Timing of Pedestrian Navigation Instructions*

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Abstract

During pedestrian navigation in outdoor urban environments we often utilize assistance systems to support decision-making. These systems help wayfinders by providing relevant information withing the context of their surroundings, e.g., landmark-based instructions of the type "turn left at the church". Next to the instruction type and content, also the timing of the instruction must be considered in order to facilitate the wayfinding process. In this work we present our findings concerning the user and environmental factors that have an impact on the timing of instructions. We applied a survival analysis on data collected through an experiment in a realistic virtual environment in order to analyze the expected distance to the decision point until instructions are needed. The presented results can be used by navigation systems for instruction timing based on the characteristics of the current wayfinder and environment.

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1 Introduction

Various studies have investigated design implications for navigation instructions: instructions should be simple [20] as well as connected to landmarks [14, 15], and the mode of the instruction (e.g., visual or auditory) is of secondary importance for user performance [9]. Besides requirements on how to compose navigation instructions, there is almost no research about *when* to provide the user with such information. The following general conclusion was stated by Winter [29] in the context of landmark-based navigation systems: *"People feel comfortable if they recognize reference features early, before arrival at a decision point. They*

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feel confirmed that they are on track, and they do not need to break movement at the decision point, but can interpret the next wayfinding instruction in advance." (p. 350).

Even though there are certain obvious implications for the timing of instructions based on this statement, there are no specific guidelines with regards to spatial and temporal dependencies of navigation instructions for pedestrian navigation aids. This type of guidelines has already been identified and discussed for in-vehicle navigation systems [21], and has been addressed heavily by research since the 1980's mainly due to safety implications.

Pedestrian navigation does not show as many safety concerns connected to instruction timing as car navigation. Nevertheless, instruction timing can be an essential component for wayfinding experience. Sub-optimal instructions timing could lead to unnecessary interaction with the assistance aid [6] as well as increase the cognitive load of the user. Therefore, there is a need to establish design guidelines for pedestrian navigation that include instruction timing.

The main contribution of this paper is to address a research gap in pedestrian navigation considering instruction timing. We report on the results that were gained through a time-to-event analysis (Survival Analysis, [12]) on data collected in a user experiment performed in a realistic virtual urban environment. Through this analysis we identified factors which have an impact on timing, provide a survival rate function (i.e., the probability distribution that a wayfinder would have already asked for instructions at a given distance) as well as the estimated parameters for applying the model in navigation assistance systems.

The rest of this paper is structured as follows: we continue with related work and provide an application scenario that is followed by the relevant research questions. Next, we introduce the utilized methods, describe the experiment and provide the results. We close with a general discussion and provide conclusions and future research directions.

2 Related Research

2.1 Aided Wayfinding

When we want to reach a destination, we usually follow an intended, predefined route. In fact, a prerequisite for such coordinated and goal-directed movement is our ability to successfully navigate, which, according to Montello [16], activates the two separate sub-processes wayfinding and locomotion. The former, which lies within the focus of this study, has been defined as "the process of determining and following a path or route between an origin and destination" [8], and thus emphasizes the planning aspect of navigation.

Planning ahead is especially relevant due to the fact that the destination of a wayfinding process is typically not directly accessible, i.e., it is located outside of our immediate perceptual field [18]. In such cases, we either rely on our own memory or external wayfinding aids, such as verbal or graphical route descriptions and depictions, for making the correct choices at decision points [25]. Apart from a mere cartographic representation of the environment, route descriptions can include both destination descriptions [26], with the focus on *where* to go, and turn-by-turn directions [30], focusing on *how* to get there. The latter usually consist of a set of communicative statements which include environmental features (e.g. landmarks or decision points), delimiters (e.g. distance designations), verbs of movement (e.g. walk or turn), and state-of-being verbs (e.g. you stand in front of the train station) [1].

In general, however, both aided and unaided wayfinding are still challenging tasks. Giannopoulos et al. [7], for instance, identified the environment, the route instruction, and the user as determining factors for the complexity of wayfinding situations. For instance, a more complex environmental layout, e.g. an intersection with a higher number of connecting streets, is harder to mentally represent and to become familiar with [26]. Even in a less complex environment, though, wayfinding may fail due to inappropriate route instructions, which, for instance, can differ in terms of their sequential ordering from the decision points actually encountered in the environment [1]. Finally, users do not belong to a homogeneous group, but rather differ in terms of their spatial abilities, preferences, environmental familiarity, and specific needs [17]. As a result, they may require different times for route instruction comprehension and following, or prefer different representations of route instructions. In order to provide optimal route instructions and decrease the complexity of the wayfinding process, thus, these factors have to be taken into account.

2.2 Timing of Route Instructions

A further aspect which has so far been largely overlooked in the discussion on optimizing route directions is their timing. An instruction provided too early might result in a user simply forgetting it until finally reaching the related decision point. An instruction which is given too late, on the other hand, can lead to a user completely missing the decision point and the required behavior, or making an uncomfortably sharp turn [22]. Apart from safety issues, such shortcomings are likely to reduce system acceptance.

Despite the importance of appropriate instruction timing, to the best of our knowledge, there is currently no empirical evidence on how to determine this point in time for mobile pedestrian navigation systems. There have been, however, several studies which aimed to provide practical guidelines or identify the determining factors on instruction timing for car navigation, and which can be of relevance for other modes as well. Thus, in [22] for instance, experts provided test drivers with simple route instructions that were intentionally given either too late, too early or at an optimal point in time. Based on posterior ratings of the temporal appropriateness of the instructions by the test persons, the authors could identify the significant factors, which included the distance and time to the next junction, the driving speed, the type of required maneuver, and the complexity of the route instruction. These findings are in accordance with the U.S. Federal Highway Administration's general guidelines for navigation systems [4], which add the factors weather and driver characteristics such as age to the list. A further empirical study also found age and gender of the car driver, the speed and type of turn (left or right), as well as the number of vehicles ahead to be significant for defining optimal distances prior to intersections for auditory route instructions [5]. Further environmental aspects were examined by Schraagen [23], who found the visibility of road signs to be of relevance for deciding when to present a new route instruction. Verwey et al. [27], finally, proposed to stack instructions which refer to decision points encountered in close succession (within less than 10 sec) to decrease cognitive load.

In general, due to the significant systemic differences between walking and driving, it is highly questionable whether these findings can be transferred to pedestrian navigation. Thus, in unobstructed spaces, the walking speed is relatively constant, and therefore possibly not of relevance for instruction timing. Regarding other factors discussed, such as the distance or time to the next decision point, visibility relationships, the complexity of the required maneuver, or the user characteristics, in contrast, a relation to route instruction timing seems more plausible, and should be investigated further. An additional aspect could be the type of route instruction, since, for example, reading a textual instruction would require more time than looking at a graphical depiction or listening to an auditory instruction [13]. Another worthwhile direction could be to develop adaptable systems which allow for personalization of the timing conditions for different types of instructions [31].

2.3 Modeling

Modeling of the relationship between a dependent variable and a set of independent variables (covariates) has been the focus of interest in many fields. Essentially, modeling constitutes a way to identify and quantify the impact that the covariates exert on the dependent variables. Statistical modeling enables making statements about how much “faith” we can put in those estimates and also provide ways to improve the overall fit, and in turn the predictive accuracy of the developed models on the basis of a set of mathematical assumptions. Without doubt, the most popular and widely employed model is the family of linear regression models. However, such models have some underlying assumptions which if not met, can result in biased and inconsistent coefficient estimates, and thus incorrectly estimated and perhaps misspecified models. One of the main assumptions is the normality of the error terms and different ways have been developed to by-pass this, resulting in new modeling frameworks. When it comes to the problem of analyzing time-to-event data (also called *Survival Analysis*), linear regression fails to provide “correct” estimates mainly due to the underlying distribution of the modeled process. Time-to-event models have been widely applied to a plethora of problems in different domains, varying from biometrics to industrial engineering to transportation research. An overview of applications is presented in [3, 11, 12]. Departing from the time setting, Waldorf [28] explored and verified the conceptual equivalence between survival models applied to both temporal and spatial processes, focusing on the “at-risk” concept. In addition, he highlighted the limited number of applications of hazard models in spatial settings. Following his study, a number of applications have built upon that and utilized hazard models for such distance related problems (e.g. [2]).

3 Instruction Timing

3.1 Application Scenario

The following application scenario aims at highlighting the importance of instruction timing on the wayfinding process by outlining three scenarios with different types of outcomes depending on when instructions are available to the user.

Consider the following typical situation: Alice has just arrived at the main station of Zurich as a fist time visitor. She wants to walk to her hotel from the main station and types the address into her navigation system that will guide her through the city by providing audio instructions.

- **Scenario A**: *Alice is approaching the first intersection and just when she thinks she would like to know where to go next, the navigation system instructs her to “Turn left at the restaurant with the red façade”. Alice was already observing the next intersection and immediately spots the restaurant and turns left at the intersection.*
- **Scenario B**: *Alice just passed the first intersection and the navigation system already provides the next instruction. By the time Alice arrives at the next intersection, she is not sure anymore if she is supposed to turn left or right.*
- **Scenario C**: *Alice passed the second intersection. She continues walking and gets closer to the intersection without receiving any instructions. Alice is getting nervous and starts feeling uncomfortable.*

In Scenario A the instruction is provided to the user with the right timing whereas in Scenario B the instruction is given too early and in Scenario C too late respectively. Scenarios B and C demonstrate two situations where the wayfinder might get confused and cognitively overloaded, leading to poor user experience and possibly poor wayfinding performance.

3.2 Research Questions

The focus of this work lies on the investigation of the environmental and user properties that have an effect on instruction timing. Furthermore, we are interested in predicting the timing of an instruction based on the characteristics of the wayfinder and the environment. The main research questions of interest are the following:

RQ1: Do wayfinders prefer to receive a navigation instruction multiple times?
RQ2: Which properties of the environment have an impact on navigation instruction timing?
RQ3: Which properties of a wayfinder have an impact on navigation instruction timing?
RQ4: Is it possible to predict when an instruction should be optimally provided?

With these research questions we aim to investigate the topic of instruction timing for pedestrian navigation allowing us to include or exclude certain characteristics (e.g., spatial abilities) for further research. The first research question investigates the possibility that a navigation instruction should be given more than once. The second and third research questions address the properties (e.g., visibility of a decision point, user's spatial abilities) that influence instruction timing. Finally, the fourth research question addresses the possibility of estimating a model that will allow us to predict the timing of instructions based on the characteristics of the wayfinder and the environment.

4 Method

4.1 Implementation

A prototype of a navigation system based on local landmarks [19] connected to audio instructions was implemented in a realistic virtual environment. Navigation instructions were triggered by the participants by pushing a button of a joystick.

The used hardware consisted of a Logitech 3D Precision Pro joystick to enable movement and interaction with the navigation system, an HP XB31 digital projector for displaying the virtual environment and a gaming computer for rendering, executing the experiment and logging all user data.

The realistic virtual environment including street layout, building blocks and façade textures was designed using the ESRI CityEngine[1] with the aid of the Complete Street Rule which features realistic street furniture, such as traffic lights and benches (see Figure 1a). The generated city was imported into the Unity3D[2] game engine where a realistic skybox was added as well as data collection scripts and the interaction with the navigation system. The correct interaction with the navigation system (i.e., the instruction only for the next decision point was played) was achieved by using colliders that were placed and filled up the space between decision points.

4.2 Experiment

A user study was conducted in the virtual environment to evaluate preferences for instruction timings. The participants were divided into two groups: the first group was able to request instructions per decision point as often as they wanted (multiple-clicks) whereas the second group was limited to one instruction per decision point (one-click). The navigation instructions were given as audio instructions (e.g., 'turn right at the building with the green façade')

[1] `http://www.esri.com/software/cityengine`
[2] `http://www.unity3d.com`

(a) (b)

Figure 1 (a) shows an example scene of the virtual environment. (b) shows the complete route of the navigation path with 8 decision points and the length of the segments in meters.

connected to colored façades in the virtual environment simulating local landmarks. The audio instructions were given using a female American-English computer-generated voice.

Participants were standing in front of a height-adjustable table where the joystick was placed in the middle and used to navigate through the virtual environment. The virtual environment was projected to the opposite wall so that participants faced it at a distance of about 3 meters.

4.2.1 Design

The user experiment was designed as a Between-Subjects study. Participants were randomly assigned to the two conditions, trying to balance gender and spatial abilities. The navigation path they were required to move along consisted of 8 decision points (see figure 1b). We designed a route with several decision points, having different numbers of connections, with the intention to investigate the effect of decision points with varying structure and complexity [7]. The considered types were Cross-intersection, T-intersection, Y-intersection and Star-intersection. Each type occurred twice on the route, once with the next intersection being visible from the beginning and once not. This allowed us to investigate the impact of decision point visibility.

4.2.2 Procedure

First, the participants were informed about the experiment and the procedure. Second, they had to provide their demographic information, as well as to fill in the *Santa Barbara Sense of Direction Scale* questionnaire for the self-estimation of their spatial abilities (*SBSODS*, [10]).

After filling in the questionnaires, the actual task started. Participants were instructed to stay on the sidewalks and use the pedestrian crossings. They started walking (constant speed 5m/s) along the navigation path in a first-person view. Based on the condition, they were able to ask once or multiple times for instructions by pushing the joystick button.

The user location (x,y) and the corresponding decision point were logged whenever a navigation instruction was requested by pushing a button of the joystick.

4.2.3 Participants

A total of 45 people participated in the user experiment. Due to tracking problems, one participant had to be dropped. The one-click condition had 23 participants (11 female) with a mean age of 25.7 years (*SD = 5.4*). The multiple-clicks condition had 21 participants (11 female) with a mean age of 27.7 years (*SD = 8.2*). This results in a total number of 352 cases (44 participants * 8 decision points). The participants in both conditions came from various professional (e.g., Geography, Marketing) and cultural (e.g., Swiss, Greek) backgrounds.

4.3 Modeling Approach

Given the nature of the time-to-event process that we aim to model, the family of hazard based models is exploited. Naturally, the choice of a model with a fully parametric hazard function advances as the most appropriate, offering the medium for simultaneously describing the basic underlying survival distribution and quantifying how that distribution changes as a function of the covariates [12]. In addition, in cases where the distribution of the survival times can be adequately approximated by an existing mathematical function, the use of a fully parametric model is preferred since it can facilitate the transferability and generalization of the model estimates. Two such models exist, differing essentially in their underlying assumptions of how the hazard, and subsequently the survival function, is modeled. In particular, the proportional hazards model assumes that the covariates have a constant multiplicative effect on the hazard function while the accelerated failure time (AFT) models [12] assume that the effect of the covariates on the hazard function is multiplicative on the time scale, thus not constant.

Based on the problem at hand, assuming a constant impact of the covariates on the hazard rate would constitute a rather restrictive choice that is not aligned with our expectations. The choice of the AFT models on the other hand, assuming that time (distance in our case) has an effect on the impact of the covariates, appears as a more plausible alternative of the underlying survival function we want to model, being capable of facilitating both accelerating and decelerating effects on the survival time.

Let us denote the traveled distance from the previous decision point where instructions were asked (in analogy to the time-to-event concept) as t, having a cumulative distribution function T such as $F(t) = Pr(T \leq t)$. The survival function gives the probability of observing a survival distance higher than t, denoted as $S(t) = \Pr(T > t) = 1 - F(t)$. The probability of a process ending at point t, given that it has lasted up to that point, is called hazard rate and is defined as:

$$h(t) = \frac{\mathrm{f}\,(\mathrm{t})}{S(t)}\,. \tag{1}$$

In the case of the AFT models with a Weibull survival function, a convenient way to characterize the distribution of time is $T = e^{\beta_0 + \beta_i x} * \varepsilon$, with β's representing the effect of the covariates and ε an error component. This function can be easily linearized as $ln(T) = \beta_0 + \beta_i x_i + \sigma * \varepsilon^*$, with $\varepsilon^* = ln(\varepsilon)$ following the extreme minimum value distribution, denoted as $G(0, \sigma)$ with σ called the scale parameter. Then the hazard and the survival function can be written as:

$$h(t, \chi_i, \beta_i, \lambda) = \frac{\lambda t^{\lambda-1}}{\left(e^{\beta_0 + \beta_i x_i}\right)^{\lambda}} = \lambda t^{\lambda-1} e^{-\lambda(\beta_0 + \beta_i x_i)} = \lambda\gamma\left(te^{-\beta_i x_i}\right)^{\lambda-1} e^{-\beta_i x_i} \tag{2}$$

$$S(t, \chi_i, \beta_i, \sigma) = exp\{-t^{\lambda} exp[(-1/\sigma)(\beta_0 + \beta_i x_i)]\ \} \tag{3}$$

with $\lambda = 1/\sigma$ *and* $\gamma = exp(-\beta_0/\sigma\ )$. With this formulation, the equation for the median survival time is:

$$t_{50}\left(\chi_i, \beta_i, \sigma\right) = \left[-ln\left(0.5\right)\right]^{\sigma} e^{\beta_0 + \beta_i x_i}\ . \tag{4}$$

5 Results

Before proceeding to the estimation of the model, the distance values are normalized to the range of [0,1] in order to make them comparable and compatible for the estimation process. As distance we consider the traveled distance up to the point in space where the participants requested instructions. Subsequently, we center our focus on estimating an AFT model with a Weibull survival distribution in terms of maximum likelihood, using a robust "sandwich" standard error estimator capable of identifying clusters of residuals, hence relaxing the independence-of-observations assumption. The estimation was conducted using the open-source statistical software R, making use of the *Survival* package [24]. It should be mentioned that other parametric forms of survival functions (e.g., exponential, Gaussian, logistic etc.) have been checked as well, however the Weibull provided the best fit.

The variable selection process was conducted iteratively on a goodness-of-fit basis by minimizing the Akaike Information Criterion (AIC) which penalizes for the number of included parameters, hence accounting for over-fitting. The reported estimates are presented in Table 1 and they are all found to be statistically significant at the 5% level. An estimate with a positive sign implies a longer survival (i.e., instructions will be necessary at a later point), while a negative one implies the opposite. The rate of how longer or shorter the survival becomes varies along the survival function, but on its median it can be easily quantified by the following formula:

$$TR\left(x_{11}, x_{12}\right) = \frac{t_{50}\left(x_{12}, \beta_1, \sigma\right)}{t_{50}\left(x_{11}, \beta_1, \sigma\right)} = \frac{\left[-ln\left(0.5\right)\right]^{\sigma} e^{\beta_0 + \beta_{i-1} x_i - 1 + \beta_1 * x_{12}}}{\left[-ln\left(0.5\right)\right]^{\sigma} e^{\beta_0 + \beta_{i-1} x_i - 1 + \beta_1 * x_{11}}} = e^{\beta_1 \Delta x_1}\ . \tag{5}$$

Essentially, obtaining the betas allows us to estimate the survival and hazard functions for different sets of covariates (and hence individuals and spatial variants) and consequently we can proceed to obtain point estimates of quantiles of the distribution (e.g., the median) that can be of potential interest for prediction purposes.

In the plots of Figure 2, the estimated mean survival function per intersection type is presented (mean in the sense that the mean value of the covariates is plugged into the formula) along with the observed non-parametric survival function to provide a visual evaluation of the model's fit. In the plot of Figure 3a, different variations of the characteristics of Alice are presented to highlight the impact of the covariates on the survival function. All included attributes were found to be statistically significant, while the magnitude of their impact (parameters) is highlighted in the figures with different variables' values. Last, in Figure 3b, a scatter plot of the predicted median survival values versus the observed ones for the sample of observations is presented.

6 Discussion

This section interprets and discusses the results from the user experiment. The mean distance at which the wayfinders asked for instructions was at 45.4% (*SD = 25.2%, Median = 44.7%*) of the total segment length. More than half of the times, i.e., in 68.7% of the cases, the wayfinders asked for instructions after the decision point was visible from the distance (the visibility point occurred in average at 48% of the segments' length. The cases where the next decision point was visible from the beginning were excluded).

Table 1 The β estimates (N = 352, Log Likelihood = 28.3, χ^2 = 107.38 with p<.001, AIC = −34.65).

	Value	SE	Z	P
Intercept	*−1.627*	*0.151*	*−10.76*	*<0.001*
DP Visibility	*2.031*	*0.480*	*4.23*	*<0.001*
Long Segments	*−0.504*	*0.226*	*−2.23*	*0.026*
Condition	*−0.203*	*0.051*	*−3.97*	*<0.001*
Y-Intersection	*0.488*	*0.114*	*4.27*	*<0.001*
Star-Intersection	*0.488*	*0.127*	*3.84*	*<0.001*
T-Intersection	*0.243*	*0.117*	*2.07*	*0.039*
Age	*0.019*	*0.005*	*3.91*	*<0.001*
Age older than 27	*−0.348*	*0.084*	*−4.16*	*<0.001*
Low Spatial Abilities	*−0.173*	*0.075*	*-2.29*	*0.022*
Log(scale)	*−0.639*	*0.085*	*−7.53*	*<0.001*

RQ1: Do wayfinders prefer to receive a navigation instruction multiple times? Although participants in the multiple-clicks condition could ask for instructions as often as they wanted, they did not. Only 14.4% of the cases (25 out of 168) participants asked more than once for instructions. The maximum number of times that an instruction was asked for regarding a certain decision point was 3 times and occurred only for 1.7% of the cases. This result suggests that receiving a wayfinding instruction once is considered sufficient.

RQ2: Which properties of the environment have an impact on navigation instruction timing? According to the results (see Table 1), there are environmental properties that have a significant impact on instruction timing. The visibility of a decision point (DP Visibility), which is the location on the segment from which the wayfinders could perceive that a decision point is coming ahead of them, has a significant effect on the timing of instructions. Furthermore, the length of the segment (Long Segments) that has to be traveled as well as the type of intersection (Cross-, Y-, Star-, and T-Intersection) have also a significant effect. The estimates for the visibility and type of decision point all have a positive sign, revealing that the further away the visibility point and depending on the type of the decision point (based on the estimates, the order is Cross-, T-, Y-, and Star-Intersection), the later the wayfinders will need instructions. Subsequently, as shown in Table 1, the longer the segment the sooner (in terms of normalized distance) instructions will be necessary. The effect of the decision point type on the survival rates is illustrated in Figure 2.

RQ3: Which properties of a wayfinder have an impact on navigation instruction timing? The relevant wayfinder properties (see Table 1) that have a significant impact on instruction timing are the age of the wayfinder, the age threshold (Age older than 27), which categorizes them as younger and older wayfinders (based on the mean age of our sample, 27 years) as well as their spatial abilities, which were clustered into low (below a SBSOD score of 3), medium, and high (Low Spatial Abilities). Furthermore, the condition (single- or multiple-clicks) also had a significant effect. The inclusion of gender specific effects were found to be statistically insignificant. The estimates for age have a positive sign, showing that the older the wayfinder the later instructions will be necessary, however, taking into account the negative sign of the age threshold, there is a diminishing effect for ages over 27. The estimates for the spatial abilities have a negative sign, which reveals that if the wayfinder has low spatial

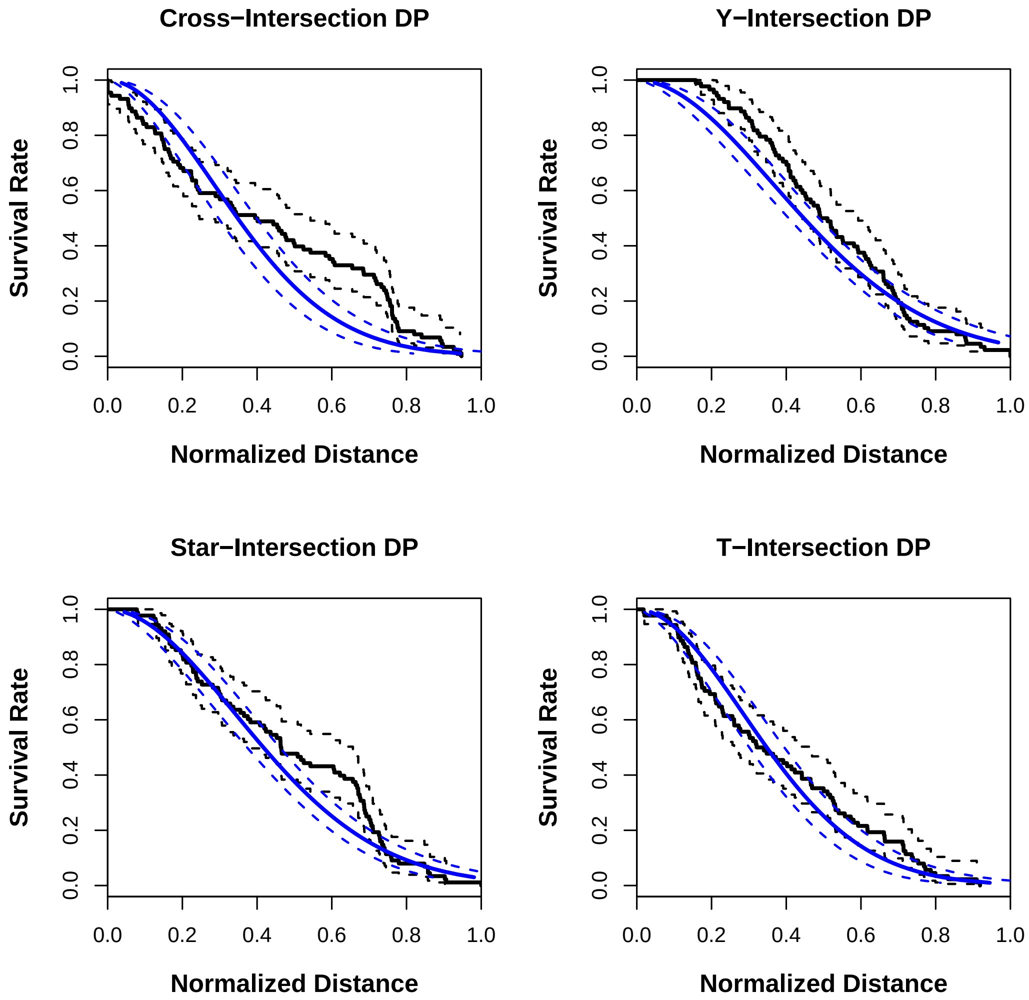

Figure 2 The mean survival functions (blue) for the four types of intersections vs. the mean observed ones (black). The 95 % confidence intervals are presented with dotted lines.

abilities (below a SBSOD score of 3), the sooner instructions will be necessary. These results are exemplified in Figure 3a. The red line depicts the survival rate for agent Alice, who is 22 years old, having medium to high spatial abilities (SpatAb: 0). The red dotted line illustrates the survival rate for agent Alice if she would have low spatial abilities. A possible interpretation of this result could be that the higher the spatial abilities, the higher the confidence of the wayfinder concerning the interpretation and mapping of instructions just before the decision point. Another interpretation could be that wayfinders with high spatial abilities wait longer in order to minimize the possible space where the given instructions can be mapped. Figure 3a illustrates also the effect of age. The blue lines represent the survival rates for Alice, who is 45 years old. The 45-years-old agent Alice will ask for instructions later than the younger agent Alice. One possible interpretation of this effect could be that the older we get, the more experience we gain, and similarly to the previous interpretation of high spatial abilities, we wait until the possible space where an instruction can be mapped is less.

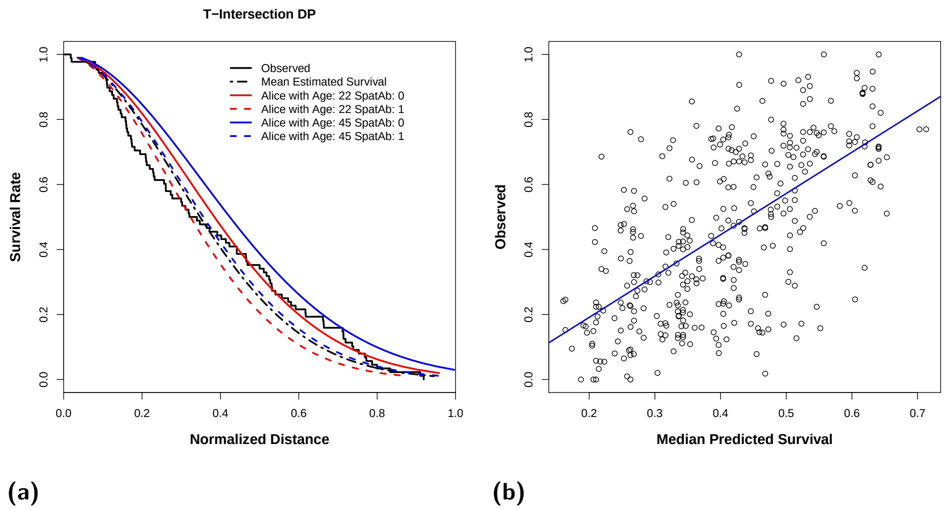

Figure 3 (a) illustrates an example of the change in the survival distribution for different agent user characteristics. (b) shows the predicted median survival values vs. the observed ones for our sample.

RQ4: Is it possible to predict when an instruction should be optimally provided? Figure 3b indicates that such a model allows us to make statements on when an instruction should be given (Adjusted R-squared: 0.389, $p < 0.001$). More specifically, observing the spread, no clear patterns can be identified along with no heteroscedasticity issues. This indicates that no main factor was left out of the model. Taking into account the statistical significance of the reported estimates, we can draw concrete conclusions that these factors have an impact on the process of instruction timing.

Plugging the estimates into equation (3), the survival rate function can be easily calculated for individual wayfinders and different environmental settings (as we did for for the examples in Figure 3a). Given that we provide estimates for a survival rate function, exact prediction of the time when an instruction should be provided is not feasible. Instead, the survival function can be applied in order to determine, based on a given situation, when to provide an instruction on the basis of different criteria (e.g., median survival estimate). A navigation assistance system could benefit from such a survival function by reacting according to the characteristics of the current wayfinder and environment.

Making use of equation (5), the impact of a change in a factor can be quantified on the median survival rate. For instance, a difference on the median survival rate between low and high spatial abilities is approximately 16%.

7 Conclusions and Future Work

In this work we identified relevant environmental and user properties that have an impact on instruction timing. Furthermore, we report the estimated covariates that can be used to calculate a survival function for a given wayfinder and environmental setting. This function can be calculated on the fly by an assistance system and time the instructions accordingly. Since this function provides a probability distribution, the assistance system has also to decide the criteria of the timing, e.g., provide the instruction based on the median survival estimate. Since the observed instruction timings were retrieved based on user preferences, in future work, we will investigate if the proposed way of timing instructions is also increasing the wayfinding experience and performance. Furthermore, we will focus on the generalization of instruction types and environments as well as consider in more detail the environmental complexity [7]. Additionally, we will perform experiments in real urban environments to investigate and compare the external validity of the current work.

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