ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #35255

Human-centered geometric design of roads using an autonomous vehicle problem

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Abstract

Geometric design of roads is a key component of an undergraduate civil engineering curriculum. At the University of Illinois, geometric design is taught in a senior design class for upperclassmen and new graduate students. In order to encourage critical analysis of design standards, especially human-related factors, a new design project was implemented that incorporates Autonomous Vehicles (AVs). Working in multi-disciplinary teams, students were required to develop new geometric design standards for fully autonomous AVs together with human cyclists on a principal arterial in Puerto Rico. The class was given an introductory lecture on AVs, after which they were required to review the literature, modify existing standards, and implement the findings into their roadway designs. The teams evaluated the human-related aspects of design by re-considering multiple geometric design parameters for AVs, as well as interaction between AVs and cyclists. All teams recommended that lane width, perception reaction time, and stopping sight distance criteria be modified, while none that speed limit and maximum rate of superelevation be modified. All teams also recommended that cyclists be separated from AV lanes, with most teams recommending a shared shoulder. During peer assessment, students also expressed strong satisfaction with their teams while working on this futuristic roadway problem.

Introduction

Geometric design of roadways is an important component of an undergraduate civil engineering curriculum, especially in the sub-disciplines of transportation and water resources engineering. In 1986, Khisty [1] surveyed practitioners and educators in transportation engineering on topics that should be included in a transportation engineering curriculum. Both sets of respondents ranked the geometric design of highways as the most important topic. Twenty years later, in 2006, Turochy [2] conducted another survey of practitioners in order to determine the most important topics to include in a first course in transportation engineering. Once again, geometric design came out on top, even as topics like vehicle operating characteristics declined in importance, while a newer topic, Intelligent Transportation Systems (ITS), ranked 10th out of 31. Therefore, it is reasonable to expect that geometric design will continue to be a primary topic in the civil engineering curriculum as new vehicle technology demands increasing attention.

Among these new topics, Autonomous Vehicles (AVs) has seen rapid development in the past few years, with major implications for transportation engineers. As of 2020, 40 US states had enacted legislation or executive orders related to autonomous vehicles [3]. The federal government has also developed guidelines for the development and eventual deployment of AVs on US roads

[4]. These guidelines classify AVs based on the extent to which human intervention is required for their functioning, with Level 5 AVs being capable of driving themselves without any human control under all conditions. Over the past several years, multiple private companies have been running field trials of their prototype AVs. Dixit et al. [5] presented a meta-analysis of some of the results from those field trials, and reported that currently, AVs tend to disengage and return control to human drivers during system failure or when the driver manually takes control due to a lack of trust in the software. AVs are being continually improved to overcome these challenges and can be expected to see widespread adoption in the near future, presenting transportation engineers with new opportunities and challenges.

A study of the literature related to AVs reveals that most studies from transportation engineering have been devoted to travel pattern and demand forecasting [6, 7, 8, 9], and traffic control systems for AVs [10, 11]. With respect to vehicle navigation, control, and safety, numerous studies have examined vision and control systems for AVs [12, 13, 14]. A few studies also look at the impact of AVs on the geometric design of roads. Hayeri et al. [15] discussed a scenario in which, by 2040, only AVs would be on the road. They concluded that because of lower wander as well as increased throughput of AVs, the capacity of roads could be improved by decreasing the width of existing lanes. McDonald and Rodier [16] reached a similar conclusion, but suggested that until 100% adoption of AVs, some lanes could be designated as 'fast lanes' for AVs, with other lanes being used by human drivers. Thomas and Martinez-Perez[17] focused on the role of autonomous trucks and the effect of platooning on the design of vertical and horizontal curves, specifically the K values and Horizontal Sight Offset (HSO), respectively. Washburn and Washburn [18] however, cautioned that while improved vehicle performance would lead to changes in geometric design standards, they would still be limited by line-of-sight limitations and the comfort of passengers in the AVs.

While researchers and practitioners have suggested potential changes in geometric design as a result of large-scale adoption of AVs, there are presently no standards available for them. As current students can be expected to be called upon to design such standards in the future, AVs represent both an opportunity and a challenge to transportation engineering educators: an opportunity to engage students in a new area that they may face in the future as professionals, and a challenge because of the lack of standards to teach from. Traditionally, geometric design in the US is taught using the AASHTO Policy on Geometric Design of Highways and Streets ([19]), popularly called the Green Book, which is currently in its seventh edition (individual states have tailored their own design manuals based on the Green Book as well). AVs can be expected to change many geometric design parameters. Some of them, such as Perception Reaction Time (PRT), are based on human factors, which may no longer be important for AVs. Therefore, in updating these parameters for different levels of AVs, it becomes necessary to go back and reassess their relationship between drivers, vehicles, and the roadway. In the classroom, this expands geometric design education from being an almost mechanical implementation of design standards to assessing how AV impact human decision-making and safety. This, in turn, trains civil engineering students to be more conscious of the needs of their clients and the community in their careers.

This paper discusses how AVs were integrated into a geometric design class for upperclassmen and graduate students in Civil and Environmental Engineering at the University of Illinois through a Problem-Based Learning (PBL) approach. The aim of the study is to discuss both changes to existing standards recommended by them as well as the reasoning behind it. Additionally, the effectiveness of implementing this approach by building multi-disciplinary teams will be presented.

Instructors can use this study to design their own geometric design classes with an eye on bringing a more human-centered touch to engineering.

Background

Geometric Design of Roads is a 4 credit hour design class for upperclassmen and graduate students in civil engineering at the University of Illinois. The class has a pre-requisite course, Introduction to Transportation Engineering, which provides a brief introduction to students on several topics, including geometric design. The Geometric Design of Roads class is cross-listed with another class on Urban Hydrology and Hydraulics that teaches design of roadway drainage. The geometric design part of the class runs through the first half of the semester, while the drainage content occurs during the second half of the semester. Students who sign up for either class go through the same course content and semester project. The course is required for undergraduates focusing on Transportation Engineering, while the cross-listed course is required for Water Resources Engineering and Science majors. It is a technical elective for students focusing in other civil and environmental engineering areas as well as graduate students.

The geometric design and urban hydrology/hydraulics classes and contents are linked by a common design project that students must complete in teams of four to five. This paper discusses findings from only the first half of the class, in which teams must submit an initial conceptual design (Deliverable 1) and a detailed geometric design of the roadway (Deliverable 2). Each week of the semester, students attend three hours of technical content lectures, one hour of homework problem discussion, one hour of laboratory session to learn relevant design software, and one hour open to discuss their team projects with each other, the instructor, and teaching assistants (TA). In addition to the design project and homework, students are also evaluated through quizzes and exams. Thus, the course is a blend of problem-based learning, in which each team has to complete the design project, as well as traditional lecture-based recitation learning.

Semester Project

For the 2018 edition of the course, the design project selected was the construction of a new tourism corridor in Puerto Rico, called the PR-2 Tourism Corridor (PR2TC). As shown in Figure 1, the road to be designed was a new bypass to the PR-2 highway connecting highway PR-8865 in the east to PR-679 in the west, within the municipality of Dorado. In the project area were several small urban clusters and the Rio de la Plata river as well as several smaller streams. The topography of the area was hilly, which added to the complexity of the design.

PR2TC was to be designed exclusively for Level 5 AVs (which do not require any human control) traveling at a design speed of 50 mph, which would carry tourists though a scenic route to stimulate the local economy. Simultaneously, the corridor was specified to accommodate recreational cyclists. These two constraints required students to consider not just the behavior of AVs but also their interaction with human cyclists. Student teams needed to consider existing design criteria from the Green Book, which are for human drivers, and modify them if necessary to account for Level 5 AVs and cyclists. Level 5 AVs were selected in order to give students full freedom to modify any design criteria without technological or regulatory constraints. While no alignment was specified, starting and ending stations were. Most designs developed by students resulted in a

Figure 1: Project area in Dorado municipality of Puerto Rico, which is in the northern part of the island.

4.8 km (3 mi) long alignment, with a large volume of cut and fill because of the hilly nature of the terrain.

Semester Project Design

The purpose of creating a design project around AVs was to develop a more human-centered approach to geometric design and the way it is taught. Traditionally, geometric design was taught by familiarizing students with existing standards and applying them in a class project. The focus was thus on applying the standards but not analyzing or modifying them for local conditions. However, with the advent of AVs, ITS, and other technology that is changing both driver and vehicle performance, such an approach will quickly become inadequate for students once they enter the profession. Thus, there is a need to make them question, critically analyze, and modify design criteria for a problem that they may face in the future.

During the course, students were given one introductory lecture on the potential impact of AVs on geometric design. This lecture started with some definitions related to AVs and then an open-ended discussion on their impacts on roads, but no specific design recommendations were made. Teams were required to investigate the topic further to develop new design parameters. While analyzing human-related factors was the main learning objective, an additional objective was to ensure that team members worked well with each other in order to prevent the learning process from being derailed by interpersonal conflicts.

To demonstrate their learning, teams were given specific tasks, the successful completion of which provided evidence that course's objectives were met. For the conceptual design in Deliverable 1, they were required to write a minimum one-page literature review on developments in AV technology related to their deployment on roads, with a specific requirement to cite five or more references, which could be articles in magazines/websites, peer-reviewed journal articles, articles from conference proceedings, reports, or any other source. Successful completion of this task would expose students to the variety of thoughts and approaches being used in research for AVs and setup a general set of assumptions that they would make about the performance of AVs on roads. While wider public consultations was not possible within the limitations of this course, this task would also equip students to use feedback from such consultations in the future.

For the detailed design in Deliverable 2, they were required to analyze whether existing geometric design parameters should be changed for AVs, or whether they would remain the same. Specific parameters were not listed so as not to constrain the search to a pre-defined list. In addition, they were required to consider how bike lanes could be safely incorporated into the corridor design. Teams were not required to necessarily change every parameter, but only to recommend whether a change was necessary or not and if it was, recommend a new design value. In this task, success was quantified in terms of the number of teams that made a recommendation on each parameter as compared to the number that didn't. A failure to make a recommendation was considered a failure to meet the course objectives. Thus, the metric for success in this task was the average percentage of teams that made a recommendation for the design parameters. Successful completion of this task would show that students could use their judgment to develop new knowledge and suit their designs to local needs.

Finally, teams were required to implement the updated geometric criteria into their project designs. During this process, team satisfaction was measured through two peer evaluation surveys (one at the end of each Deliverable). A high level of team satisfaction would indicate that the students worked well with each other to reinforce their learning. The implementation of each of these tasks and their results are discussed in the following sections.

Project Teams

Team Building Methodology

Students were divided into thirteen project teams of four to five students each using demographic information collected through the CATME team-maker and peer assessment tool [20, 21]. As the course was primarily a transportation engineering course cross-listed with a water resources engineering course, most of the students were expected to be from those two sub-disciplines. However, from previous experience, students from other sub-disciplines, such as structural engineering and construction management, were also expected to participate in the course. Although the course did have pre-requisites, historically, students have not taken them all or are taking them concurrently. Both groups of students were allowed to take the course, but were warned that they would be responsible for pre-requisite knowledge. Students were also given access to content from the pre-requisite course.

For building teams, the CATME tool was used to design a survey that would obtain responses to the following questions from each student:

1. Sub-discipline within civil and environmental engineering that they specialize in (undergraduate students at the University of Illinois are required to specialize in a primary area of study as well as a secondary area, while graduate students are required to specialize in one area)

2. Whether they had taken the pre-requisite course(s)

3. Months of work experience
4. Availability to meet teammates over the weekend
5. Year of study
6. Familiarity with 3D geometric design software
7. Self-rating of their writing skills

Results from questions 1, 2, 3, and 5 are relevant to this paper and have been approved for sharing by the University of Illinois' Institutional Review Board (IRB). The CATME tool was subsequently used to build teams of four to five students by grouping together students with dissimilar responses to each question, except question 4, for which similar responses were grouped together.

Demographic Information

Of the 62 students registered in the class, 60 consented to participate in the study (97% consent rate). Data from the two students that did not consent were deleted and the remaining data was anonymized by staff not associated with the course. Figure 2(a) shows the distribution of students based on their sub-discipline. Transportation and water resources engineering each had roughly one-third of the students in the class, with structural and environmental engineering contributing about another 13% each. Construction Management and Geotechnical Engineering made up the remainder.

Clearly, the technical diversity of students represented a variety of courses and experiences. Teams were formed in such a manner as to ensure a distribution of CEE specializations with at least one member each from transportation and water resources engineering. In addition to their declared specializations, students were also asked as to whether they had taken the pre-requisite introductory course transportation course. Although recommended readings were provided to the students who had not taken it, teams were built to ensure students with pre-requisite skills were distributed uniformly to avoid teams with a singular sub-discipline advantage. Figure 2(b) shows that approximately 60% of the class had taken the pre-requisite class.

Work experience was considered an important variable because students who had hands-on experience, whether through a previous internship or a full-time job, were expected to bring in additional knowledge, practicality, and mature thinking to the project. The work experience did not have to be in CEE, keeping in mind that most students would have at most a few months of experience. The results are shown in the histogram in Figure 2(c), with a finer bin size between zero and ten months given the vast majority of the responses were in that range. A majority of students had between zero and five months of experience, which represents at most a summer or two of internships. A few students had much longer periods of experience and were pursuing a graduate degree after some years of working in industry.

The last demographic data was students' year of study, which is an indicator of their maturity and breadth of knowledge. This course was open to upperclassmen and graduate students. As shown in Figure 2(d), a little over half the students were seniors with another 30% being juniors. The remaining students were in graduate school pursuing a Master's degree only, and was evenly divided between those in their first year or with multiple years in graduate school. The goal still was to group students into teams to maximize heterogeneity, but because of the large number of

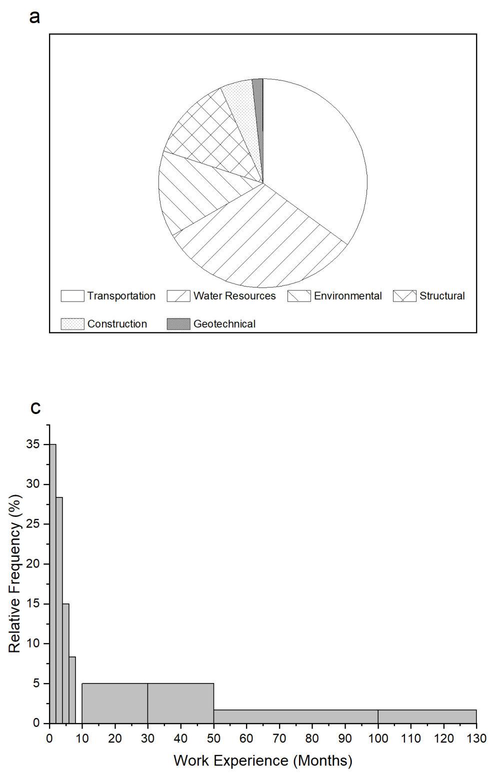

Figure 2: Distribution of students in the class based on (a) their CEE sub-discipline, (b) whether they had taken the transportation engineering pre-requisite course, (c) months of work experience, and (d) their academic year of study.

seniors as well as the effect of the other demographic factors, this was not always possible, and therefore, four teams had over half their members as seniors.

Demonstration of Learning

As discussed in the Methodology section, for each of the two deliverables, teams were given specific tasks that would demonstrate their ability to learn about AVs and apply their findings to design the geometry of the road. Students demonstrated successful learning by summarizing the existing literature, using their findings to modify existing geometric design standards, and then applying it to the class project. The diversity of the results, presented in the following sub-sections, demonstrates that the approach of this design project was indeed successful.

Works Cited

In the first deliverable, teams were required to write at least a one-page summary of the potential impacts of AVs on geometric design based on the team's review of technical literature and news articles. Figure 3 shows the distribution of the different types of sources that the teams cited. Broadly, there were four types of sources: reports (both from private corporations and government agencies), conference publications, journal articles, and articles from websites. There was a nearly-even distribution of each source type with reports making up the highest fraction. Students did not differentiate between the sources in terms of how authoritative there were, giving equal consideration to all of them.

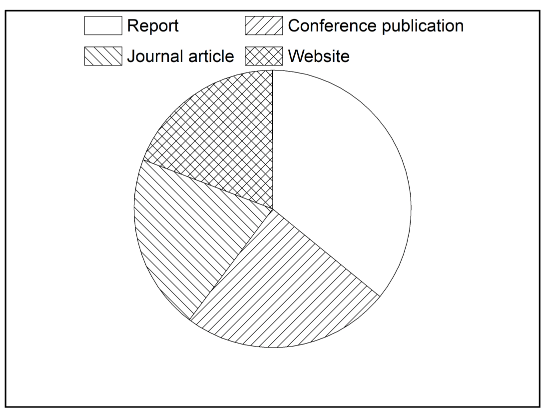

Figure 3: Distribution of types of sources cited for AVs.

The National Highway Transportation Safety Administration (NHTSA) source [4] and another one from the Florida Department of Transportation (FDOT) [22] were the most commonly-cited with ref [22] used by several teams to justify a reduction in lane width. Students also cited other reports that were mostly authored by private companies. Almost all the conference publications cited by the teams, such as refs. [23, 24, 25, 26], were related to various technologies and algorithms used to control AVs. These were used to understand the performance of AVs under a variety of driving conditions. One presentation on the possible influence of AVs on geometric design presented at the 91st Transportation Short Course 2017 at Texas A&M University [27] received several citations and was used by several teams in their project reports.

There are only a few journal publications that discuss AVs from the perspective of geometric design. Like the conference publications, most of the papers cited, such as Refs. [28, 29, 30], were related to the control of AVs. However, the meta-analysis of crash data from field trials of AVs by Dixit et al. [5] received several citations, and was the most cited work among all categories of sources. The most important application of this work was in development of an updated value for PRT. The last category of sources was articles from websites. While these articles may not be long-term resources, they nonetheless provide valuable insight for students as a first step towards exploring peer-reviewed and long-term archival sources. An article by Tom Sohrweide on the website of SEH, Inc. [31] received several citations as it directly dealt with re-designing roads for Level 5 AVs.

All teams successfully completed the task given to them in Deliverable 1, and the diversity of sources that they cited shows that they were successfully exposed to the research being conducted on AVs and had acquired sufficient background knowledge to make assumptions about the performance of AVs and proceed to the next task.

Design Parameters

For the second deliverable, teams were required to apply their knowledge gained from the literature review to develop and implement new geometric design criteria for AVs, while also provisioning for bike lanes in the corridor. Teams were encouraged to be creative but reasonable in their assessments. Based on the recommendations of each team, the design criterion was classified into one of three categories: criteria that would be changed for AVs, criteria that would not be changed, and criteria on which the team made no recommendation. In most cases, criteria that received no comment were kept the same as existing design standards. However, a failure to comment on a criterion implied that students did not analyze it.

Figure 4 summarizes responses by the teams to various design criteria encountered in the project. For each criterion, the percentage of teams that did and did not make any comment was calculated, and the average percentage was then evaluated. On average, 70% of the project teams commented on the listed design parameters, indicating that a majority of the teams successfully developed new knowledge by studying the literature and applying their judgment. Some of the main results from the recommendations are summarized next.

All teams recommended changing PRT, median width, and Stopping Sight Distance (SSD) (all of which are related to human factors), while 45% of the teams did not comment on cross-slope and the minimum radius of horizontal curves. There was unanimous agreement that lane width, PRT, and SSD could be reduced because of the elimination of human errors (students were only required to design for SSD, and not other types of minimum sight distances). Most teams stated that the design speed and cross slope would not be increased for AVs to ensure passenger comfort, although some teams did not comment on these factors. A majority of teams recommended that median widths could be reduced with narrow inner shoulders, again due to the elimination of human error.

Most teams believed that AVs would not change the kinetic friction from the AASHTO recommended value, and thus any change in SSD would be on account of the change in PRT only.

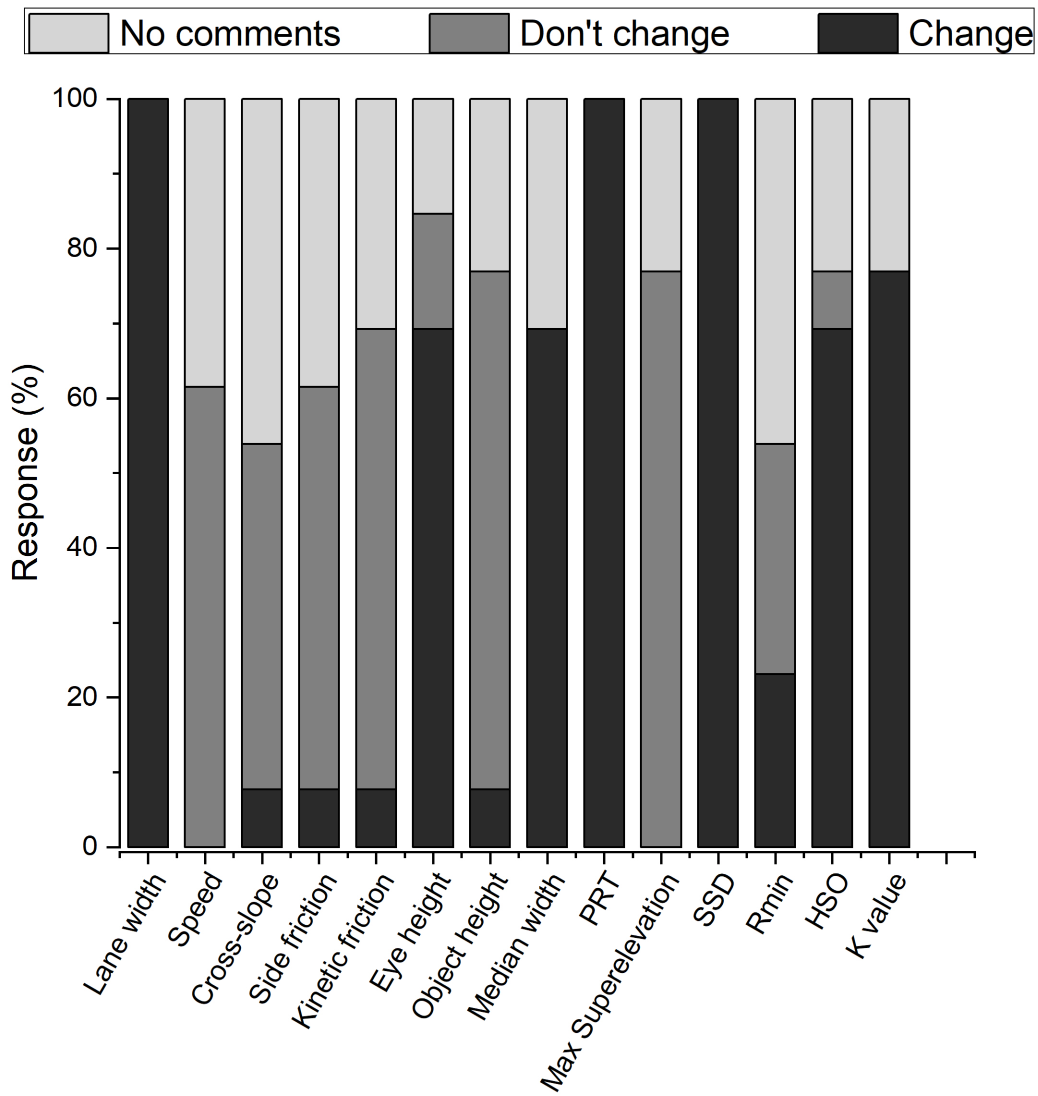

Figure 4: Modifications to geometric design criteria for AVs suggested by class project teams.

Based on changes in SSD, a majority of teams also believed that the design K value for vertical curves (related to curve length) and the Horizontal Sight Offset (HSO) could be modified, although this was not unanimous. One team also believed that the concept of sight distance for AVs was superfluous since it was a purely human limitation, and introduced the concept of a connectivity distance between which two AVs could communicate directly with each other. One shortcoming of this team's recommendation was they did not comment on how the AVs would react to objects on the road, such as debris or wildlife. No team recommended any change to the criteria for rate of maximum superelevation, while only one recommended changes to side friction. One team recommended increasing the minimum side friction because the AASHTO recommended values are based on human comfort and not imminent vehicle skidding and thus, could be increased safely with AV control. A large proportion of teams also recommended reducing the minimum radius of horizontal curves as they felt that AVs could negotiate sharper curves than human drivers.

Finally, a majority of teams recommended changing the eye height for the purpose of evaluating sight distances. These teams were however, divided in their opinions on whether the eye height should be increased or decreased from the AASHTO recommended value of 3.5 ft for human drivers. One set of teams felt that a sensor would be placed near the front bumper of the car, and thus the eye height would be reduced to about 2 ft, while another team felt that the sensor would be placed on top of the car at a height of approximately 5 ft. These different assumptions reflect different types of sensor systems for AVs: image analysis or Radar-based systems may place a camera near the bumper, while Light Detection and Ranging (LiDAR)-based systems would be placed on top of the car. In contrast, a majority of teams concluded that there would be no change to object height from the AASHTO recommended value of 2 ft, corresponding to the tail lights of the vehicle.

Preliminary AV-based geometric design recommendations

Among the proposed design criteria changes to accommodate AVs, four are discussed in detail in order to illustrate the thought process used by the teams. This process, extracted from their explanations in the project deliverables, shows how students considered human-related aspects in their designs.

Figure 5(a) shows the distribution of PRT for AVs recommended by the teams. A majority of teams adopted the PRT value of 0.83 sec obtained by [5] as an average over data from several field studies, while others used a value of 0.50 sec, which was among the values reported in [5] and [17]. One team chose a somewhat arbitrary value of 1.0 sec, and another chose an unrealistic reaction time of zero for AVs. The overall average PRT values recommended by the teams was 0.67 sec, with no team using the AASHTO-recommended value of 2.5 sec. Thus, all teams concluded that AVs would out-perform human drivers with respect to PRT.

Figure 5(b) shows the distribution of the recommended travel lane width. Like PRT, all recommended values were less than the 12 ft width recommended by AASHTO for principal arterials. It should be noted that teams were told to assume that there would be no trucks on the corridor. Most teams reduced this to 10 ft, as they felt that AVs would have a very small wander distribution within a lane as compared to human drivers. For several of these teams, the reference used to justify the assumption was [22]. The overall average recommendation for lane width was about 10 ft. A few teams were even more aggressive in the designs, recommending a lower value of 9 ft, while others were more conservative and recommended 11 ft.

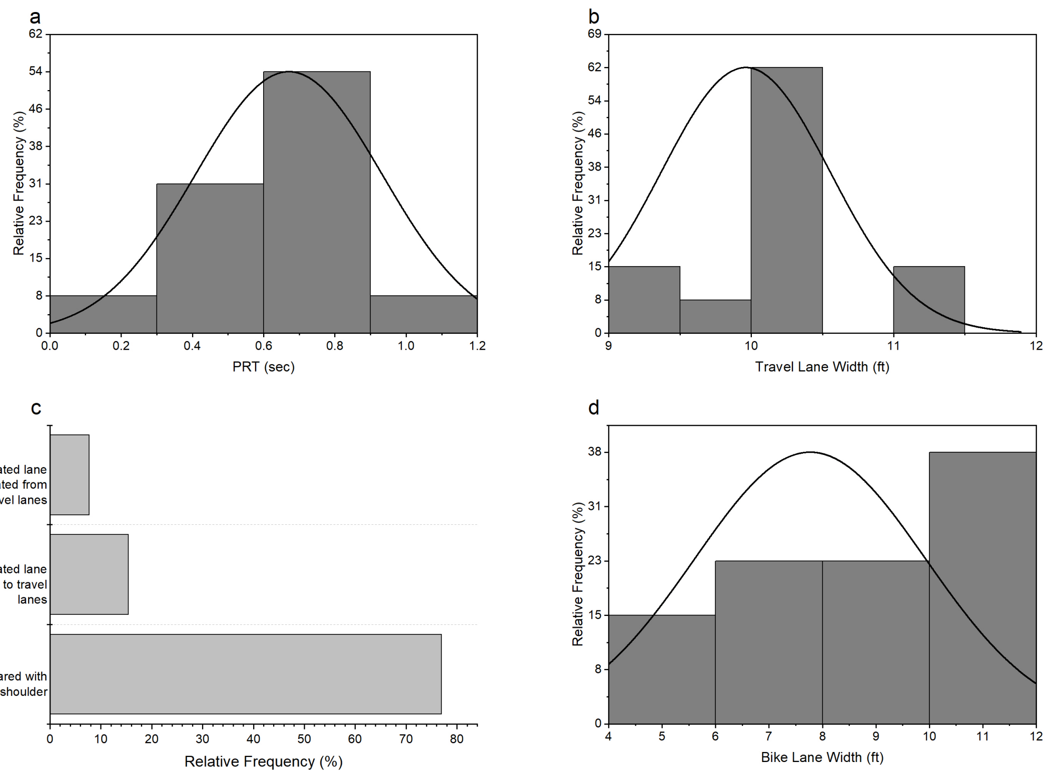

Figure 5: Student recommended AV roadway design parameters for (a) PRT, (b) lane width, (c) incorporation of bike lanes, and (d) bike lane width.

Teams were also required to accommodate bike lanes in their geometric designs to simulate human-AV interaction. Teams adopted one of three strategies: providing a dedicated bike path separated from the travel lanes by a physical barrier (such as a curb or shoulder), a dedicated bike lane that was between the travel lanes and shoulders and separated by pavement markings, and bike lanes that also served as the outer shoulder for emergency vehicle stops. The distribution of the number of teams that recommended each strategy is shown in Figure 5(c). Only one team recommended the first strategy (bike path), two teams recommended an adjacent bike lane to the traveled way, while the vast majority believed that cyclists could safely interact with the occasional AV parked in the combined bike lanes/shoulders and AVs traveling on the shoulder would be able to handle any interaction with cyclists. No team recommended a shared bike lane that would be used simultaneously by AVs and cyclists. Thus, the students largely took an ”optimistic but safe” approach for this parameter.

The distribution of the width of the bike lanes recommended by the teams is shown in Figure 5(d). As most teams recommended bike lanes that would serve also as shoulders, bike lane widths were largely similar to that of travel lanes, between eight and twelve feet, so as to accommodate vehicles on them during an emergency. The few teams that recommended a different strategy had much narrower bike lane widths, as expected. An additional factor was whether the bike lanes were one-way or two-way, with the former being narrower. The average recommended bike lane width was about 8 ft.

Team Satisfaction

Survey Methodology

At the end of the conceptual design in Deliverable 1 and again the detailed geometric design in Deliverable 2, students were asked to perform peer assessment of their teammates, with their detailed responses and ratings being shared only with the instructor and TA, and not other teammates. The peer assessment survey was conducted through the standard peer assessment questions on CATME [32, 33, 34, 21]. While the CATME peer-assessment questions are not directly relevant to this study, the following three additional questions were taken from the CATME database to gauge the level of satisfaction of each team member with working in their respective teams:

1. **Q1:** I am satisfied with my present teammates
2. **Q2:** I am pleased with the way my teammates and I work together
3. **Q3:** I am very satisfied with working in this team

Q1 gauges the student’s satisfaction with teammates at an inter-personal level, Q2 at a professional level, and Q3 the overall level of satisfaction. Together, these questions explain the students’ reactions towards both the teammates they were assigned and the activities they performed together. These questions were answered in terms of degree of agreement on a scale of 1-5 (with 1 indicating strong disagreement and 5 strong agreement). This data was considered relevant to the study as it shows the ability students gained to work in teams, which is necessary for engineers to be more attuned to the needs of the customer and the community in their designs.

At the end of each peer assessment exercise, students rated with a lower level of satisfaction and effectiveness by their teammates met with the instructor to discuss reasons for poor ratings and suggestions for correction. Subsequently, the teams that these students belonged to met with the instructor to participate in a mediation session in order to improve team functioning. Ultimately, individual students who were rated poorly by their teammates lost additional points on the team's assigned deliverable grade, but were given a chance to appeal the instructors decision.

Survey Results

The first survey was administered after the teams submitted the first project deliverable with a 100% response rate. A summary of the response to each question is shown in Figure 6(a). The average rating for Q1 was 4.58, and that for Q2 and Q3 were 4.55 each. These high values indicate that team satisfaction at the end of the first deliverable was very high at the inter-personal level, professional level, and overall satisfaction.

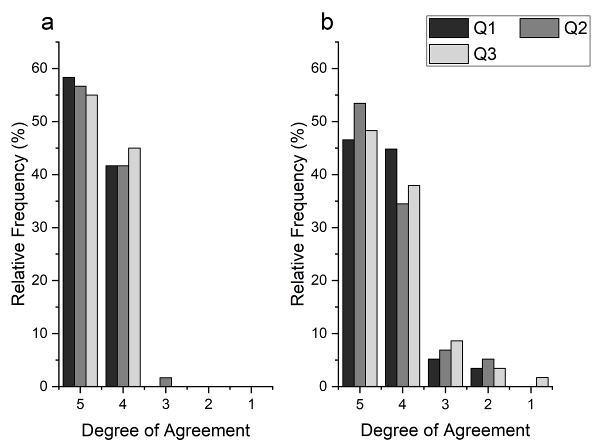

Figure 6: Summary of responses to (a) first and (b) second peer assessment survey (where 1 corresponds to 'strongly disagree' and 5 corresponds to 'strongly agree').

The second survey was administered after the second deliverable was submitted with a response rate of 96%. The responses are summarized in Figure 6(b). As compared to the first peer evaluation, the level of satisfaction was slightly reduced. In the first evaluation, there were no responses of 1 and 2, and only one response of 3. However, by the second evaluation, there were a number of responses that were 2 and 3 and one response of 1. The average of Q1 decreased to 4.33, while that for Q2 and Q3 decreased to 4.17 each.

A two-tailed t-test was performed for each question to determine whether the means of the two peer evaluations were significantly different from each other for each question asked. At a 5% level of significance, the differences were statistically significant (p-value for Q1 was 0.022, 0.003 for Q2, and 0.005 for Q3), even though the magnitude of the difference was small. Thus, while there was a statistically significant degradation in an individual's team satisfaction between the two peer evaluations, the magnitude of decline was small, and the overall satisfaction was still high. The instructor identified two teams that were showing a significant breakdown in team dynamics and where team members gave low responses on all three questions. Individual and team mediation sessions were conducted in order to assist in resolving team dynamic and trust issues in order to arrest any further decline in learning. A few other students reported minor issues with some teammates, but most individuals did not report any teammate problems.

The instructors observed that students that indicated a high level of satisfaction in working with their teams also delivered higher quality results, while those teams that experienced a breakdown in team dynamics produced lower quality work. Clearly then, the approach used to develop human-focused designs requires successful cooperation between team members. Without a formal peer-assessment mechanism, a potential breakdown in team dynamics would inhibit learning for all team members.

Conclusion

The development of Autonomous Vehicles (AVs) has received increasing attention in the private sector, government agencies, and popular media as a potentially disruptive technology that could have a major impact on roadway design particular for transportation engineers. Currently, there is little guidance in the literature or accepted standards on how AVs would affect the geometric design of roads especially with respect to human-related factors, which makes it challenging for educators to teach students about their potential effects. At the University of Illinois, the senior design course on geometric design was modified to address this problem using a Problem-Based Learning (PBL) approach. The 2018 class was asked to design a new in Puerto Rico road for exclusive use by Level 5 AVs, with no human control component, while also allowing recreational cyclists to use the road. The objective of the project was to develop a human-centered approach to geometric design and more broadly, civil engineering education.

Students were grouped into heterogeneous teams representing a variety of backgrounds, experience, and maturity. Each team was required to read literature to acquire a basic background on AVs, analyze existing design parameters (especially human-related ones), and develop and implement new ones to account for AVs and human cyclicts in the proposed corridor. Teams cited an almost equal mixture of reports, conference publications, journal articles, and articles from websites in their literature review and successfully demonstrated their ability to assimilate information on a new topic. In their newly-developed design criteria, teams unanimously decided that lane width, PRT, and SSD could be changed to account for improved performance of AVs over human drivers. By the same reasoning, most teams also reduced the width of the inner shoulders and medians, and recommended that the outer shoulder also serve as a bike lane in order to minimize (but not totally eliminate) interaction between AVs and human cyclists. Across all the design criteria, an average of 70% of the teams made recommendations on their applicability to AVs, indicating that a high level of success in achieving the project objectives.

To meet an additional objective of training students to work in teams, two peer evaluations were performed during the project. The first showed overwhelmingly positive team satisfaction, while the second saw some reduction for individual team members. The decline in average team satisfaction was statistically significant but relatively small in magnitude, with only two teams showing a significant breakdown in team dynamics that required the instructor's intervention. In summary, the incorporation of AVs into a geometric design class was effective in enhancing students' understanding of human-related factors in engineering design. It also met three ABET learning objectives: promoting multi-disciplinary teamwork, engaging students with evolving developments in their field of study, and training students to communicate their results effectively through technical reports.

Acknowledgments

This study was part of the Widening Implementation & Demonstration of Evidence-Based Reforms (WIDER) project at the University of Illinois. Funding for the study was provided by the National Science Foundation through Grant Number DUE1347722. This study was approved by the Institutional Review Board (IRB) at the University of Illinois. The authors are grateful to Dr. José Mestre, Dr. Geoffrey L. Herman, and Hannah Choi for their valuable inputs, and Mr. Sachindra Dahal for anonymizing the data.

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