UTT: A Conceptual Model to Guide the Universal Design of Autonomous Vehicles

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Autonomous vehicles (AVs) are closer to becoming a reality in changing the landscape of commercial and personal transportation. The launch of these vehicles come with the promise of improved road safety, reduced traffic fatalities, and enhanced mobility. However, there are questions as to whether the design of AVs will meet the needs of everyone, including people with disabilities and older adults. We argue that there exists no conceptual model that guide sthe inclusive design of autonomous vehicles to benefit all intended users. This paper proposes such a model, called the User Transportation-Activity Technology (UTT) model, which supports the inclusive design of AVs. We present a review of current models of assistive technology design and their drawbacks followed by an introduction of the UTT model and its application in AV design. This paper may benefit researchers, designers, and developers of autonomous vehicles interested in addressing accessible design issues in such vehicles.

INTRODUCTION

Stephen W. Hawking, a renowned theoretical physicist, cosmologist, and author who suffered from amyotrophic lateral sclerosis (ALS), in his foreword of the WHO report on disability (World Health Organization & World Bank, 2011) says "Governments throughout the world can no longer overlook the hundreds of millions of people with disabilities who are denied access to health, rehabilitation, support, education and employment, and never get the chance to shine." We hold on to his words and believe that the inclusion of all people is essential for a fair, supportive, diverse and developing community. We aim to make a meaningful contribution to the conversation around the need for technology developers to keep the disabled community in mind as they continue to innovate and develop. As Autonomous Vehicle (AV) technology gradually becomes commercially available, the enormous benefits of this technology have become ever more broadly discussed (Brinkley, Daily, & Gilbert, 2018, 2019; Brinkley et al., 2020; Brinkley, Posadas, Woodward, & Gilbert, 2017; Huff, DellaMaria, Posadas, & Brinkley, 2019). The ability to drive is an essential component that supports daily activities for many.

With the most advanced AVs making the need of a driver obsolete the technology holds the promise of supporting an independent life and access to employment for people with disabilities (Barnes, 1997). We propose a model referred to as the User Transportation-Activity Technology (UTT) model, that is designed to guide the universal and inclusive design of autonomous vehicle technologies. We designed the model through a critical review of current conceptual models that guide the development and outcome of assistive technologies. The focus was on analyzing how the principles of existing models may not appropriately align with the design goals for autonomous vehicles. Our study primarily focuses on the Human Activity Assistive Technology (HAAT) model, commonly used for design, research, outcome evaluation, and initial matching of assistive technology. Additionally, we studied concepts of universal design and user-centered design which integrated into model. The proposed model will benefit the disabled community by acting as a template for AV technology designers in ensuring disabled users are kept in consideration and universal design goals are supported.

REVIEW

Aquilano, Salatino, and Carrozza (2007), in their research, studied three fundamental parts of evaluating assistive technology devices (ATD). They discuss characteristics and requirements of the ATD expected by the end user, validation tasks, and analysis of experimentation results that consequently verify the acceptability level of the system. In their article, Driscoll MP, Rodger SA, and deJonge DM (2001) discuss assistive technology integration and outline the barriers including attitude of the parties interacting with the technology, the knowledge and awareness of the technology, and the issues associated with the environment. Moreover, they depict the positive aspect of consulting an experienced user to help identify possible difficulties with the integration of assistive technology. Similarly, (Giesbrecht, 2006) in their thesis describe how choice is based on user's perception of device value in meeting their expectations.

Friederich, Bernd, and De Witte (2010) studied frameworks that supported a holistic view and client centered practice with the commonality of describing relation between user, environment and the occupation. Hersh and Johnson (2008), in their research discuss an approach to a new model, Comprehensive Assistive Technology (CAT) model. The CAT covers all major human activities, provides a systematic structure for chosen categories whilst minimizing overlapping. The model defines activity areas with a precise degree of specificity, which identify barriers encountered by different groups of disabled people. In their study, Wu (2018) addressed expectations of a good human performance model which quantifies the relationship between the model's input and output based on the human cognitive and/or motor systems' mechanisms, the usefulness of the system, and its robustness and generality.

Assistive Technology Definition

The World Health Organization defines assistive technology devices as "any item, piece of equipment, or product,

whether it is acquired commercially, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of individuals with disabilities" (World Health Organization & World Bank, 2011). The Assistive technology act of 1998 defines assistive technologies as "Any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase, maintain or improve functional capabilities of individuals with disabilities."

HAAT Model

The Human Activity Assistive Technology model (see Figure 1) was introduced in the first edition of Assistive Technology: Principles and Practices (Cook & Polgar, 2014). "The model describes a human doing an activity in a context using an assistive technology" (Cook & Polgar, 2014). The model was designed to guide the assessment and prescription, as well as evaluation of the result of an assistive technology, that is well suited for a user with a disability. The performance of the entire system, rather than the evaluation of human performance, was considered the most important factor. The model has been used for the development of AT, research, assessment involving the initial selection of AT and ongoing evaluation of the outcome of its use.

Limitations. Although the HAAT model recognizes the influence of environment factors on human performance for a given activity, it does not address the application of interventions to decrease the demands of the environment, thereby enhancing human performance (Haynes, Bruce, & Sanford, 2009). The HAAT model provides a strong application for AT prescription in clinical practice, but there is limited evidence for the relationships between concepts or how they impact outcomes as the model lacks substantive testing (Bernd, Pijl, & Witte, 2009; Lenker & Paquet, 2003).

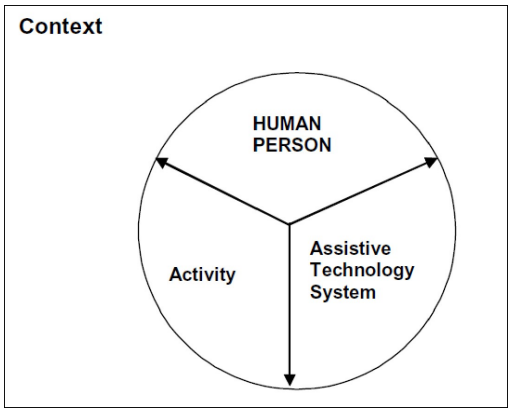

Figure 1. HAAT Model, (Cook & Polgar, 2014)

PPP Model

The Person-Performance-Press (PPP) (see Figure 2) model incorporates the use of technological interventions on both sides of the performance measurement and complies with the process of making an accommodation for a person or persons with a disability (Haynes et al., 2009). The PPP model is a flexible human performance model that integrates the use of technological

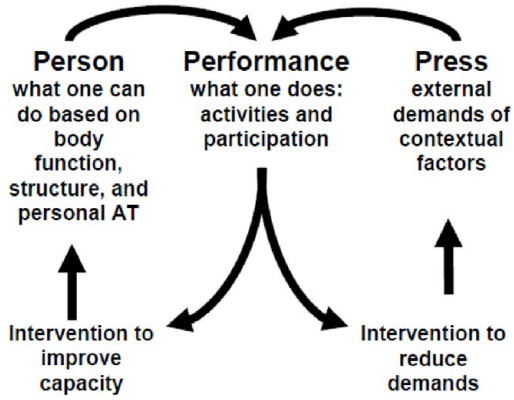

Figure 2. PPP Model, (Haynes et al., 2009)

interventions on both sides of the performance measurement. The model depicts how the capacity of a person combines with the environmental press to determine performance. The bottom left section indicates interventions that may take the form of AT to improve the capacity of the person, while on the bottom right of the model the intervention takes the form of accommodations or design solutions that reduce the demands of the environment.

Limitations. The PPP model fails to account for design considerations of the assistive technology, while focusing primarily on the external contextual factors and the ability of the person to perform a task under a situation. Moreover, the model describes the interventions to improve a person's capacity and reduce environmental demands but neglects the psychological interventions encountered by the disabled person.

Universal Design and User-Centered Design

The Disability Act of 2005 defines Universal Design, or UD, as:

> The design and composition of an environment so that it may be accessed, understood and used (1) to the greatest possible extent; (2) in the most independent and natural manner possible; (3) in the widest possible range of situations; (4) without the need for adaptation, modification, assistive devices or specialized solutions, by any persons of any age or size or having any particular physical, sensory, mental health or intellectual ability or disability, and (5) means, in relation to electronic systems, any electronics-based process of creating products, services or systems so that they may be used by any person.

According to the Interaction Design Foundation, User-Centered Design (UCD) is defined as "an iterative design process in which designers and other stakeholders focus on the users and their needs in each phase of the design process. UCD calls for involving users throughout the design process via a variety of research and design techniques so as to create highly usable and accessible products for them." (*What is User Centered Design?*, n.d.).

Universal design principles urge designers to explore solutions that are inclusive; design solutions that push the limits as far as possible without compromising the integrity or quality of

the product. Our proposed model focuses on the principles of universal design and UCD with the user at the center. In this way we make possible provisions for designing AVs to accommodate persons with disabilities by considering AV not as an assistive technology, but a technology in general with a universal design.

UTT MODEL

After reviewing the strengths and limitations of the various models outlined in the previous section and also looking at aspects of universal and user-centered design, we developed a model that we refer to as the User Transportation-Activity and Technology (UTT) model (see Figure 3). The model consists of three main components, all of which lie within the context in which the user will use technology to perform the transportation activity. The model is defined as "A technology (the autonomous vehicle) that enables any person (all users irrespective of age, disability, or other factors) to travel from source to destination (the transportation activity) within changing environments (the context which may be impacted by interventions)." We use the term 'any person' as opposed to terms like 'a human', 'a person' or 'someone' which may fail to create the mental idea of universal and inclusive design.

We shall define each element of the model and provide the rationale for each aspect.

User

In models such as the HAAT model or the PPP model the user is referred to as Human or Person, both of which tend to refer to a singular entity or a group of people sharing a characteristic trait or disability. The terms human and person works well with these models for guiding the design of assistive technologies. These models are primarily used for matching a person or human with a particular disability to an appropriate assistive technology specifically that will suit their needs to complete an activity in a given context.

In our model we opt to use the term 'user' as a user is anyone that could be interacting with the autonomous vehicle and not just one person or a group of people with a particular disability. Also, we believe the term user is generalized and seems to work better for guiding universal and user-centered design (Newell & Gregor, 2000; Quintana, Krajcik, Soloway, Fishman, & O'Connor-Divelbiss, 2013). Additionally, we keep the user at the center of the interaction between the technology and the transportation activity, so that the focus is on the user.

The transportation activity and technology component represent the interconnected relationship between the technology, the user who utilizes the technology, and the transportation activity for the user to perform. We make the model more specific to the consideration of the transportation activity rather than just a generalized activity. The rationale is so the focus is just not on the technology implemented for the activity of driving, but it is inclusive of all technologies within the vehicle that contribute to making the transit a facile activity (e.g. being able to adjust the car temperature). Our focus is for designers to keep in mind every aspect of making the transportation activity as easy as possible when designing the various technologies that come with autonomous vehicles.

Technology

We replace the term 'assistive technology' used in the HAAT model to 'technology', even though in this case the AV could be considered an assistive technology as it assists a person with a disability in the transportation activity. Assistive Technologies, by definition, refers to technologies that are developed only for persons with disabilities (Cook & Polgar, 2014). In the case of autonomous vehicles, although it can be considered an assistive technology for persons with disabilities, it enables even users not classified as disabled personal mobility. Therefore, we try to build the model with a universal design perspective so that it caters to people irrespective of age, disability or other factors. Hence, the term 'technology' works better and is more inclusive as compared to assistive technology.

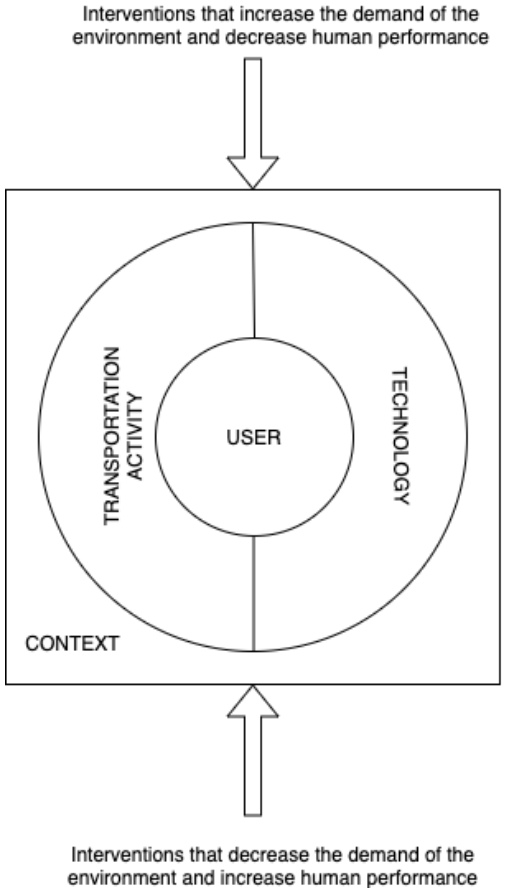

Figure 3. User Transportation-activity and Technology Model Transportation Activity

Context

The context includes the physical, social, cultural and institutional factors that may affect the performance of the user in using the technology for transportation. The models reviewed do not address changing context, they only address the current context in which a user is present and predominantly surrounded by such as the users' house and workplace. But when dealing with transportation technology that context is bound to the user as they may use the AV to travel to different locations

that have different types of context. The performance of the user and technology may be affected by change in context and therefore it is important to address this change while designing technologies for Autonomous Vehicles. For example, if you drive from Toronto, Ontario to Montreal, Quebec in Canada the official language changes from English to French, therefore if there was a voice interface in the AV that took commands only in English, this voice interface would fail if commands were given in French. Additionally, it also takes into consideration interventions that may occur in the current context that could impact the performance of the user by increasing or decreasing the demands on the environment and in-turn impact human performance. For example, interventions include but are not limited to accidents, technology breakdowns, being pulled over by the police and other such situations that may impact the user experience and performance of the human in the transportation activity.

DISCUSSION

Traditionally, accessibility has been a post- production adaptation to the vehicle for people with disabilities. When implemented, such modifications are costly to build and/or purchase. With AVs holding promises of mobility freedom for the disabled community, with the UTT model we aim to lay the groundwork for accessibility to be included as part of the design/development process rather than as an afterthought.

The UTT model currently focuses on guiding the universal design of AV technologies in a way that it is made accessible to users with disabilities and older adults. It builds on models previously used to develop the assistive technologies.

This model performs better when used specifically for assistive technologies within the context of an autonomous vehicle. If we were designing a control panel, for instance, to adjust the car temperature in an autonomous vehicle, the design guided by the HAAT model would lead to a control panel that is built for users with a specific disability (e.g. visually impaired or deaf and hard of hearing persons) with the goal being to complete the activity of adjusting the vehicle temperature, perhaps by using a voice user interface. However, the model is restrictive to blind and visually impaired people; a person who is deaf or of hard of hearing would perhaps have trouble interacting with the system and would require another HAAT model-developed technology to address their specific user needs. While the same control panel designed in accordance with the UTT model would be designed in a way that it would interact with all users to achieve the goal. The outcome would be measured from a broader perspective; how through achieving this goal, was the transportation activity made more easy, usable and comfortable?

Finally, our model builds on the HAAT model and the PPP model, with the integration of interventions into the model and the context including social and cultural environments. Our model guides the universal design of technologies specific to autonomous vehicles, whose outcome is evaluated by the human performance and the success of the transportation activity.

ACKNOWLEDGEMENT

This material is based upon work supported by the National Science Foundation under Grant No. 1849924. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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