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INVITED ARTICLE

Wayfinding and navigation research for sustainable transport

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Abstract: Spatial information science contributes to the foundations of sustainable transport development. This article focuses especially on the role that research on human wayfinding and navigation plays when it comes to designing digital connectivity and autonomy in urban transport.

Keywords: wayfinding, navigation, sustainable development goals, mobility, interaction

1 The challenge and its relevance

Societal challenges such as climate change or sustainable development are commonly cited motivations for mobility and transport research. While mobility demand is derived from our desire (or need) to participate in activities, and thus by-and-large given (although hard to pin down due to some conundrums such as induced demand), it is *the way* people and goods move that have varying impact on climate change or sustainable development. Accordingly, the UN's Advisory Group on Sustainable Transport writes: "Transport is not an end in itself, but rather a means allowing people to access what they need: jobs, markets, social interaction, education, and a full range of other services and amenities contributing to healthy and fulfilled lives" [13]—the same paper the UN Secretary General opens with the words: "Sustainable transport is fundamental to progress in realizing the promise of the 2030 Agenda for Sustainable Development and in achieving the 17 Sustainable Development Goals."

Prominent examples of the variables at stake are the fossil fuel emissions: CO_2 (impacts on climate change), NO_x (forms smog and acid rain, and impacts on the troposphere), and particle matter PM_{10} and $PM_{2.5}$ (impacts on public health). Emissions can be reduced by more efficient combustion engines, by cleaner fuel, or by changing mobility behavior. Other factors contributing to sustainable transport are electrification (clean energy), road safety, and modal choice. Disciplines pushing related research visibly are car manufacturing, transport, optimization, and urban planning.

The role of spatial information science in this complex picture is not well recognized—meaning that it was not an obvious candidate to be listed among the above. This article sets out to claim some ground rather than accepting to be considered a mere data and technology provider for sustainable transport. Within spatial information science the research most relevant for sustainable transport is linked to "digital connectivity" mentioned in the above report: It is about how people interact with 'intelligent transportation' designed to be sustainable, and hence about the well-known field of human wayfinding and navigation [9] in new contexts. These aspects will be the focus of this article.

Claims that spatial information science contributes to sustainable transportation come with a price though: the basic research has to be communicated to the other communities to be recognized and to have any impact, i.e., outside of our comfort zone and exposed to sceptical scrutiny. Obvious communities in the domain of my claims are *intelligent transportation systems* and *computational transportation science*. This cost has to be considered on the background that spatial information science in itself is already interdisciplinary.

2 Review of progress in the last decade

Research on human wayfinding and navigation is well established in neuroscience (brain), spatial cognition (mind and behavior), spatial linguistics (communication), computing (routing), and spatial human-computer interaction (decision support)—I abstain in this short article from a thorough review of this literature. I also do not claim that human wayfinding and navigation is comprehensively understood already. This article focuses solely on a relatively underexposed relationship: How wayfinding and navigation research can and does support the UN's Sustainable Development Goals (SDGs) [12].

Human mobility consumes resources, and therefore is at the center of the Sustainable Development Goals on sustainable cities and communities (SDG 11) and climate action (SDG 13), and tangentially relevant to the ones on poverty (SDG 1), inequality (SDG 10), infrastructure (SDG 9), and responsible consumption (SDG 12), as I'll illustrate below. Research in wayfinding and navigation can therefore actively address sustainable development goals.

Montello defined *navigation* as a coordinated and goal-directed movement involving *wayfinding*—the planning part—and *locomotion*—the execution part [9]. His notion of wayfinding includes also *orientation* as a pre-requisite for wayfinding. On the face of it, *wayfinding* seems to be the primary factor when it comes to sustainable development goals: here is where people's mobility choices come in. But I'll argue that exchanging and understanding information is equally important, and at the level of speech acts [11] this factor is part of the execution; only afterwards, when the information is used, the planning part kicks in. Hence I will stick with the vernacularized phrase "wayfinding and navigation".

3 Three major challenges for the next ten years

I have selected three challenges that are currently hot in transportation research, and yet have a strong component for basic research on wayfinding and navigation.

3.1 Disruption and the risk of change for the worse

The advent of electrification, automated driving, and the new economies of sharing and access will be disruptive for the mobility sector [8]. The way people move in the city will change, with extreme prophecies telling us the end of private car ownership. A pre-cursor of what to come are the ride-hailing platforms currently threatening the taxi market, such as Uber, Lyft, Didi, and Ola. The consequences of ride-hailing in terms of SDGs are not yet well understood. They are complex as well, combining a new precarious workforce (SDG 1) with lower fares hence higher induced demand and cuts to public transport patronage (SDGs 9, 10, 12), with more vehicle-kilometers travelled than before (SDG 13) [6], much of the increase without passengers on board, and with a significant shift of parking demand (SDG 11) [5].

The success of ride-hailing platforms mainly relied on two factors linked to the 'digital connectivity' mentioned above. One is their connectivity with the two sides of their market: passengers and drivers. These platforms are perceived as user-friendly. The other factor is that they coordinate their customers by demand and supply, having access to these figures in real-time. Electrification and automation may further push the market share of ride-hailing, due to further dramatic cost cuts [1, 2]. The arising challenges for societies are not only emerging monopolies or oligopolies, but also by the non-sustainable consequences of ride-hailing that need to be well studied and encountered.

3.2 Autonomous vehicles and interaction

Fully autonomous vehicles will provide "the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver" [10]. But while a human *driver* will no longer be required to interact with the vehicle on wayfinding and navigation, this vehicle still transports passengers according to their mobility needs, i.e., interacts with them, and it participates in the social interaction in the street space, including other autonomous vehicles but also pedestrians, or people-driven vehicles. This interaction is always also about wayfinding and navigation, especially locomotion. The way people communicate and interact with these vehicles on navigation tasks must consider human conceptualizations of their environment, a degree of personalization (what does this person know about the environment), and spatial common language, both verbal and gestural [4]. Since this research is mostly addressing the usability of the city, it contributes to SDG 11.

3.3 Mobility-as-a-Service

Assuming that the purpose of wayfinding is efficiency in the navigation process (which it often is but does not have to be—planning the weekend hiking trip follows other criteria) it is already designed to minimize the consumption of human resources—time, emotions, money. External costs such as emissions, however, are not necessarily considered. Hence, one direction of research on wayfinding and navigation is on impacting on the mode choices and mobility behaviour people show, either actively by taxing emissions, or passively by providing and explaining alternatives.

Providing alternatives is what Mobility-as-a-Service platforms do (MaaS) [7]. The interest to integrate (eventually all) mobility options and services in a single platform arises with the emergence of more and more transport modes and operators populating the cities.

MaaS promises a view on (urban) transport defined by passenger needs rather than by provider ontologies. But this claim opens another research challenge on wayfinding and navigation. While the human capability of wayfinding replaces typically exhaustive or even extensive search for heuristics or even habitual wayfinding behavior, machines can produce optimal solutions as well as arbitrary numbers of alternatives. This information can overwhelm, and identifying what is relevant for people's wayfinding and navigation [3] is a worthy task. Since MaaS are about choice (mode choice, operator choice, and others), they are also a key platform to influence people's choices towards sustainable development goals (and not just CO_2 footprints).

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