. (2016) considers the following five types of conflicts:

- Pedestrian – Motorized Vehicle
- Bicyclist – Motorized Vehicle
- Pedestrian – Bicyclist
- Motorized Vehicle – Bicyclist (Overtaking)
- Bicyclist – Pedestrian (Overtaking)

Casey et al. (2016) defined the conflict severity category as a grade using conflict type (bicycle/pedestrian, bicycle/motor vehicle, and pedestrian/motor vehicle) and factors (speed, distance and time) as function to indicate the seriousness of the conflict situation. Conflict categories range from A to D, with category "A" conflicts being characterized "serious" and category B, C, and D conflicts corresponding to

Table 1
Factors considered to identify the conflict severity.

Non-overtaking Conflict	Overtaking Conflict
Speed of the crossing vehicle Longitudinal distance to the vehicle Time to take evasive action	Speed of the approaching vehicle Lateral distance of the vehicle

Table 2
Conflict category and definition.

Category	Category Definition
A	A serious incident where a collision is narrowly avoided
B	An incident with significant potential for a collision where separation decreases and incident may result in a time critical response to avoid a collision
C	An incident characterized by moderate time and/or distance to avoid a collision
D	An incident with no immediate safety consequences such as encroachment of the space/area of a roadway surface designated for a vehicle/person

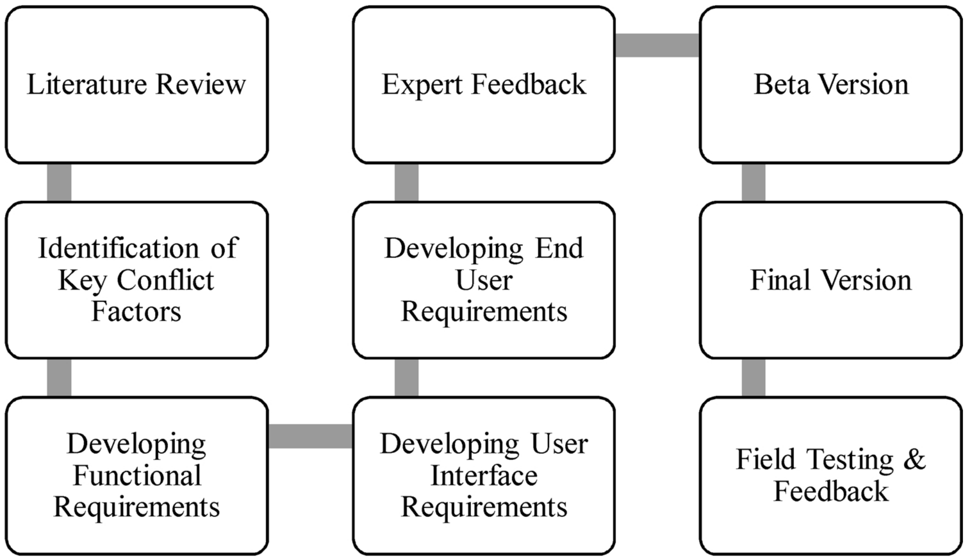

Fig. 1. Flow chart for system development and testing.

conflicts with decreasing severity (Table 2). A survey of experts was used to develop conflict categories for each combination of factors. The survey asked experts to use the different factors to grade the conflict and place it into one of the four categories, A to D. Casey et al. (2016) provides a detailed explanation of the methodology for identifying the severity from the survey data and the conflict performance measure.

The study develops an android-based smart phone app to capture data using crowd-sourcing of conflicts experienced by pedestrians and cyclists at different types of transportation infrastructure. The entire app design and crowd-source data collection process for conflict analysis includes three broad phases (Fig. 1). At the beginning of the project, the research team performs an extensive literature review to identify the key features associated with conflict analysis for better understanding the continuum of conflicts between transportation modes. At this stage, they also identify key stakeholders related to bicycles and pedestrians and get feedback at various level of app development process. Utilizing stakeholders during the various parts of a study increases the validity of the study by verifying specific needs and present an opportunity to gain additional knowledge from an outside source. Most of the stakeholders associated with this study can be characterized into three general groups:

- Those concerned with bicycle and pedestrian safety,
- Those concerned with public/environmental health, and
- Those concerned with city/regional planning and management.

While working with the stakeholders, the research team developed the functional requirements of the app along with user interface requirements and end user requirements. This helped the research team outline the key features for the app and design the app prototype. The research team then tested the prototype and obtained additional feedback from the stakeholders.

During the feedback process, the research team received valuable information related to both the design and functional requirements. Based on the feedback, the team developed a beta version for the app and the corresponding database. After beta testing, the team made the field test version of the app available in Google Play Store as *Safe Activity*. Later, the research team contacted the stakeholders who agreed to take part in the snowballing process during previous focus group meetings. The stakeholders and junior-level civil engineering students took part in the app field test. This paper presents the data collected by the students at 25 different elementary school locations and during their daily travel activities. After the end of one month of data collection, the participants provided feedback on the user-friendliness of the app and its different features.

The main software architecture contains two main components; the mobile application collects the necessary data from user inputs as per the requirements and uploads the collected data to the cloud-based database. The research group developed a prototype of the application and tested it to obtain initial feedback. The final user interface includes a map view, survey user interface, list views, and menu options for the users to sign in and search. The interface related to the cloud-based database service utilizes an Amazon Dynamo DB mapper, which provides a simple and easy way to access the cloud-based database in AWS. The AWS cloud database contains tables created to store conflict inromation and user group related information. The application also connects to the Google cloud to use services like Google Maps, Sign In, and Location APIs.

In this particular case, the new Android based app called *Safe Activity* utilizes crowdsourcing in order to generate mass data about potential safety issues from a pedestrian's or bicyclist's point of view. Crowdsourcing can be beneficial by limiting the cost related to data collection, creating a more efficient system of data retrieval, and minimizing the time to conduct data collection. Some limitations exist such as accuracy, unusable, and uncertain biased data collected based on the user's accuracy. Despite some of the potential disadvantages affiliated with crowdsourcing, with informed subjects and clear, concise statements, this method of data retrieval can vastly innovate

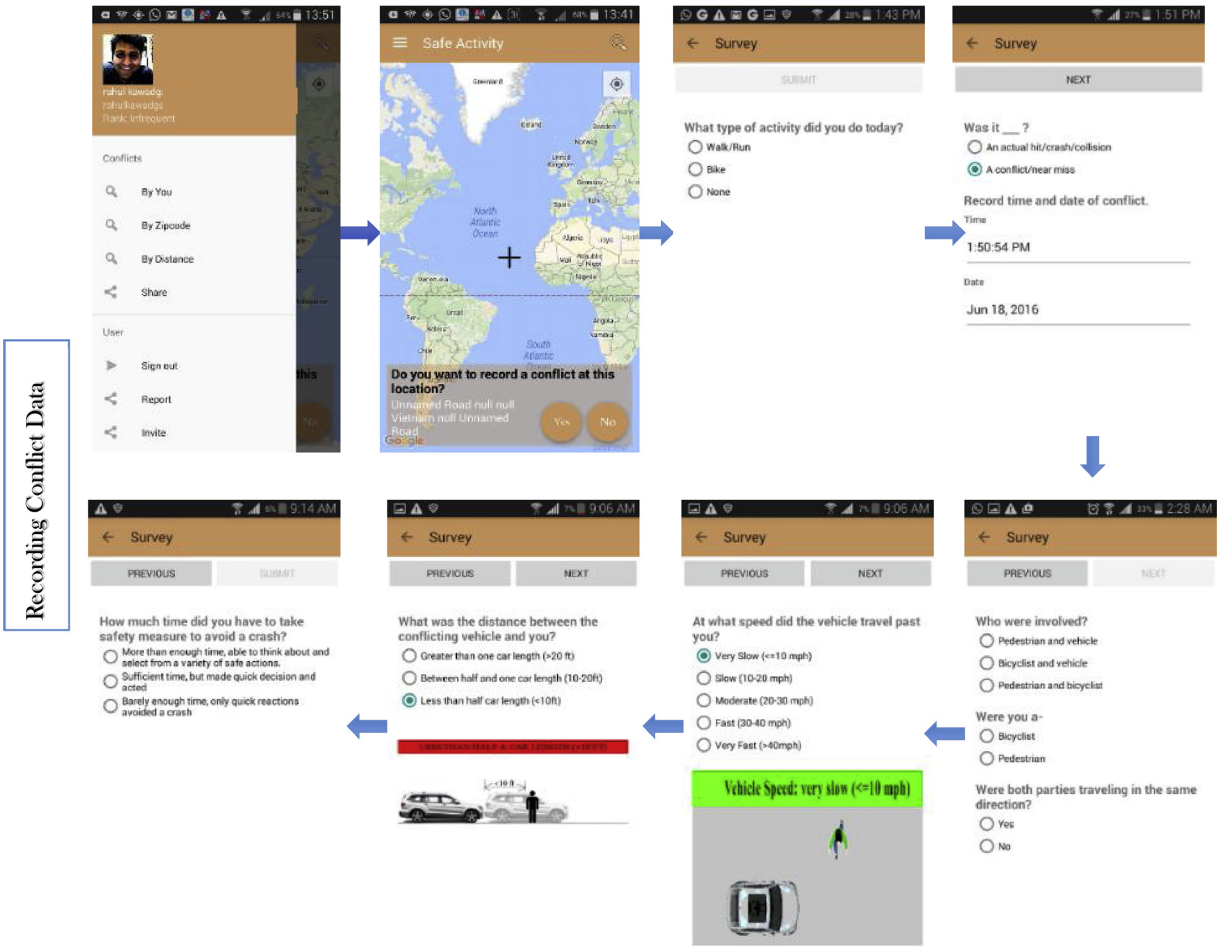

Fig. 2. Example of app interface for conflict data record.

transportation planning and safety analyses. When an app user faces a near miss or conflict, he or she may log into *Safe Activity* and complete a few questions to generate a severity index for his or her specific incident. The app provides an active notification once per day in the evening to see if the user experienced a conflict during the day. Fig. 2 shows an example of the app interface for collecting the conflict data. When a conflict occurs, the user opens the app and provides a location and time for the conflict, the parties involved in the conflict, the speed of the conflicting vehicle, the closest distance between the conflicting parties, and the time available to take any evasive action. The app can also record information about any crash related incident. Based on this information, the app stores the incident and its severity level in the Amazon Cloud in files that can be used by municipalities and transportation planners for further research. The app not only uses crowdsourcing as a form of data retrieval, but it also allows the users to see conflicts that have been logged by other users, which in return crowdsources knowledge about the safety issues that are present near a user. The app only works when the user starts it, and it does not run in the background, which eliminates any battery drain concerns.

In response to the comments received from the field test participants, the team finalized the app with only two user groups. The regular user group receives a reminder once a day for recording a conflict, and they also receive prompt notification of any conflict recorded in their current zip code. The second user group, which requires access permission from the developers, represents those that will work with the data and be able to share the database. The database can be shared as a *.CSV file or as a *.KML file, which can be opened in an Excel file or in a Google map file.

4. Results

At the end of the field test, the research team downloaded and cleaned a set of 129 conflict records. During the field test, only about 7% conflicts resulted from overtaking while over 93% are non-overtaking. Pedestrian-motor vehicle conflicts represent most (83%) of the non-overtaking conflicts; the remainder are bicyclist-pedestrian (9%) and bicyclist-motor vehicle conflicts (8%). Almost 67% of the overtaking incidents involve bicyclist and vehicles and the rest occur between bicyclists and pedestrians.

4.1. Severity level analysis

The four conflict severity levels developed by Casey et al. (2016) with the help of transportation experts is adopted in this *Safe Activity* app (Table 2). Almost 36% of the conflicts recorded in the field test appear to be a serious conflict (category A), which narrowly avoided collision. Almost 9.3% of the conflicts recorded fall into category B where incidents have a significant potential for a collision but may be avoided with a time critical response. A category C conflict means that the conflicts do not appear extremely severe and the incident can be avoided with moderate time and/or distance available to the parties involved. Almost 31% of the non-overtaking conflict falls under this category. Finally, the remaining 17% of the conflicts identified as category D likely have no immediate safety consequences (Fig. 3).

4.2. Hot spot analysis

Identification of hazardous locations (black spots, hot spots or

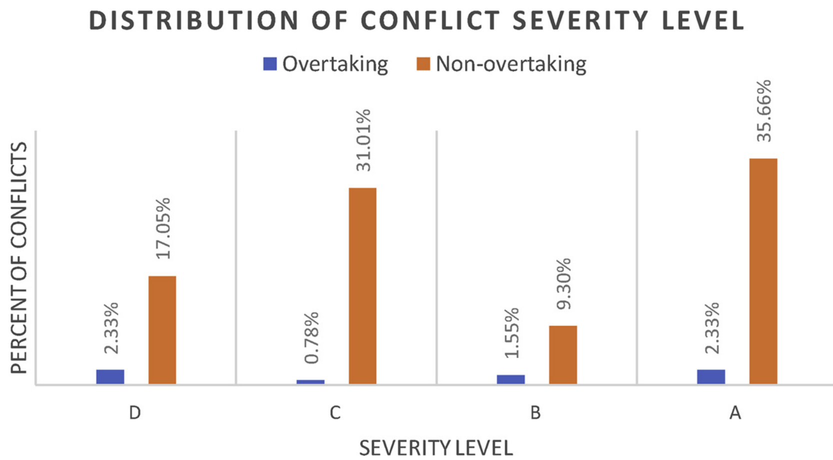

Fig. 3. Total percentage of conflict records and their severity level.

collision-prone sites) is a systematic process for distinguishing high risk road segments or intersections that suffer from crashes. This method represents a cost-effective countermeasure and helps prioritize specific treatment sites. This same concept can be used to identify hot spots for conflicts, which may indicate risk prone locations before crashes occur.

The researchers collected four years of pedestrian and bicyclist fatality data are collected and mapped on the previously downloaded Google Earth file. Juxtaposing the fatality data with the data collected during the field test, the research team identified four different geo-spatial hotspot matches. At least four different locations with a previous pedestrian or bicyclist fatality coincidewith locations where users have identified a category 'A' conflict at one location and category 'D' conflicts at the other three locations. Due to the uncertainty of crash occurrence and hence the limited data on crashes and fatalities, the total number of crashes for this example may not identify the comprehensive capabilities of future hot spot analysis. This outcome indicates that the limited data collection effort provides some mapping to locations that have produced fatalities in the past (Fig. 4). A more in depth analysis of hotspot and crash location matching remains critical for future crash predictions and identification of the failure mechanism; however, this requires a more significant market penetration and corresponding community use of the app.

4.3. Feedback survey

The researchers use a set of Likert scale and open ended questions to collect app users' and end users' feedback during the field test. While some of these questions are designed using a five point Likert scale, others are just yes/no or open ended questions. Forty-one app users completed the survey. The survey asked questions about the overall competency of the app interface and the performance of its features. Examples of sample questions include:

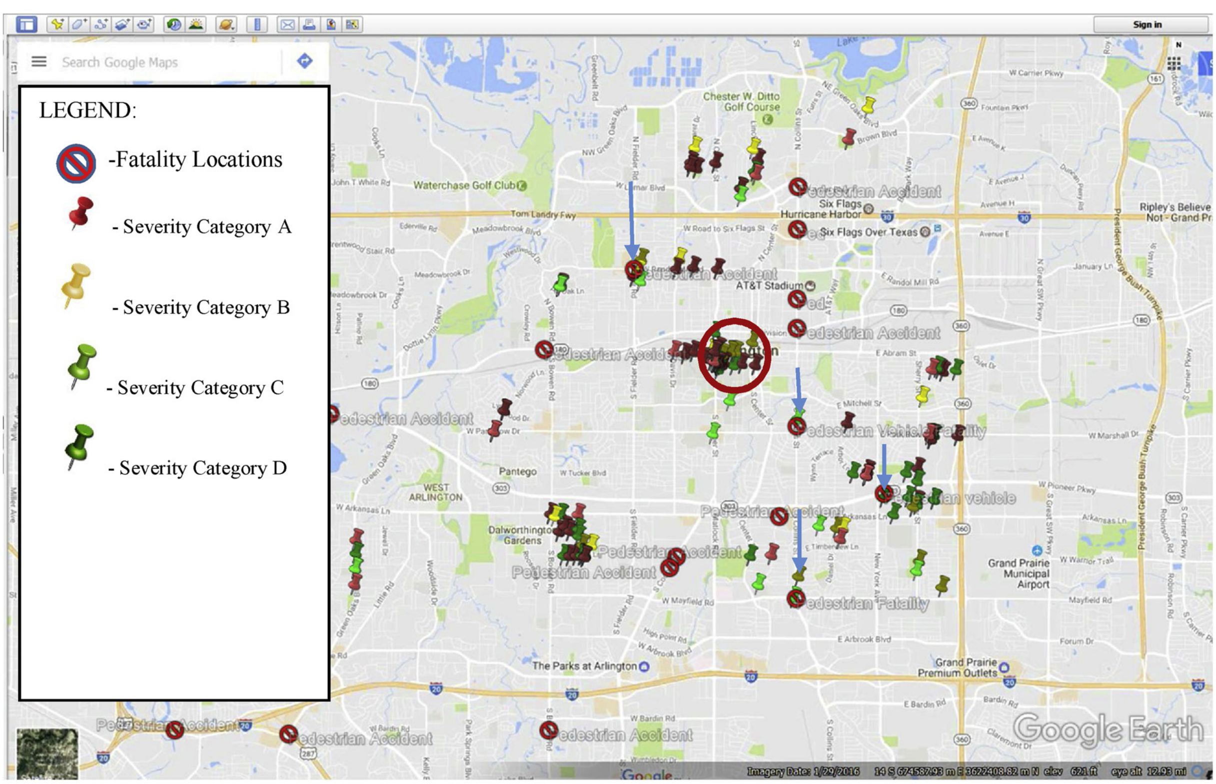

Fig. 4. Hot Spot of Fatal Crashes and Clusters of Recorded Conflict.

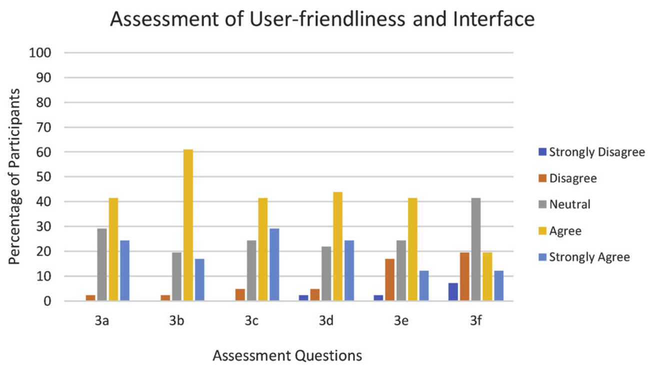

Fig. 5. Percentage of participants agreeing/disagreeing on user-friendliness.

- I can answer the questions easily
- I was able to accurately determine the location of conflicts
- The notifications provided via the app encouraged me to use the app in timely manner?
- How likely will you suggest the app to your friends?

Fig. 5 presents the percentage of users agreeing or disagreeing to certain app features. Based on the three indicating factors identified by Casey et al. (2016) (speed, distance and time) that define conflict severity, the app asks a set of survey questions. Question 3 asks a set of questions on the user-friendliness and is designed on a five point Likert scale. Question (3a) asks the users whether the app use is intuitive or not. More than 65% of the participants *agree or strongly agree* that they can use the app intuitively and approximately 30% remained impartial. Question (3b) asks whether the users can easily answer the app survey questions about their speed, the separation distance and the time for taking any action. More than 78% of the participants *agree or strongly agree* that the app survey seems easy to complete and most of the remainder (20%) remain impartial. More than 70% of the users agree or strongly agree that the symbols and maps are easy to use (Question 3c). Question (3d) asks the participants about how accurately they could determine the location of the conflicts received mixed feedback. Approximately, 22% of the participants express some difficulty in marking the location on the map. Both question 3e and 3f asked users about the geo-spatial database available to the users. About 40% of the students expressed neutral opinion about seeing the conflicts recorded by other. This may be due to the fact that, at the field testing period, the option was turned off for the users.

5. Discussion

Agencies and decision-makers currently rely on crash and crash severity (property damage only, injury or fatality) data to assess transportation safety; however, conflicts appear to represent a better performance measure for vulnerable road user safety assessment. If widely adopted, the app will enable communities to create their own data collection efforts to identify dangerous sites within their neighborhoods. Agencies will have a valuable data source at low-cost to help inform their decision making related to bicycle and pedestrian education, encouragement, enforcement, programs, policies, and infrastructure design and planning.

The limited data collected during the field test resulted in a subset of the the total number of conflicts, but the limited set of data provides evidence that the conflicts merged with hot spot analysis can be a helpful data source for agencies and decision makers to identify potential safety concerns before they result in a crash hot spot. In Fig. 4, the red circle highlights a location with a large number of conflicts where the City implemented a pedestrian crossing signal before a crash occurred. This represents the practical application of data collected through the app to analyze locations with a large number of conflicts and develop potential solutions.

The major implication of the android-based data collection app are-

- A priori knowledge on potential safety concern from conflict analysis
- Potential cause behind crashes from conflict data analysis at hot spots
- Improvement of perceived safety for active commuters
- Development and maintenance of complete streets with zero conflict spots
- Conflict analysis for jurisdictional boundaries or for cities or counties
- Comparison of conflict pattern in EJ and Non-EJ population
- Future planning for removal of present crash locations from conflict analysis and encouragement of more active users.

6. Conclusion

The initial app field test shows promise with support from many users to continue using the app and the app's effectiveness in mapping conflicts to previously recorded fatalities. Most of the field test users find the app easy to use. This study presents significant opportunities for further research and development. Now that the concept has been proven, modifying the app to function on different platforms represents the most critical next step in the product development process. A detailed strategy on trying to snowball the app adoption among both end users and app users requires further development, and likely requires exploring the role of social media/networks in the adoption of a crowd-source data collection instrument.

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