A Global Review of Current Instrumented Probe Bicycle (IPB) Technology and Research

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ABSTRACT

Bicycling has been shown to provide many benefits, including: environmental, social, health, economic and transport. It produces minimum fossil fuel emissions, is affordable to almost 80% of the world's population, is a source of exercise, reduces cost of travel and uses much less road space as compared to other modes of transport. However, the transport environment in most North American cities is still car-centric. Portland has one of the highest rates of bicycle commuters in North America (NA), around 6.3%, which can be considered very low when compared to many European cities, for example Copenhagen, where over 30% of commuters use bicycles. Various studies have revealed that the main challenges to wider acceptability of bicycle transport in NA are comfort and safety. Several indices have been developed to model perceived comfort and safety of bicycle riders. Researchers have also tried to quantify the effects of dedicated bicycle infrastructure, bicycle-vehicle interactions, and bicycle velocity, acceleration or angular velocity on perceived comfort and safety. The most recent technological development in this area is the Instrumented Probe Bicycle (IPB); used to monitor the bicycling environment. In this paper, previous research from around the world in this field is outlined. Next, through a survey of predominantly North American researchers, the current state IPB research in NA is summarized. Finally, a strategic IPB research plan for NA is proposed, with its ultimate aim to improve IPB technology and promote bicycling. First, further development of IPB software technology is suggested with the aim of automating steps between data collection and analysis. Second, further bicycle comfort and safety research utilizing IPBs is proposed in conjunction with improved bicycle education programs. Finally, independent IPB technological development can lead to diverse designs from which the best ideas can be drawn. It is not crucial for IPB designs to be standardized at this time. Once IPB technology is developed further, standardization can take place.

Keywords: Level-of-Service, Instrumented Probe Bicycle (IPB), transport mode.

1 INTRODUCTION

The transport sector is vital to the global economy and is essential for everyday life. However, it is also a major source of greenhouse gas (GHG) emissions and a leading cause of injury and death worldwide [1,2]. Automobiles play a significant role. In the United States, cars and light trucks contribute roughly one-fifth of total GHG emissions [3, 4]. Injuries and death caused by road crashes have been deemed the 8th worst epidemic in the world by the World Health Organization (WHO), and given current trends, will be the 5th worst by 2030. Road crashes are costing 2% of GDP worldwide and road fatalities are the leading cause of death among people aged 15-29 years [2]. All of these issues can be addressed by convincing drivers to embrace alternative modes of transportation such as cycling.

The numerous benefits of cycling in comparison to driving include better health, improvements in air quality, and a decrease in congestion among others. According to human factors and ergonomics (HFE) professionals, increased use of bicycles is one way to slow climate change and improve health [5]. In one study of Latin American cities, increasing the share of trips by bicycle from 1% to 10% was shown to reduce the amount of greenhouse gas emissions by 8.4% [6]. The health and safety benefits for bicycling are substantial as well. It is estimated that the health benefits of bicycling due to increased physical activity can amount to a 3 to 14 month gain in total life span, substantially outweighing the negative effects due to greater exposure to air pollution (0.8 to 40 days lost) and risk of traffic accidents (5 to 9 days lost) [7]. Perhaps the most significant advantage of bicycling is its affordability and social equity. While cars are affordable to only 10% of the world's population; 80% of people in the world can afford bicycles [8]. Economically, the benefits of cycle networks are estimated to outweigh their investment costs by a factor of at least 4 to 1, making bicycling investments potentially more beneficial to society than those for other transport modes [9].

Despite these benefits, figures summarized in Table 1 shows that automobiles remain the dominant mode of transportation in many cities across North America (NA), caused largely by concerns over the safety and comfort of cycling. Hence, bicycle safety and comfort prediction models can be valuable tools for planners and engineers who are trying to develop desirable bicycle infrastructure. Instrumented Probe Bicycles (IPB) are an important research tool for developing such models.

Table 1 – Percentage mode share in various cities worldwide [10, 11, 12, 13, 14]

	Chicago	Toronto	New York	Beijing	Netherlands
Private Transport	63	67	33	20	28
Cycle	1	8*	1	32	30
Walk	19		39	21	24
Rail	5	-	12	2	18
Taxi	1	-	-	1	-
Bus	11	-	10	21	-
Local Transit	-	22	-	-	-
Go Train	-	2	-	-	-
Others	-	1	5	3	-

*For Toronto, 8% represents the mode share of cycling and walking

Although utilizing IPBs (Figure 1) for bicycle safety and comfort research is common in Europe and Asia, IPBs remain only an emerging technology in NA. During the January 2014 Annual Meeting of the TRB in Washington, DC, there was found to be a lack of available data on IPB design, configuration, research objectives, and data processing methods. For the ability to compare data and results, as well as promote consistency in planning and design, it would be imperative to collaborate and pursue IPB research in a strategically coordinated manner.

Therefore, the motivation for this paper is to improve IPB research in NA by encouraging partnership and by serving as a useful reference for future IPB researchers to come. The objectives of this paper are to:

1) Explore the need for IPBs in bicycle safety and comfort research,
2) Summarize previously published IPB research around the world within the context of bicycle comfort and safety research,
3) Present results of a survey of North American researchers on the current state of IPB research; and,
4) Propose a strategic IPB research plan for NA, with an aim to improve IPB design, research methods, and data processing.

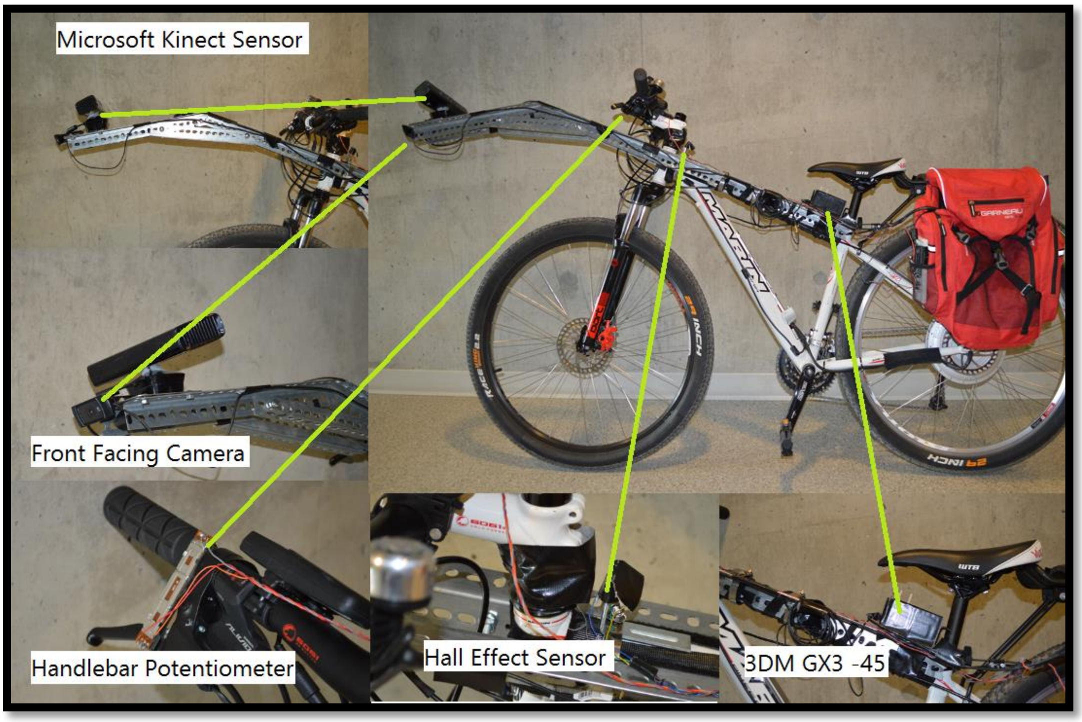

Figure 1. Example of an IPB developed at the Sustainable Transportation Safety (STS) Research Laboratory at the University of British Columbia, Okanagan.

2 A NECESSARY TOOL FOR SAFETY AND COMFORT MODELLING

The greatest mental barrier to cycling arises from the real and perceived concerns for its safety, comfort, and practicality relative to driving. A key deterrent is the perceived danger due to traffic. Many parents in the U.S. forbid their children to cycle for this reason [15]. Comparisons of exposure-based, traffic crash injury rates show that motor vehicle occupants have lower fatality rates compared to bicyclists per billion kilometres travelled [4, 16]. A lesser but still significant mental barrier is the perceived longer travel time sometimes associated with cycling relative to driving. However, an Adaptive Stated Preference (ASP) survey conducted in Minnesota concluded that commuters are willing to ride an average of 23 more minutes in order to switch from riding on a road with on-street parking to an off-road bicycle trail [17], suggesting that the travel time is not the main concern for cyclists.

To increase ridership, a better understanding of perceived rider safety and comfort is required so that more desirable bicycle facilities and effective policies can be introduced. However a knowledge gap exists, namely, lack of reliable empirical tools that can evaluate planned projects and predict the level of perceived rider safety and comfort. Research has therefore begun on ways to extend previous research by developing a bicycle comfort and safety prediction models that can assist with the planning and design of bicycle facilities in this regard [18, 19, 20]. In order to develop these models, there is a need to collect more accurate and continuous real-time data that appropriately represents the cycling experience. Due to completely different driving conditions, traditional instrumentation in other motor vehicles like cars is unsuitable for bicycles. However, certain individual instruments employed like accelerometer and GPS can be used for developing bicycle specific instrumentation for data collection. IPBs have already been widely utilized in Europe, Asia and Australia to assess cyclist behaviour and perceptions [18, 19, 21, 22, and 24].

3 IPB RESEARCH AROUND THE WORLD

There has been several studies involving the use of IPBs for carrying out naturalistic experiments and to study the interaction between bicycles and other vehicles. In 2007, Walker employed a camera and sensors to study the effects of riding position, helmet use, vehicle type and apparent gender on drivers overtaking bicyclists [23]. In 2010, Johnson et al. used a helmet-mounted video camera to study the naturalistic driving behaviour of bicyclists in Melbourne, Australia and tried to identify the risk factors affecting them [24, 25]. In 2012, Gehlert et al. used a data acquisition system to record the speed and video data of different bicyclist categories, namely pedelec, e-bike and traditional bicycles [26].

In 2012, Zhang et al. utilized an instrumented bicycle to study the interactions between the rider and the bicycle [27]. The contributions of this research included the development of a rider/bicycle dynamics model, as well as a new position estimation scheme. Although the system was a stationary bicycle simulator, this study provided insight into possibly the first development of an instrumented bicycle system in NA, referred to within the study as the "smart bicycle" system. Rider movement was recorded utilizing a camera-based motion capture system and a body-mounted inertial measurement unit (IMU). Other sensors were fitted to measure handle bar and seat forces.

In 2013, further research utilizing IPBs was conducted for a variety of different topics. Vanwalleghem et al. conducted research to estimate cyclist comfort due to vibrations [28]. The researcher proposed a vibrational comfort evaluation that assessed the vibration at all contact points between the rider and the bicycle: handle-bar, seat and pedals. An instrumented bicycle, fitted with acceleration, velocity and force sensors, was used to collect data for the model. The absorbed power method, developed by Pradko and Lee (1966), was used to evaluate vibrational comfort by considering the amount of energy transferred to the body as well the interactions between the vibrating structure and the body in contact with it.

Joo et al. [18] proposed an intelligent system to evaluate the safety and mobility of the bicycle environment, called the Bicycle Monitoring Index (BMI). Its goal was to be a useful tool for public bicycle-sharing systems. This model was based on a fault tree analysis (FTA) technique in order to integrate safety and mobility monitoring. An instrumented probe bicycle (IPB) was utilized to collect the necessary data for the development of the BMI. The IPB was equipped with a GPS receiver, accelerometer and a gyroscope sensor. The collected data allowed the researchers to evaluate environmental factors such as heavy vehicle volume, surface conditions, grades, crossings, humps and curbs. A survey was applied to collect actual responses about perceived safety and comfort during the field experiment.

Twisk et al [22] studied the safety of electrical-assist versus traditional pedal-power-only bicycles for elderly users, by conducting a field study utilizing IPBs equipped with a speedometer to collect riding speed, a potentiometer to record steer angle and steer acceleration, a GPS, a camera, and an inertial measurement unit. Additionally, the rider was equipped with a peripheral detection task (PDT) measurement unit (to measure mental workload), a heart rate monitor (to measure physical work load), and a helmet-mounted camera to record head movement and traffic situations. The data collected from the IPB showed that riders rode faster on electrical assist bicycles, with no significant difference for metal workload between bicycle types.

One of the greatest leaps forward in IPB research came in 2013 from Dozza and Fernandez [21], who developed an advanced IPB to study bicycle dynamics and cyclist behaviour. Their vision for the future is the development of intelligent applications to improve the safety and mobility of bicycling (i.e. curve speed warning) in the same way that similar applications have been developed for vehicles. Such intelligent application systems are already in use on vehicles, and now focus is shifting to bicycles. In 2013, Gustafsson et al. [29] aimed to create a cooperative application able to prevent accidents by warning both driver and cyclist of an imminent threat through an application called BikeCOM. The BikeCOM application relies on bicycle-to-vehicle GPS and wireless communication in order to exchange safety information between Android device users, effectively turning cell phones from a risk to a potential countermeasure tool. To develop intelligent applications such as BikeCOM, Dozza and Fernandez reason that we must first achieve an understanding of bicycle dynamics and cyclist behaviour that is on par with our current understanding for crash avoidance technology in use on motorized vehicles. It is with this aim that Dozza and Fernandez constructed five IPBs to monitor the daily bicycling activity of 20 cyclists over a two week period. Each IPB was fitted with a camera (one IPB had two cameras, one directed forward and one directed at the cyclist's face), two inertial measurement units comprising of an accelerometer, gyroscope and compass, a GPS, and a brake force sensor. The IPB was equipped with a data logger, complete with automatic start up, file saving, and shut down procedures. The IPB developed in this research presents a successful implementation of hardware and software to collect continuous bicycling data from multiple sensors.

The most recent published IPB comfort and safety research was by Yamanaka et al. (2013) [19]. The study developed one model addressing each of the five topics of interest: 'safe sense to other traffic', 'discomfort in roughness of road surface',' discomfort of narrow bicycle space', 'comfort of cycling speed' and 'total level of comfort.' To develop the models Yamanaka et al. conducted a total of 1432 IPB trials using a total of 74 street segments, 4 to 6 riders, 7 cities, and 3 countries (2 cities in China, 4 cities in Japan and 1 city in France). Riders rode each segment between 4 and 8 times, resulting in each segment being ridden between 16 and 32 times. To evaluate the riders' sense of safety and comfort, subjects were asked to provide ratings on a five point Likert scale through a microphone as they passed each road segment for each of the topics of interest. More than 30 independent variables assessing parameters such as speed, braking, acceleration, and traffic volume were evaluated for model development. The aim of Yamanaka's IPB research was to determine key factors that influence a cyclists' perception. A future scope to this research was the study of the effect of rider characteristics and other obstacles (such as vehicles, pedestrians, other cyclists, curves and intersections) on the comfort and safety of bicycle riders. A summary of researchers from around the world and the type of IPB design used by each is provided in Table 2.

Table 2 – Summary of IPB researchers from around the world and the IPBs used by each [18, 19, 21, 22, 23, 25, 26, 28, and 29]

RESEARCHER	INSTRUMENTS UTILIZED WITH PROBE BICYCLE
Divera Twisk Institute for Road Safety Research Netherlands	Speedometer, potentiometer (steering sensor), GPS, GoPro 3 Silver video camera, ProMove 3D (Inertial Measurement Unit)
Marco Dozza Chalmers University of Technology Sweden	GoPro Hero, Hero2 video camera, Phidget IMU 1056 (Inertial Measurement Unit), Phidgets GPS 1040, Flexiforce resistive force sensor (Brake force sensor)
Yizhai Zhang* Rutgers University United States of America	8 Bonica cameras from Vicon Inc. (motion capture), Inertial Measurement Unit - Motion Sense Inc., handle bar force/torque sensor, seat force/torque sensor, pedal force sensor, EEG sensor, EMG sensor, eye tracking sensor, CompactRIO - National Instruments Inc. (controls pneumatic actuators that support the bicycle frame)
Joachim Vanwalleghem Ghent University Belgium	Velocity sensors, Force sensors including handlebar force sensors
Shinhye Joo Hanyang University Republic of Korea	Inertial Measurement Unit, GPS
Hideo Yamanaka The University of Tokushima Japan	SHARP GP2Y0A02YK0F (PSD distance sensor – lateral distance sensor), MicroStone MA3-04AD (Vibration Sensor), Race Technology DL1 (Data logger and GPS), speed sensor, braking sensor – displacement sensor, steering sensor – string sensor, video camera and microphone
Ian Walker University of Bath United Kingdom	Massa M-5000/95 (Ultra sonic distance sensor), Video Camera, laser (to assist cyclist with maintaining fixed distance from edge of pavement)
Marilyn Johnson Monash University Australia	Oregon Scientific ATC3K Action Camera (Helmet Mounted camera)
Tina Gehlert German Insurers Accident Research Germany	ACME FlyCamOne eco V2 (front and back camera), SM Modellbau GPS-Logger (GPS), SM Modellbau Unilog2 (Wheel Sensor and Altimeter)

*Stationary IPB (not all sensors were mounted on the bike)

4 METHODOLOGY

As most IPB research within NA is in early development, a survey was utilized to collect information for this study. The objectives of the survey were to gain a better understanding of ongoing research, incorporate policy suggestions for promoting bicycle ridership, identify factors affecting comfort and safety of riders and finally to take suggestions on a common IPB platform for all research in NA.

In order to find potential IPB researchers in NA, a brief literature review was conducted in which names of potential researchers were collected. Next, an invitation to an informal IPB research group was also distributed to researchers involved in this field. The group would serve as a forum in which the exchange of information would help work towards the development of IPB research technology, comparable IPB research data, and improved data quality. An invitation to the survey was distributed to individuals at the 2014 TRB meeting that were labelled as ''interested' in participating in the IPB research group and to other researchers in the bicycle research field. A total of 17 researchers from 13 Universities, one city, and one transportation authority across the U.S. and Canada were invited to participate in the survey, among which 5 completed the survey. An invitation was also extended to 2 leading IPB researchers from Europe (2 Universities) in the hopes that their greater experience in this field will allow for a unique perspective. One of the researchers from Europe completed the survey. Figure 2, depicts a map of North America and Europe, indicating the universities and transportation authority that was contacted. The response rate in absolute terms is relatively low at roughly 30%; it belies the emerging status of IPB research. As such, the results must be taken as not exhaustive nor comprehensive, even though they likely represent the majority of IPB researchers on this continent. From the results of the survey and from email correspondence, North American institutions confirmed to have IPBs in operation include: University of British Columbia Okanagan, University of Iowa, San Francisco County Transportation Authority, McGill University, Portland State University, City of Cambridge MA, and University of California Davis.

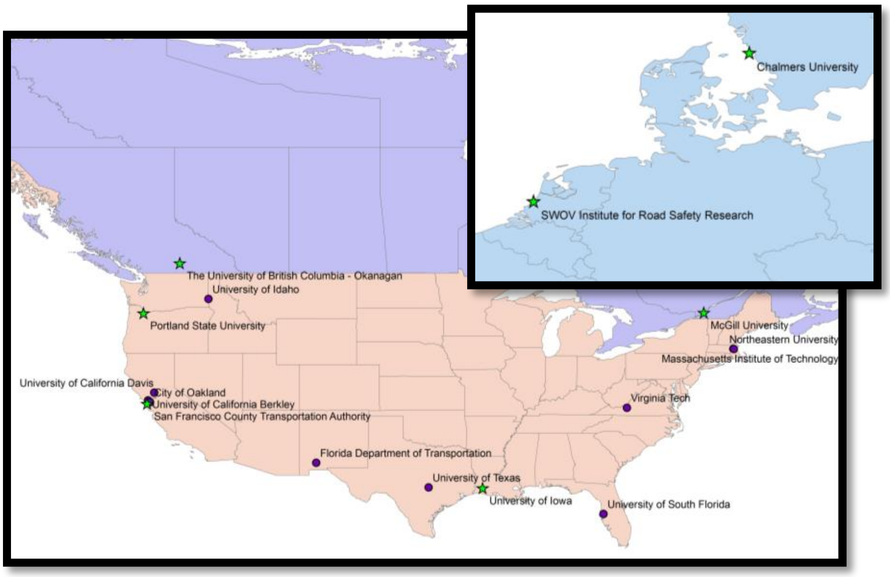

Figure 2. Map shows the locations of institutions that were invited to complete the survey. A green star indicates institutions that were able to complete the survey.

The survey consisted of four sections (See Appendix). Part 1 of the survey asked respondents for their general background information including contact information, university affiliation, and current position in the university. As IPBs are a versatile tool, researchers were asked in Part 2 to describe the aim and methodology of their research in order to gain insight on other research topics that utilize IPBs. Specifically, survey questions asked about IPB configuration, post-processing methods, model development, research motivation, findings and the challenges faced. As much of the IPB research in NA has not yet been published, one of the objectives of this paper is to serve as a reference to current researchers so that the experiences, knowledge and lessons learned could be shared. Part 3 of the survey asks respondents about their views on policies towards bicycle comfort and safety. There was an interest in expert opinions on the main barriers to cycling as well as the policies that they are most in favour of to increase ridership. Therefore, questions asked respondents what variables they believe are the most significant to bicycle safety, comfort and level of service (LOS). Finally, part 4 of the survey asks the respondents for their opinion on the importance of IPBs as a tool for bicycle research, and whether or not they believe there should be a consistent IPB design and configuration for the sake of data quality and consistency, and, research comparability and collaboration. These final questions allowed this study to determine a strategic IPB research plan for NA that reflects the viewpoints of the researchers in that field.

5 RESULTS AND DISCUSSION

The following seven researchers responded to the survey:

- Gordon Lovegrove (UBC, CANADA)
- Cara Hamann (University of Iowa, USA)
- Krista Nordback (Portland State University, USA)
- Marianne Hatzopoulou (McGill University, CANADA)
- Marco Dozza (Chalmers University of Technology, SWEDEN)
- Divera Twisk (Institute for Road Safety Research, NETHERLANDS)
- Elizabeth Sall (San Francisco County Transportation Authority, USA)

From the survey responses, it was found that IPBs were currently being used in NA for a variety of research purposes. UBC is currently developing a Bicycle Comfort and Safety Prediction Model (BCSPM) utilizing data collected from an IPB [20]. Iowa's research project aims to identify riding patterns and various risk exposures of child and adult bicyclists. Research in San Francisco is studying the effects of bicycle infrastructure on regional travel demand. McGill is studying the relationship between bicycle facility design, built environment and cyclists' exposure to air pollution.

The sensors utilized were found to be as diverse as the research topics. UBC's IPB utilized a GPS-Aided Inertial Navigation System (GPS/INS) brake sensors, handlebar turn sensors, a Microsoft Kinect Camera, and a forward facing video camera. Hamann's design was simpler, requiring just a GPS and forward facing video camera. Marianne Hatzopoulou's IPB included research-specific sensors such as a TSI Condensation Particle Counter, Black Carbon Microaethalometer, TSI Dust Track, Harvard Impactor Air Pollution monitors in addition to a GPS and video camera. A summary of surveyed researchers in NA and the type of IPB design used by each is provided in Table 3.

Globally, the main concerns raised by all seven respondents were cost, data collection, and data processing. Among these, data processing was identified as the most significant challenge encompassing all aspects of data acquisition, from developing software for instruments to post-processing protocols in preparation for data analysis. Synchronization methods for multiple sensor data streams were noted as another area for improvement. Extracting data from video cameras were especially time-consuming as it required each video to be watched. The cleaning and smoothing of data from GPS and IMU sensors can also be time consuming.

Bicycle-related research using IPBs require a large amount of time for cleaning sensor data, coding and extracting data from videos.

Table 3 – Summary of researchers surveyed in NA and type of IPB used in their research

RESEARCHER	INSTRUMENTS UTILIZED WITH PROBE BICYCLE
Gordon Lovegrove University of British Columbia Canada	Microsoft Kinect, Kinect2 Camera, Logitech HD Pro Webcam C910, PTB6043-2010BPB103 Potentiometer (Hand-brake sensor), A1324 Hall effect sensor (Handlebar sensor), 3DM GX3 -45 (GPS-Aided Inertial Navigation System)
Cara Hamann University of Iowa USA	GPS, Speedometer, camera
Krista Nordback Portland State University USA	No current IPB research
Elizabeth Sall San Francisco County Transportation Authority USA	Smartphone and associated applications
Marianne Hatzopoulou McGill University Canada	Air pollution monitors (TSI Condensation Particle Counter, Black Carbon Microaethalometer, TSI Dust Track, Harvard Impactor), GPS, Go-Pro Video Camera, Holter monitors (on cyclists)

Most researchers agreed that there is great potential for improving existing transportation infrastructure in NA to support bicycling. Many barriers to bicycling were identified including, inexpensive parking, ease of automobile use, sprawling developments, a lack of bicycle infrastructure, uncomfortable weather, a lack of bicycle infrastructure connectivity, negative attitudes of various community members towards bicycling and the presence of steep road grades. Therefore, the most important policy suggestions to improve attractiveness of bicycles in NA were the development of better bicycle infrastructure (smooth pavement, visible markings, and separation), bicycle-conscious road design and educational programs promoting bicycling. Other suggestions include the promotion of bike sharing programs, increased fees for motor vehicle use, land-use reform, and the use of electric assist bicycle. However, the list is not exhaustive and further suggestions from other road safety experts are suggested.

The main factors contributing towards both comfort and safety of cyclists were identified as policy decisions (such as separate bicycle lanes, bicycle crossings and bike zones), the traffic characteristics (such as traffic volume and speed limit) in the region and the characteristics of the roadways (width of roads, slope of roads and other design elements). Rider characteristics such as skill, experience and previous training were identified by some researchers to as significant contributors to the perceived level of comfort and safety. In the case of electrical assist bicycles, bicycle dynamics also play an important role to safety and comfort. Apart from comfort and safety, other significant factors affecting the Level of Service for cyclists were the efficiency of the network, and the presence of parking facilities.

PROPOSED IPB RESEARCH PLAN FOR NA

All researchers encouraged the use of IPB in future bicycle-related research. Of the six respondents, two researchers acknowledged that that current research in NA is not well coordinated, while one felt that research is well coordinated. Three researchers held a neutral opinion. While the majority of researchers supported the use of a consistent IPB design and configuration as it would allow for better data quality, research comparability and collaboration, one researcher disagreed and raised some key points. The researcher states, "It is the variety of tools, instruments, and methods that will enrich the literature in this field. If we all follow the same protocol, we will never be able to find out whether a divergence from the protocol will result in the same findings. It scientifically incorrect to normalize methods in a field that is still at its infancy. There is still a lot that we don't know and through the variability of methods, we can then infer whether some findings are accidental vs. 'true'. It is still too soon for this research field to normalize methods." The IPB research plan proposed for NA within this study consists of three objectives and is summarized in Table 4.

Table 4 – Summary of main topics discussed and corresponding proposed plan

CONCERN	OBJECTIVE
Challenges in post processing of data and synchronization of multiple data streams	Further research and development into improving IPB software technology.
IPB configuration and design standardization to allow for data comparability	IPB research may be allowed to develop independently from one another to promote diversity. Once the best design is determined, it can be standardized. Task-specific IPB design standards are necessary.
Lack of bicycle infrastructure quality and quantity	IPB research focusing on the development of safety and comfort prediction models. Introduce of improved educational programs.

First, further research and development into the synchronization and packaging of multiple sensor data streams into a single output file would be beneficial for allowing more data to be collected and processed in a shorter amount of time. The system will ideally have very simple user-interface systems that can be used to start and end/save data collection. Further development of automatic post processing methodologies through software for GPS, IMU and video recording data is also crucial to decrease post processing time. Software can be developed specifically to process run IPB instrumentation so that final data can be obtained directly from the single output file. These issues are common to any instrumented vehicle research and further improvement in this field would be beneficial. Specific challenges to IPB's are the weight of sensors/processors, and the battery life. In contrast to sensors mounted on vehicles, the additional weight on an IPB can significantly impact the riding experience of the cyclists and thus affect the results. Additionally, battery life for all the sensors on the IPB can be a limitation in some cases especially with IPBs that are heavily outfitted with sensors. Further development of IPB's should include improvements to sensor configurations to minimize weight imbalances and increases.

Second, consistency in IPB design will allow for more comparable data, but perhaps IPB research can also be developed independently in order to promote diversity in IPB technology until the field has matured. This would allow the best designs and ideas to be utilized when

IPB technology is finally standardized as a design tool or data collection tool. Additionally, the same standard of IPB design would not be suitable for all IPB tasks. Multiple standards of IPB design and configuration would be necessary depending on the task for which the IPB was designed for. Ultimately, with more diversity in the research, the most effective standard can be chosen.

Finally, in order to address the issues in quality and quantity of bicycle infrastructure, one of the focuses of IPB research should be on the development of safety and comfort prediction models as tools for engineers and planners to design better, more desirable bicycle infrastructure and bicycle-conscious road design. Additionally, knowledge from IPB research on comfort and safety can uncover information that is instrumental to improving educational programs. For instance, research may uncover certain situations where cyclists are at particularly high risk, which educational programs can then address. Introduction of improved educational programs promoting bicycling skills and rules of the road training will be crucial for improving rider safety and comfort, and will also greatly contribute to increasing ridership.

6 CONCLUSION

This paper summarizes previously published IPB research from around the world. Although IPB research is still in its early stages in NA, through a survey of North American researchers, it was found that the IPB has potential for the future of bicycle research in NA. Currently, IPBs are being used in many domains, including bicycle comfort, safety, route choice, and the effect of air pollution. Their broad application is expected to encourage further development. Given the large scope and infancy of IPB technology in NA, standardization of design will take time before the most effective configuration can be chosen. Current IPB sensors and design have been summarized. A strategic IPB research plan for NA has also been conceptualized and summarized based on the concerns and needs expressed by respondents.

The IPB research plan proposes a strategy for the continued development of IPB technology and research in NA for all areas of study and for improving the quality and quantity of bicycle infrastructure in NA. The IPB research plan consists of three objectives. First, to overcome the challenge of data post processing and synchronization, further development of IPB software technology is suggested with the aim of automating steps between data collection and analysis. Second, in order to address concerns for North American bicycle infrastructure quality and quantity, it is proposed that further bicycle comfort and safety research utilizing IPBs be conducted to develop predictive models to be used as design tools. This would be conducted in conjunction with improved bicycle education programs. Finally, it is believed that independent IPB technological development will lead to diverse designs from which the best ideas can be drawn. It is not crucial for IPB designs to be standardized at this time. Once IPB technology is developed further, standardization can take place. The results presented in this paper provide an overview for NA researchers in the field of Instrument Probe Bicycle (IPB) and encourages further study in this area.

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APPENDIX (SURVEY QUESTIONNAIRE)

[A Global Review of Instrument Probe Bicycle (IPB) Research in North America]

To All Ad hoc Members of the IPB Research e-list

PART I: TELL US ABOUT YOURSELF

1. **Please mention your name and contact details (email and phone number).**

2. **Which University are you affiliated with?**

3. **What is your current position in the university (RA, Asst. Prof, Assoc. Prof, Prof, other)?**

PART II: TELL US ABOUT YOUR RESEARCH REGARDING INSTRUMENT PROBE BICYCLE (IPB)

4. **Please briefly explain the aim and methodology of your current research using IPB's?**

5. **Which previous research (if any) have motivated your current research (cite author(s) and year if possible)?**

6. **What challenges (if any) did you encounter during IPB development?**

7. **Which sensors have been used on the IPB? What data is it capable of recording? If possible, please email a picture to us.**

8. **How is the post-processing of data from sensors done? What challenges are faced during this stage of research?**

9. **Have you fit models to the data collected by the IPB? If so, please cite published papers.**

10. **What have been the important research finding(s)/progress to date?**

PART III: GIVE US YOUR TAKE ON THE CURRENT POLICIES TOWARDS BICYCLE COMFORT AND SAFETY

11. **How well (on a scale of 1-10) do you think your community promotes bicycle ridership? What do you think are the main barriers for the same?**

12. **Which policies/steps are you in favour of to promote increased bicycle usage in your community?**

13. **Comfort may be defined as physical or physiological ease for doing an activity. Rank the following factors in order of importance towards bicycle comfort? (You can add other parameters) Please give numbers 1 (Highest priority) to 10 (Lowest Priority) to each choice for ranking.**

    - Bicycle characteristics (shock absorbers, better tires, seats, etc.) - ________
    - Policies (separate bicycle lanes, bicycle crossings, etc.) - ________
    - Roadway characteristics (width of roads, number of lanes, slope, etc.) - ________
    - Rider characteristics (gender, age, build, etc.) - _________
    - Traffic characteristics (traffic volume, speed limit, etc.) - ________
    - Others (please specify):

14. **In the context of bicycles, safety may be defined as protection against physical or psychological damages due to accidents. Rank the following factors in order of importance towards bicycle safety? (You can add other parameters) Please give numbers 1 (Highest priority) to 10 (Lowest Priority) to each choice for ranking.**

    - Bicycle characteristics and safety equipment (helmets, seat design, etc.) - ________
    - Policies (separate bicycle lanes, bicycle crossings, etc.) - ________
    - Roadway characteristics (width of roads, number of lanes, slope, etc.) - ________
    - Rider characteristics (gender, age, build, etc.) - ________
    - Traffic characteristics (traffic volume, speed limit, etc.) - ________
    - Others (please specify):

15. **Level of Service may be defined as a measure of the quality of a traffic service. Which of the following factors are important regarding Bicycle Level of Service (please tick your choices) :**

- Comfort - ________
- Safety - ________
- Others (please specify):
-

PART IV: GIVE US YOUR TAKE ON THE CURRENT BICYCLE COMFORT AND SAFETY RESEARCH IN NORTH AMERICA

16. **Please select one – 'The current research regarding bicycle comfort and safety in North America is well co-ordinated' –**

    1. Strongly Agree
    2. Agree
    3. Neutral
    4. Disagree
    5. Strongly Disagree

    Also please tell us why you think so?

17. **Please select one – 'The IPB is a great asset for bicycle research' –**

    1. Strongly Agree
    2. Agree
    3. Neutral
    4. Disagree
    5. Strongly Disagree

    If you don't agree, please tell us why you think so.

18. **Please select one – 'It is important to that researchers around the world using IPBs be consistent in IPB design and configuration for the sake of data quality and consistency, and, for the sake of research comparability and collaboration.' –**

    1. Strongly Agree
    2. Agree
    3. Neutral
    4. Disagree
    5. Strongly Disagree

    If you don't agree, please tell us why you think so.