The Normal, Natural Troubles of Driving with GPS

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ABSTRACT
In-car GPS based satellite navigation systems are now a common part of driving, providing turn-by-turn navigation instructions on smartphones, portable units or in-car dashboard navigation systems. This paper uses interactional analysis of video data from fifteen naturalistically recorded journeys with GPS to understand the navigational practices deployed by drivers and passengers. The paper documents five types of 'trouble' where GPS systems cause issues and confusion for drivers around: destinations, routes, maps & sensors, timing and relevance and legality. The paper argues that to design GPS systems better we need to move beyond the notion of a docile driver who follows GPS command blindly, to a better understanding of how drivers, passengers and GPS systems work together. We develop this in discussing how technology might better support 'instructed action'.

Author Keywords
GPS, Driving; SatNav; Video Analysis; Interaction Analysis

ACM Classification Keywords
H.5.2 User Interfaces.

INTRODUCTION
In-car GPS based navigation systems (SatNav or 'GPS') are now a common part of driving, providing turn-by-turn navigation instructions on smartphones, in the form of portable units or in-car dashboard navigation systems. Recent surveys have suggested that in Western Europe and North America over 30% of cars are equipped with some sort of navigation system. While there is considerable variety in terms of their features, interface and physical form factor, these systems share the ability to display maps and to provide turn-by-turn instructions through visual and audio guidance. Designing these systems presents many challenges - such as maintaining driver safety, providing information at the right time in the right way, preventing distraction, as well as supporting an enjoyable driving experience. These challenges are exacerbated by the often small size of the navigation display, and the inherently failings of sensors and maps. Within HCI a number of papers have documented users' attitudes towards navigation systems [24], how these systems change driving [23], how GPS systems affect safety and driver performance [16], as well as experiments with specific designs of navigation system [22, 28, 30]. Much of this work has been simulator based, drawing results from experimental navigation and driving tasks. While this work has opened up consideration of GPS, there has been little analysis of what is involved in driving and navigating with GPS in non-controlled settings.

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This paper uses analysis of naturalistic video data of driving with GPS to examine how the activity of driving is changed through the use of navigation systems. We specifically focus on the *skills* involved in drivers understanding and following the instructions that navigation units provide. Close attention to the work of following a route reveals how using a GPS systems replies upon overcoming 'troubles' - how the instructions given by GPS units require considerable reconstruction by drivers. We show how using a GPS is not simply blindly following instructions, but involves active instructed-action.

Building on this video analysis we develop three connected set of implications. The first concerns designing GPS so as to better fit with the complexities of driving and the inherent limitations of existing technology. Central to this is a move to designing for the active driver. The second implication concerns opportunities for understanding this new form of navigating with a machine and how we might teach these skills. We argue that rather than diminishing or replacing the task of navigation by drivers, GPS systems require new competences and skills that drivers need to deploy if they are to navigate successfully and safely. Lastly, we discuss GPS as an example of the inescapable, endemic and often frustrating work of following any set of instructions [9, 32]. Understanding instructed action opens up opportunities for designing systems that rely on providing time critical instructions to users.

Navigation with GPS
There has been impressive growth in the use of dedicated GPS units, and in-car fixed navigation systems to support driving. This systems have recently been supplemented with the growth of turn-by-turn navigation functionality in smartphones. Yet all these navigation systems - smartphones, dashboard-mounted and dedicated units - share much of the same functionality. They move beyond providing maps and directions (such as with standard smartphone maps applications), to full navigation applications that provide context-sensitive turn-by-turn directions, using positioning systems and maps to calculate a suitable route for the driver, and to give context sensitive audio and visual instructions to the driver. We refer to these systems here broadly as 'GPS'.

The popularity of GPS systems has helped to prompt specific attention to their design in HCI. For example, Schreiber *et al* examined different designs of map displays, contrasting congruency and the complexity of map displays [30]. Hipp *et al* [13] documented how commercial GPS units frequently fail to provide directions that correspond with driver intentions. They predict that 41% of navigation commands given by GPS units are incorrect, in that they do not correspond with the driver's intentions. Kun *et al* [18] explored how navigation systems distract drivers and lead to driving errors, measuring errors in speed and car direction between the use of spoken word and visual navigation units. Moving beyond existing systems Patel's work explored how to simplify routes ('route compression') [28], drawing on the everyday knowledge of drivers.

Much work around GPS makes use of experimental driving simulators to test specific design conditions. For example, Medenica et al [25] tested the use of augmented reality GPS systems with conventional map based GPS systems, finding broad benefits from the use of an augmented reality navigation system. Yet two recent CHI papers have explored the real world use of GPS while driving. Jensen et al's [16] work examined the distraction and impact on driving of the use of GPS units. In a controlled experiment drivers used in-car GPS units to drive to a provided location, with performance video-recorded and compared between conditions with visual only, audio only, and visual and audio navigation information. They found that drivers performed better (drove more safely) in the audio only navigation condition.

Leshed et al's [24] paper takes a qualitative approach to documenting the use of GPS. This paper focuses for much of its discussion on how GPS changes the engagement (and disengagement) with the environment. This paper offers an number of insightful points concerning the interactions around the GPS by passengers and drivers, and how the unit supports interaction both with the 'virtual' and actual physical environment being navigated through. Drawing on Borgmann they go beyond design to offer a fundamental critique in that [GPS navigation] "demand[s] less skill and attention by providing orientation and navigation as a commodity, with instant availability, ubiquity, safety, and ease of use, resulting in loss of engagement with the environment and others".

A broad engagement with driving and design is taken by Juhlin and his colleagues with research that spans analysis of driving to the development of in-car game systems that support passenger experiences [17]. Juhlin's fieldwork underlines the ways in which driving is a process whereby road users "solve coordination problems with other road users [and] try to influence each other" [17, p49]. This work positions driving as a form of social interaction on the road.

METHODS

The data we collected was based on routes chosen by drivers themselves, as part of journeys they would still have taken if they had not been in our study. The drivers were not asked to modify their driving or route in any way, apart from having cameras in their car recording their journey. We recruited all fourteen drivers through our local university, eleven of the drivers were students, and three were parents of students. The drivers were given video cameras and asked to record a journey they were taking where they planned to use the assistance of GPS to get to their destination. We fitted two cameras in each car, one capturing the view out the windscreen (and the GPS), and a second pointing at the driver and passengers. The drivers and passengers were themselves in charge of starting and stopping the cameras, and we did not meet with or interact with the drivers on the day of their journey. In total we collected data from fifteen journeys (one driver recording two different trips), totaling just over 9 hours of video. Journey time ranged from 13 minutes to 113 minutes, with an average trip time of 37 minutes. Four of the journeys involved drivers traveling on their own, with the remaining drivers having at least one additional passenger.

The GPS units themselves varied - six journeys involved in car dashboard GPS systems, seven used portable, dedicated navigation-units, and two used smartphones' navigation applications. One limitation with this data is that all the data was collected from driving in California, and although there is a mix of street and highway driving the environment driven on is a distinctly North American urban and suburban environment. We acknowledge there is a wide variety of car wayfinding practices both internationally and in different environments [33]. As part of the informed consent for this project we advised drivers on the placement of the cameras and their GPS so as to not interfere with their visibility. While none of the driving in our study was dangerous as such, some aspects were ill-advised (such as the handheld use of the GPS unit in figure 1). To some extent this may be unavoidable in a naturalistic study.

Along with the video data we also drew on an autoethnographic component - the authors travelled on ten journeys taking part as both passenger or driver, making use of GPS. At the end of each journey the authors wrote field notes documenting their use of GPS, and any problems that arose. This data was particularly valuable when combined with the video data, supporting the understanding of particular incidents through reflection on the authors own experiences.

Our analytic approach builds on our earlier analyses of in-car conversation [21, 26] and in particular how directions are shared through in-car conversations [20]. We drew on interactional analysis [12] - focusing on the activities which took place around the task of navigation, both using GPS and not. In individual and group data analysis sessions we surveyed the journeys, editing the 9 hours of video down to 75 one to two minute clips for focused analysis, of which 37 were transcribed and analysed in depth. Our transcripts paid particular attention to interaction with the road, car and other drivers. We drew extensively on ethnomethodological approaches to skilled practice - in particular Watson's [33] work on driving and our earlier research into map use [4, 19]. We also drew upon phenomenological anthropology such as Ingold's [14] discussion of engagement with the environment. Our focus then was on the work of seeing and movement in the world where GPS is only one resource

**Figure 1: A turn with GPS.
A video figure accompanies this paper.**

drawn upon alongside the controls and kinesthetics of the car and the perspectives on the environment emerging through driving into it. With this analytic focus on embodied interactions with place and space, this work is in contrast with much of the existing literature on map use, focusing on the role of cognitive representations of space [4, 10].

RESULTS

Driving with GPS, as with the skills of driving more broadly, are commonplace and in many ways taken for granted. Through close video analysis of driving we sought to render visible some of these skills we take for granted. We start our analysis with two different clips which although both typical of the data display different characteristics. The first shows how a seemingly straightforward turn can involve orientation work, following the GPS and ignoring an incorrect instructed turn. The second clip shows how using the GPS can involve *not* following the instructed turn yet still engaging with the instructions given.

Following the GPS

Figure one shows three frames from one extract where the driver follows the instructions of the GPS to take a right hand turn. In this case the GPS is held in the hand of the driver. The GPS recommends that the driver take a right turn and in the second frame the driver has started their turn but stopped to allow a pedestrian to cross the road. In the last frame the driver has completed their turn and continues their journey. In some ways this turn is an unproblematic example of following a turn with a GPS - perhaps familiar from our own GPS use - the GPS gives an instruction for a road maneuver, which the driver then follows. Yet even this seemingly simple case reveals some subtle complexities. First, the driver needs to take into account the driving conditions and the road as they make the turn, they are not simply following the GPS's commands, but competently driving - such as waiting to let the pedestrian cross the road.

Second, the GPS actually changes its view (visible in the second frame) as the driver starts her turn, displaying the relevant instruction for after the current turn. While later relevant this offers an incorrect instruction for that exact point in time. This does not appear confusing to the driver as they continue to complete their turn. When the driver consulted the GPS - as the driver approached and started to execute the turn - GPS offered the 'right' instruction.

Whatever the (potentially serious) safety implications of holding the GPS while driving the driver, the position of the GPS and the angle at which it is being held also complicate understanding of the GPS's instructions in terms of a specific road that the driver should manoeuvre the car down with the GPS is held at a range of angles. At this turn are four possible exits from the junction and as the car itself moves toward the turn the angles of the road and the GPS display add considerable ambiguity. Indeed, continuing 'straight ahead' would involve a slight turn to the right (visualised on the GPS as taking a 45 deg turn). The driver must thus do some 'orientation work' [19] so as to find and complete the correct turn.

While this clip is straightforward the use of the GPS is clearly not without skill - the driver need select the correct road to turn down, ignore the GPS as it changes its display, and manoeuvre the car while holding the GPS.

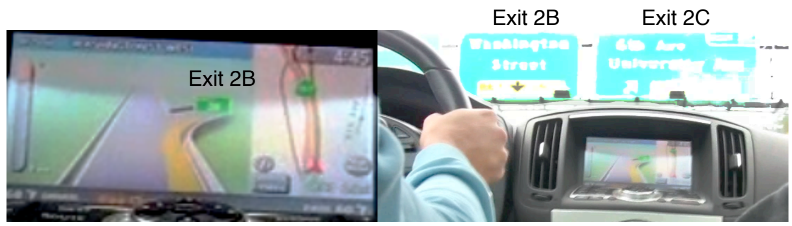
Not following the GPS

As a second extract from our data show how the use of the instructions from the GPS can be even more involved. As typical as extracts such as *figure 1* are in our data, incidents where drivers did *not* follow the GPS instruction were also common (supporting Hipp et al's claim that GPS instructions are frequently not followed by drivers).

For example, in figure two the passenger and driver are on their way to a bar that is on the street "University Ave". In this extract the car is driving along a highway and approaching a junction which offers turns to both University Ave ("exit 2C") and Washington Street (exit "2B"). Here the driver decides to take a different turn from that suggested by the GPS - taking the car on exit 2C towards University Ave (line 4). While the driver takes this earlier turn the GPS actually shows the car taking 2C until line 13. In this case it is not that the GPS is ignored - indeed the driver speaks *soto voco* to the GPS in line 7, and the passenger comments on the driver not following the recommended turn (lines 11 & 12). There are a number of potential reasons for the driver making this earlier turn - he could be choosing the 'safe' route - since this exit is signposted with the street that is their final destination. The car also slows in traffic on approaching this junction, and the driver could be choosing to avoid traffic.

Whatever the exact reason the action is referred to by both driver and passenger in light of what the GPS is recommending. The driver comments that they are 'going to go this way 'n get lost', in some ways doing a pre-emptive

```
1.  G: In about three quarters of a mile exit number 2 bee on your right then left turn
2.     ((section excluded))
3.  D: We're going to go this way 'n
       get lost (4.0)
4.     ((Changes lane to the right, to
       take exit 2C))
5.  P: (4.0) I wz just gonna say just
       go over here
6.  G: Exit number two b [*] on your
       right then-- left turn
7.  D: Oo:: is that what happens
8.     (2.0)
9.  D: Nope I took the wrong exit (1.) uh-oh
10.    (4.0)
11. P: You do realise
12. D: [(I do realise)]
13.    ((GPS shows car not taking turn))
14. P: [2B is right there] [*]-----------
15. P: ((points-[---------------[----))
16. D:      ((looks))    okay
17. G: In about quarter of a mile take
18.    a left exit onto university avenue
19. D: okaey
```



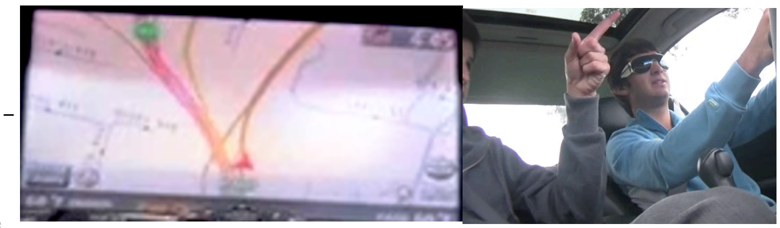


Figure 2: "2B is right there" In these transcripts, D is driver, P is passenger and G is GPS. Some of the transcripts involve lengthy discussions of other topics and so have been shorted for brevity. To aid understanding of some of the driving we have also inserted (marked with an [*]) images from the video, along images of the GPS display.

strike - if they do get lost then the driver did at least originally acknowledge the matter. Route choices are, after all, accountable matters where you can get into trouble for going the wrong way [4] - indeed, in line 11 the passenger goes on to question the drivers choice.

While complex these sorts of road junctions are relatively commonplace - here the GPS offers clear instructions, in good time, to take the instructed junction. The driver's choice is not a mistake but is a deliberate decision. The GPS, however, sticks on the original route even though by line 4 the driver has positioned themselves to take a different lane, and by line 6 the car has entered an 'exit only' lane. The GPS still recommends the original, later, turn 2B onto Washington Street. In common with the first example the GPS is not ignored, but the instructions it gives are read with respect to the current road conditions and car position - the driver chooses to diverge from the given instruction. The instruction both creates a relevant occasion for the driver's decision-making but also provides relevant options (following / not following the GPS). Using this information about the multiple junctions the driver can assume that it is still possible to reach the destination taking the alternative turn. The GPS also goes on to provide a resource for the discussion between the driver and the passenger. Lastly, whatever turn is taken by the driver he can be sure that the GPS will recalculate, and it has, by line 17, adjusted the route; they will not "`get lost`".

Normal, Natural GPS Troubles

Both these videos offer typical and uneventful examples of GPS-instructed action. In many cases in our video corpus the GPS would direct action 'correctly', even when the the driver chose a different turn from that recommended. The GPS acted to provide alternative courses of action - with potential and recommended turns alongside close-by street names and other relevant information.

However, as any prolonged exposure to a GPS will make clear, GPS units do frequently 'make trouble', in that their sensors, maps or routes, fail to make sense to the driver, or offer obviously irrelevant instructions. Frequently the source of these troubles not the GPS incorrectly determining some aspect of the world, but rather aspects of the broader interaction with the technology. We call these events 'normal troubles' to indicate that while they are problems for drivers (they sometimes cause confusion or disorientation) and in some cases could be alleviated by better designed technology, they are also 'normal' in that overcoming them is part of ordinary use of a GPS. Bittner and Garfinkel [3] describes "normal, natural troubles" as cases when a record of some sort (a file or a map) is put to a purpose that could not have been foreseen when it was created. In this case, the driver must take the instructions and maps provided by the GPS and 'fit' them with the situation they find themselves in. Competent GPS use thus involves being able to overcome and deal with these 'troubles'. We outline five 'normal troubles' here: destinations, routes, maps and sensors, timing and legality.

1. Destinations

This is perhaps most clearly demonstrated if we consider how destinations are dealt with by GPS systems. For example, in one journey the driver stops off on her route to pick up cupcakes for the event she is going to. As she diverts from the original route the GPS continuously recommends her to return to the original route. When she has finished her errand and is navigating to the destination that is set in the GPS, the GPS then continues to recommend that she drives on the surface roads. Meantime she has taken her preferred route along the freeway (comparing these routes there is no significant difference in the time they will take). In an attempt to make the GPS software recalculate the route the passenger sets the junction with the freeway as an intermediate stop. Unfortunately he sets the wrong junction which in turn results in a series of further incorrect directions being given by the GPS. In many senses the GPS is not making a mistake here, since it could hardly guess about the cupcakes, or the choice of route. Yet, the end result provokes considerable frustration - the driver remarks, "`these GPS things it's really confusing`", whereas the passenger is more succinct: "`ahh shutup`".

For drivers in many cases the destination may be deliberately and fruitfully ambiguous or approximate. Drivers and passengers might only have a limited idea of their exact destination, or know in some detail where they are heading but be missing the address or zip code. Indeed, it is common enough for drivers or passengers to identify their final destination from what they recognize when they get closer. Also the the details of the destination may be reliant on information that is not immediately available and might be provided later (by calling to the destination, or by looking up the address). The final destination might also be contingent on features of the environment of which the GPS is unaware. Cars need to be parked, for example, so the final destination for the car rather than its occupants might be street parking distant from their actual destination.

Thus the driver may choose to specified a destination to the GPS not as where they actually heading, but what they can find rapidly in the GPS interface - as an approximation to their final destination. For example, in the case above the passenger sets the destination as a freeway junction, not because that is the final destination but because their desired *route* involves the freeway. Drivers might also not specify a detour to the GPS. Seeing a shop from a freeway, for example, a driver might detour to go to that shop and would be unlikely to bother to program this into the GPS.

This divergence between the actual and specified destination in turn has a corresponding effect on the route that the GPS specifies. In some cases it will simply be irrelevant to the driver. For example, in one of our recorded journeys, a driver turns off the freeway to get petrol - at which point the GPS immediately commands her to turn and rejoin the freeway. If a driver choose a different route from that the GPS recommended that could cause considerable problems - we observed 'recalculating storms' - where the GPS recommends that the driver return to the commanded route, and ignorant of their own choice, recalculates on each junction when they do not return to that route.

GPS systems have attempted to address some of these challenges - such as by supporting the ability to have more complex routes with multiple stops or the relatively easy setting of detours to a route (such as finding a close gas station on route). Indeed one of the great values of the GPS over the human navigator, is that it offers an impressive amount of fault tolerance. They will recalculate a new route without complaint should the driver wander from the suggested route. Yet the persistent instruction to follow a discarded route is an obvious irritant to drivers.

2. Routes

As with destinations, the particular desired route that a driver might take is also something with considerable variety. Routes chosen by drivers do not simply take into account what might be quickest, or the particular road type, or predicted traffic, route choice is often heavily influenced by route complexity. This is understandable since with each turn there is a possibility of making a mistake, so simpler routes are preferred over more complex ones. Route selection is also influenced by existing experiences on those roads, quality of road and so on. A freeway might be preferred over a highway, even if the distance to and from the freeway make it in slower, or a highway over a freeway for a less confident driver. Routes might be chosen to avoid dangerous roads, high crime neighborhoods, or to pass through beautiful scenery or a favorite street. If a particular route has been navigated before (and is thus known to the driver) it might be preferred to unknown streets.

GPS units use specific (and sometimes proprietary) algorithms to calculate routes, they are, on the whole, focused on optimizing driving time. As a consequence GPS will often chose a route which is complex, involve driving over roads which are difficult to drive on, or involve the navigation of a complex junction, or have other qualities that make it a dis-preferred route by a human driver, even though it is faster. This led to two 'troubles' for drivers in our corpus: dealing with a dis-preferred route, and a failure to understand how the current instructed turn fits with what the route is overall. When the GPS selected a dis-preferred route drivers would struggle to understand how the recommended route differed from their own route choice and if this highlighted a problem with their own route, or it was simply the GPS provoking the confusion:

```
G:  Continue point nine miles then turn
    right on west contello avenue
P:  Yeah this isnt right
D:  Well i guess you can keep going that way
    but
P:  I think this is only for local
D:  No GPS is not for local
P:  No how it set up right now
D:  That doesnt make sense
P:  This what it did last time but it's not.
    if if were gonna take a right on con-
    tillo then bu:we wouldn't be going on
    the freeway
D:  Yeah but it'll still get you there
    adoonna why its (2.0) yeah
```

Figure 3: Wrong route choice

The second problem with routes involved cases when the driver would not understand how a particular direction fitted into the broader route. In some cases passengers or drivers would interact with the GPS unit to try and inspect the route. Getting a route overview while driving though appeared challenging. In this extract the passengers exchange the numbers of different freeways trying to work out the recommended route:

D: So i don’t think theres a ramp for the six ohhhhh. fivve

P: I donno let’s be safe

D: Sh:i would i wonder what route this thing is taking
((P starts to use GPS))

G: ((bleeps))

P: Oh

D: [You have to click the name]

G: **[In eight point one miles] keep left onto i four oh five north=**

D: =aeh:

P: Six oh five=

D: =oakey

D: °One ten°

P: Yeah one ten (six oh eight)

D: Yeah. alright (6.0)

G: ((Beeps))

D: Probably less

P: When we end up on Exposition Boulevard we should try and find parking

Figure 4: inspecting the route

Here the passengers are talking about the route to their destination. The GPS is taking them on a fairly convoluted route involving keeping on the i405 (which they are currently on), then taking the i605 then the i110. As the passenger inspects the route on the GPS she reads ‘605’, and the driver reads a subsequent freeway - the ‘110’. By default most GPS systems only give the single next turn so here the passenger and driver interact with the GPS to bring up a list of future turns, which they then inspect to make sense of the recommended route. The comparison of routes here is part of an inspection of the GPS’s chosen route: what route is the GPS taking and should they try and make their own route? Has something gone wrong with the GPS that they need to fix? While the GPS’s route is rather complex the travelers can assume that the GPS is applying rational criteria, yet something might have gone wrong (such as an out of date map, or an incorrect destination) so they need to be attentive to the GPS. Moreover, looking at the GPS’s complex route will mean that the driver is prewarned as to future turns, and allows them in the final line to move on to discussing parking at their destination.

3. Maps and sensors

One of the biggest challenges in providing a useful GPS system is the collection of accurate and up-to-date maps. As new road are built, old roads removed, junctions and one-way systems altered, GPS units can struggle to keep accurate map data, particularly for units which need user intervention to be updated. Inaccuracies with maps can indeed cause problems for drivers. In this extract the driver is initially confused by the GPS instructions to ‘exit on Hancock street’. While the exit is actually ‘Washington street’, it meets a second street called ‘Hancock street’ as it exits the freeway. The street has thus been incorrectly labeled by the GPS as ‘Hancock street / Washington street’, which the voice-instruction shortens to ‘Hancock street’. While subtle, without the involvement of the passenger this could have resulted in a missed turn:

G: **In one point seven miles exit on Hancock Street**
((section excluded))

D: I go here. I go down this way a lot for my off-campus stuff but in I haven’t seen a street called Hancock

P: <Hancock Washington street>
((looking at GPS))

D: so I see Washington street do i just go [off]

P: [yeah] yeah go off on Washington
((pass sign “Washington St 3/4 mile”))

G: **In point eight miles exit on Hancock street**

Figure 5: exit on Hancock street

While this error can be seen as a simple map error it also illustrates the sometimes complex nature of street junctions - in this case a junction that leads to Hancock Street, but is actually the ‘Washington street’ exit. It might seem reasonable to label a junction in terms of the street that it leads to, but incorrect in this case. Moreover, this is not something that would be properly represented on a map (Google maps, for example, show the street exiting onto Hancock). This is an example of a conceptual challenge that stands beyond the significant practical one - how to accurately represent the vagaries of roads and junctions in a good enough way, without having to model everything about the world - as Wood puts it: “every map show this... but not that” [34]. While in most cases the abstraction that the GPS uses - its map - is sufficient for navigation, drivers must always watch out for cases where the abstraction fails - ‘natural, normal troubles’. For example, in another video extract a driver talks about how with GPS systems “it’s really confusing sometimes, like the exit, the line doesn’t look like the exit". Even with improvements in graphics GPS systems struggle to portray junctions in a visual form such that makes it clear to drivers what junction to take.

A related problem concerns the unavoidable inaccuracy of the sensors that GPS systems rely upon. GPS signal can be easily lost, or the orientation of the car can be ambiguous or simply wrong. Particularly at the beginning of journeys this can cause a confusing start - does the driver turn this way or that way? Perhaps even worse, sometimes GPS units do not have enough confidence in their position and orientation to be able to give a route at-all - hardly something that engendered confidence at the beginning of a journey. While this inaccuracy can be misleading or lead to wrong turns, GPS systems are prone to more cosmetic errors. For example, where a driver takes a junction that has not been recommended by the GPS - and the unit continues to show the car taking the recommended junction (e.g. figure 2).

4. Timing

A related set of problems concern the timing of turn-instructions given. Reliant upon the limitations of the screen and audio, the GPS must provide timely delivery of information to the driver. One feature of driving is that for certain movements of the car sequence is important in that certain movements change the possibility of movements that can be made later - moving into a right hand lane makes it easier to later take a right turn. Sometimes the positioning of the car must be done with an eye to turns that are some distance away - particularly in highway driving lane position is important for junctions.

In this clip the announcement of 'take ramp on the right' has a different meaning as a new right hand lane appears to the right of the car after the instruction. The driver needs to quickly move the car into the new right hand lane. If the GPS's instructions had been given a second or so later, they would have been announced in conjunction with the new lane (but perhaps too late for the driver to safely take the turn). As the lane appears the driver and passenger exchange a curse, and the driver quickly moves one more lane to the right so as to be able to take the ramp. The appearance of a 'new' right hand lane, after the original turn instruction is given, is not modeled by the GPS which simply states the need to take the turn. While this is in part timing, it is also an issue of the granularity of the model of the road:

G: **In point three miles take ramp on right to I four oh five north**
((new right hand lane becomes visible))
D: oooops=
P: =shit [*]
((white car in front changes lane to right))
D: ((looks right))
D: ((puts indicator on))
D: ((looks right, indicates, changes lane))
G: **Take ramp on right to four oh five north**

Figure 6: take ramp. Alongside the video frame above is a google street view frame from the same position showing the new lane appearing on the right, after the GPS instruction is given

Questions of timing have particular importance at highway junctions where decisions have to be made quickly, and the positioning of the car in a particular lane can be important long before the particular junction need be taken. In some cases GPS units will provide information about a particular turning but will not inform the driver about the turn they should take immediately *after* this turning. Often the driver needs to position themselves in the correct lane on leaving the highway, and the delivery of the information after the first turn will be too late to be acted on by the driver.

Alongside questions of timing, GPS units can, at times give superfluous instructions that confuse the driver, or occlude the presentation of more pertinent and important information. In a number of examples from the corpus the GPS gives instructions to 'keep left onto the highway' (e.g. figure 4) - advising the driver to avoid an exit-only lane. While this (in some cases) might be useful, for the competent freeway driver this is superfluous - understanding, and expecting, exit-only lanes is part of US driving. More seriously, since the GPS is giving this instruction it can occlude the actual next turn that needs to be taken. In one case from the corpus, the GPS does not tell the driver in time about their next turn because it is busy telling them about a turn they should not take, causing the driver to have to quickly react and change multiple lanes across the highway.

5. Legality and safety

Our final 'normal trouble' concerns issues of legality and GPS use. GPS units give, on the whole, legal navigation information - it seems rather obvious that a GPS should not instruct you to make a road manoeuvre that would be illegal. Yet in many cases this can conflict with manoeuvres that are commonly practiced yet are, under a strict interpretation, illegal. Juhlin [17] gives an example of breaking the speed limit on a slip road so as to be able to safely merge with traffic on a highway. This is the 'moral order' of the road - situations where a driver would be exceedingly unlikely to be prosecuted, or where safe driving implies breaking a traffic law [29].

A relevant example for GPS use concerns where a driver would turn their car into a car park or business and would cross the middle of the road to do so. If there is a line in the middle of the highway this is an illegal road manoeuvre, yet one that would be commonly taken by many drivers. To avoid the illegal move a GPS should recommend a circuitous route around the block, rather than a simple turn. Yet this leads to confusing directions being issued by the GPS. As the driver approaches their destination the GPS directs the driver to drive away from their destination and around the block so they enter from the correct side of the road. A related problem concerns the speed that drivers cruise at on roads. Many (even most) drivers will frequently drive slightly above the legal speed limit. On an empty road with a low speed limit, with no sign of other drivers (or police) they may even choose to heavily exceed the set speed limit. This potential of fast and empty roads could not be used by the GPS in calculating arrival times. The drivers we studied thus 'raced the GPS', where they would seek to beat the predicted arrival time by the GPS, something that entailed exceeding the speed limit (but still driving at the 'natural speed' of the road [17]).

Our data also speaks to questions of the safety of GPS use. While we could not find any statistics for accidents caused by GPS-related distracted driving some experimental studies have found GPS assisted driving degraded performance, particularly with the use of visual navigation aids [16, 25]. Other simulator data and experimental of navigation use has found GPS navigation while driving to be safer than using a paper map [23]. This situation is in some ways analogous to driver distraction through driving with a cellphone. While many legislatures have outlawed this practice, the empirical evidence is somewhat unclear - simulator data suggests that driving with a cellphone is as dangerous as driving while intoxicated [31] yet accident rates have been under a slow decline in most western countries [2]. Moreover there appears to be no correlation between cellphone use levels and accident rates [2] even as cellphone use while driving has declined in states that have banned the practice.

An important problem is that experimental data on driving suffers from 'demand characteristics' [5, 11], where driving in a test is organized in ways that make it differ from the more everyday driving recorded here. While our data is still 'framed' through its collection, the nature of its collection makes for video that is more varied and natural that video collected in simulators or experimental drives. Through relying on experimental data to study driving we may be missing driving as it is actually practiced. Nevile [27] classify driver distraction using naturalistic data and document this point in more detail. As Esbjörnsson *et al* [8] point out, this has serious implications for the validity of simulator and experimental based driving data presented at CHI.

DISCUSSION

Drawing on the data here there are three arguments that we make concerning the use and design of GPS systems for driving. First, we draw a set of design recommendations focusing on how GPS systems could better support the experience of driving. Second, we argue for a broader conception of GPS use as a skilled activity. Lastly we discuss the notion of 'instructed action' and how we conceive of action as directed by technology.

Informing the design of GPS systems

It is clear that the design of GPS involves a range of difficult trade-offs, optimising for one behaviour could cause a range of conflicts with others. We described the troubles of our GPS users as 'normal natural troubles', to indicate that they are not necessarily problems that are in need of technical solution, since part of the skilled use of a GPS is overcoming these problems. Moreover, any 'recommendations for design' need to be couched in an acknowledgement of the astounding success of GPS systems and how they have changed driving. Yet if we acknowledge some of the problems drivers face managing routes and destinations it is possible that GPS systems could present more choice to a driver. For example, a secondary route could be shown on the map in a lighter colour, or GPS units could offer the option of taking a *simpler* route rather than the time or distance optimised route. As an extreme case a GPS might not even offer a suggested route, but simply label streets in terms of how likely they are to get the driver closer to their destination. When driving, if a driver ignores a particular turn then rather than attempt to instruct them back to the recalculated route, the GPS might take that turn as an indication of a choice of a distinct, preferred route. Continual ignoring of the recommended route could even automatically silence the GPS's audio instructions.

More broadly, if we see the instructions given by the GPS not simply as commands but also as information for the driver we might seek ways to better inform the driver of the route chosen by the GPS. At the very least this would involve giving the driver or passenger quick access to a route overview of up-and-coming turns so they can understand the whole recommended route. A GPS unit could offer a side view which lists future turns to be taken. This might alleviate problems of route occlusion and timing too, in that at least a driver can choose to quickly 'look ahead' in the route to see where they are heading. Issues of timing and lane choice are more difficult to address, yet it may be possible that GPS units could make use of more advanced models of the current driving situation so as to offer more detailed instructions, or to 'seamfully' [6] reveal limitations in sensors or maps. While there has been considerable advances using crowd sourced speed and map data it is possible that drivers might be able (for example) to suggest areas where instructions are unclear, or to correct difficult to follow instructions. Lastly, GPS units may offer the option to avoid superfluous instructions - such as route guidance to 'keep on highway' as an exit lane approaches.

GPS use as skilled activity

A broader analytic point, that may well be more productive for design, is to understand the use of GPS as a form of skilled activity, where drivers and passengers make use of GPS to support the driving activity. Rather than seeing this as a case of 'docile drivers' who blindly follow the instructions given, we can conceive of driving as a complex task where drivers in different ways rely upon, inspect, fight over and ignore the instructions given by the GPS. To support usability the goal should not be simply 'telling the driver where to go' but giving the driver the information they need so as to satisfactorily get to their destination.

In many cases this would mean simply giving the driver a simple route to follow. Yet even here information about other streets and the broader context of the city would not be irrelevant but part of providing contextual information to help a driver make decisions about the turns they make. Leshed et al [24] mention how the display of 'points of interest' can better support interaction with the physical environment. This paper echoes this point and raises the question of how a GPS might better support informed driving. One could imagine a GPS unit designed not to instruct a driver to a given destination but instead to teach them about the city they are driving through (on this point see [22]). One might imagine a GPS mode which did away all together with the notion of navigation, and instead sought to assist and educate the driver without directing them to take a pre-determined route to their destination.

A second argument that Leshed et al's refer to is that of Aporta and Higgs who analyse the use of snowmobiles and GPS amongst Inuit peoples. Aporta and Higgs argue that GPS is part of the commodification and deskilling of navigation: "There is a sense of fulfilment and accomplishment in being able to relate fully to the activity we perform and to the environment in which we are. GPS technology takes that experience away" [1]. Yet as we have identified above, it may be better to see the use of GPS as the revision of existing skills. After all, navigation with driving is an activity already constrained by machines of many sorts (the car itself, for one), and adding one more machine does not necessarily radically de-skill the activity. More prosaically, this question of skill leads to issues of driver education. One interesting question is whether driving tests and examinations could contain lessons about the skills involved in the effective use of GPS units, educating drivers in how to effectively use them in their driving. Knowing how to follow a GPS - and when not to follow its instructions - is surely an important part of modern road safety [7].

Instructed action

A GPS offers a very particular form of 'instructed action' where drivers are in the situation of trying to understand and read the instructions given making sense of the world around them, the movement of the car and the surroundings. As Suchman (1987) argued instructions do not determine their own application since work needs to be done, in context, to produce action from the instructions. Understanding instructions involves following earlier commands, establishing the context for the current instruction, but also to be aware of the features of the materials being working with. One illustrative example Garfinkel [9] describes is assembling a piece a chair making use of printed instructions. When assembling a chair "what a particular instruction means can only be seen at a certain point in the assembly process drawing on orientation of your own body, the party assembled chair and the parts you have left [...] the instructions have a developing coherence as part of a course of action that they do not have as a page of instructions" [ibid, p42] As with instructions so with maps - "recurrently, in vivo, maps and manuals present their users the in vivo witnessed incompetence of the text" [ibid, p205]. Instructions, on their own do nothing - they can only produce instructed action in situ, when they are brought to the world, with the work of whoever it is following the instructions trying to make sense of what a particular instruction means at a particular point in time.

What this means in terms of GPS is that the situated instructions are not 'simply' instructions but are puzzle pieces that must be assembled so that the driver has to make out what they could mean, sometimes needing to make wrong manoeuvres to be able to do that, looking around, asking questions of passengers, all to produce suitable instructed action. In many cases this will be easy or trivial - just taking a turn, yet even in these cases this is not without skill. At other times drivers are not able to understand the GPS at all, and resort to abandoning its use, or even abandoning their journey. GPS is usable as a technology in how its navigation commands are followed as instructions and that is not simply doing what you are told. The user needs to listen to the command given, and make sense of it in terms of their own expectations and predictions about what the GPS unit has calculated and the limited plan it is offering. Each instruction is taken not only then as a command but also as more evidence about what the GPS is attempting to do, and whether this fits with what the driver is trying to do. The instructions are then open to re-analysis, re-interpretation and re-use as the car moves through the environment, with each instruction, and each road passed providing information that can help the driver decide what to do next.

As a broader point, 'following instructions' given by machines rests not simply on how well the instructions are written or formed, but broadly on the skills and resources that can be brought to hand at the point of execution to act. There is always the need for the active skillful construction of action at the point of use - 'instructed action'.

CONCLUSIONS

In this paper we review some aspects of how GPS units are used to support real-world navigation. Our key argument has to move away from the model of the 'docile driver' who unquestioningly follows the instructions that the GPS gives, to a notion of active drivers and passengers who are interpreting, ignoring, re-using instructions while also combining them with related information from the environment and their own route knowledge. To establish this model we discussed five 'troubles' which GPS using drivers dealt with in response to turn-by-turn instructions. Each of these covered a different limitation and possible source of error in the instructions GPS units give, and how they are followed.

As we look to future developments in navigation technology it may be that GPS-assisted drivers lose certain skills, or that they become dependent on a particular technology. While it is possible to romanticise maps and lament the loss of particular vernacular skills it is also possible to acknowledge that with what are often assumed to be technologies that de-skill we then witness the birth of new skills and competences, and understand how these are changing and developing as the technology itself changes [15]. Rather than adopt a critical approach here to the spread of a technology that changes our perception of movement, our goal has been to understand and document these new technology-assisted forms of wayfinding. As with any complex technical activity the account we have given here is a necessarily partial one - and one that is particularly routed in the driving conditions of the routes we studied. We hope however that we have succeeded in providing some opportunity for reconsidering the design and use of GPS systems.

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