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Congestion, Safety, Economic, and Environmental Challenges of Vehicle Automation in Transport Systems

Driverless cars are expected to have the advantage of lifting requirements for driver's license ownership and fitness to drive. As such they may offer improved accessibility and mobility for those currently unable to drive, e.g., the elderly and disabled [1], [2]. Despite the postulated benefits, the role of driverless cars in future transport systems remains debatable, in terms of their potential to replace other transport modes or have a novel, unique, and complementary functionality.

Wiseman in his article "Driverless Cars will Make Passenger Rails Obsolete," (*this issue*, p. 22), makes a number of very bold statements concerning the future of transport systems. In particular, he suggests that driverless vehicles will soon replace railway systems as well as, presumably, other public transport. Following this hypothesis, he suggests that driverless vehicles should and can be facilitated through expanding car-friendly infrastructure. Yet those working in the field of transport systems, whether in modeling, policy, engineering, or economics, are well aware of such transport systems' notoriety in not following the trajectories of any long-term predictions, whether utopian or dystopian. In particular, consider a pair of past bold conjectures related to transport systems:

> "In 50 years, every street in London will be buried under nine feet of manure" (*The Times*, 1984, quoted in [3]).

> "Telework and telecommuting are likely to increase at an *accelerating pace* over the next decade" (Nills, 1985, quoted in [4]).

The commonality between those two statements is their boldness and incorrectness, even though they represent two extreme stances on the role of technological progress in transport systems: ignorance and over-optimism. Rather than debate the nature and causes of the "Great horse manure crisis of 1894" (see [5]), we observe that with his perspective, Wiseman might be falling into the same trap as authors of the statements above. Thus, we propose to treat Wiseman's article as a starting point for a more critical discussion of the role of driverless cars in relation to rail, or indeed other modes of transport, as those have to be considered in any such deliberations. We cannot offer, unfortunately, an exhaustive review and exposition of what is already a very substantial research field. Instead, we highlight some of the specific discourse and arguments that relate to the conjectures made by Wiseman, and allow the reader to obtain a more complete perspective on the issues.

"Driveless Cars Will Make Passenger Rails Obsolete"

Wiseman's article concludes that:

> "…a means of transportation that takes many people from

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> one central station to another central station has lost the justification of its existence….train stations are not often in a close proximity of the passenger, so the passenger should use another means of transport to arrive at a train station whereas when using driverless cars there is no need for the hassle of these connections" (p. 26).

This vision *can be* true, but it embodies a number of implicit, but fundamental assumptions. Therefore, let us spell out these assumptions and evaluate them in light of current knowledge, as part of the accepted best practice to appraise decisions concerning transport systems.

Assumption 1) Every traveler has access to a driverless vehicle that can serve his or her mobility needs at least as well as current rail and other public transport services

This requirement stems from the need to serve those previously traveling by rail and possibly other public transport with a similar or better level of service (generalized cost) in order to maintain a similar level of social welfare. To meet those needs, for example, New York City would need to serve the current 1.7 billion annual trips made by the subway (6) with access to driverless vehicles. For simplicity, assume a homogenous demand across days of the year and a vehicle occupancy of 3 persons per vehicle (seen typically only in high occupancy lanes). Under those, very favorable circumstances, the city would need to cope with about 1.5 million additional vehicle trips per day, i.e., an increase by a third from the present 4.5 million (7). The question remains where the vehicles (and resources to maintain them) would come from in order to serve all the commuters who currently rely on cheaper means of transport, including those working in lower-paid occupations, which are essential for the urban economy. Furthermore, the lack of affordable transport would restrict employment opportunities, especially for the less affluent or for youth, further hampering the economy (8). Overall, this situation could point towards the need for subsidies, that is, the situation to which Wiseman objected in the first place.

Assumption 2) There is enough road capacity to meet the surge in demand from modal shift due to the Assumption 1)

This assumption concerns the ability of the road infrastructure to accommodate the additional vehicle trips resulting from the removal of rail and public transport. To maintain a similar level of social welfare, i.e., to not make travelers worse off, this would imply a comparable generalized cost of travel, including travel duration, monetary costs, or waiting time. Considering the prevalent saturation of road networks across cities, especially during peak times, this would require a substantial increase in road capacity. To meet this requirement, it would be necessary to combine a set of far-reaching measures that include:

- **Ensuring rapid take-up of and penetration of traffic flows by driverless vehicles.** This requirement rests on extensive simulation efforts, e.g., (9), proving that a high penetration rate of driverless vehicles is crucial for achieving higher traffic throughput, given the substantial differences between driving logic in human-controlled and driverless vehicles.
- **Cooperative operation of the vehicles and their controllers.** This property would ensure smoothness in traffic flows and at intersections to achieve the capacity gains, especially within urban areas (10). Fundamentally, drivers exhibit different values of time (VoT), i.e., willingness to trade-off money for ability to travel faster, including crossing a junction sooner or drive at higher speeds. VoT itself is driven by broader time use and budget (income) considerations (11). Allowing vehicle controllers to reflect those heterogeneous VoT in driving style could limit stability of the vehicle platoons, which in turn is key to the postulated traffic capacity gains (8). There are emerging ideas that seek to accommodate this heterogeneity, e.g., via peer-to-peer trading (12). Those still require, however, suitable technologies and protocols, especially if the benefits are to be realized at the system level. Alternatively, an externally imposed regime of travel behaviors would deprive travelers of mobility choices that they can currently match to broader life circumstances, thus almost surely making the users worse off.
- **Broader economic justification and social acceptance of road expansion projects, especially in dense urban areas.** Substantial physical road infrastructure expansion might

> **New York City would need to serve the current 1.7 billion annual trips made by the subway with access to driverless vehicles.**

need to complement the solutions above, especially in situations where there simply is no physical space for additional vehicles. In the most problematic, densely populated urban areas, where land prices tend to be the highest, e.g., [13], [14], allocating further space to roads would simply be economically unfeasible. The proposed alternative, i.e., multi-level (elevated) roads, could solve capacity issues at arterial roads in some contexts but would be virtually impossible in protected townscapes and landscape environments or local streets and collector roads due to effects on property values of increased traffic intensity or pollution [15]. Inability to do so would make Wiseman's statement "no need for the hassle of these connections" invalid.

Assumption 3) The kinematic properties of the vehicle allow realization of traffic capacity gains but also ensure that the environment is productive/enjoyable

One of the greatest postulated benefits of driverless vehicles involves transformation of "wasted driving time" into productive and enjoyable time. The phenomenon has been extensively modeled in the context of rail, e.g., [16] and other public transport. For driverless vehicles, however, there exists a subtle interaction between the traveler's experience and ability to realize the postulated traffic gains via more dynamic velocity and acceleration profiles [17]. The fact that the latter are responsible for motion sickness remains one of the most problematic issues for enabling driverless vehicles to become productive and enjoyable environments (the issue is less prevalent in rail due to different acceleration profiles).

Assumption 4) Distribution of activity duration at the destination allows enough time for vehicles to be parked and returned, or extensive sharing (vehicle, ride) are available and used

This assumption reflects the need for driverless vehicles to have sufficient time to travel to parking facilities and return on time when required. Alternatively, they would need to remain in local circulation, effectively inflating not only fuel consumption but also traffic, and thus road capacity requirements. Otherwise, there would need to be a sufficient pool of vehicles available to use, e.g., via sharing services, in order to avoid lengthy waiting times, affecting the generalized cost and thus service level. It is not clear from either Wiseman's paper or current knowledge how either of those objectives could be met in reality.

Assumption 5) Driverless vehicles do not emit air and light pollution

This assumption is made by Wiseman to achieve postulated air pollution gains, which in addition to CO_2, NO_x, and particulate emissions need to also include noise and light pollution [18]. While there is an ongoing progress towards cleaner vehicles, especially those using sustainably generated electricity, the issues of charging or storing electricity and associated infrastructure requirements (charging, transmission, distribution) are not trivial.

With respect to the environmental impact of transport and the resulting health impacts, Wiseman focused on exhaust emission control but such benefits should be expected by both manned and unmanned vehicles. Wiseman could have argued that autonomous vehicles could enable steady travel speeds that can reduce emissions. Again, this requires non-congested roads in order to prevent vehicles from accelerating and decelerating; however, as explained in Assumptions 2 and 4, traffic capacity is expected to be an issue. Evidence of air pollution produced by trains was not provided in the article and thus, comparison could not be made. Furthermore, there is progress in terms of reduction in noise and light (from headlights and street lamps at night; however, there is still a way to achieve "silent and dark" vehicles, which would be necessary to limit nuisance to adjacent areas (assuming no need for unwelcome physical barriers and separation). The light aspect is especially difficult as today's technologies enabling driverless vehicles' operation often rely on visible light, e.g., cameras, computer vision [19].

Assumption 6) Driverless cars improve health and safety

The key safety benefit of driverless cars is that accidents related to the presence of the human driver will potentially be prevented from occurring as drivers who are not fit to drive, e.g., those who have consumed alcohol [20] or are fatigued [21], will not have to drive. However, this argument was not presented by Wiseman. Furthermore, as explained in Assumption 1, mixed traffic could be expected and thus, autonomous cars will essentially interact with other types of road space users including cyclists and pedestrians [22]. Until conclusively proven otherwise, the potential of a collision between autonomous cars and cyclists or pedestrians should be part of the discussions of the future application of driverless cars.

Finally, it was assumed that the autonomous systems will not fail in that they will continuously operate as designed. It is worth mentioning that autonomous systems rely on the capabilities of technological advancements [23], e.g., sensors will operate in all weather conditions. Technology-related failures are inevitable [24], and their contribution to potential safety issues should not be ignored.

Furthermore, the selection of safety data in the article is, at most, circumstantial. Only data from the U.S. were used and presented in absolute numbers, without taking into account travel distance and travel time by each mode of transport. As a result, cities that possess a railway system that is of vital importance to their transport networks, e.g., European and Asian cities, were ignored, leading to incomplete data selection and subsequently, inconclusive arguments.

As outlined above, there is progress in terms of enabling presence and benefits from driverless vehicles as part of transport systems. However, there remain a number of fundamental issues that, from the point of view of transport systems' planning and operation, make Wiseman's vision not a credible scenario for the near future.

Lack of Evidence to Justify Projections

Wiseman claims that the first autonomous vehicle will be available in June 2018. Almost a year after that day, only those in the experimental phase exist. The term *autonomous vehicles* used in the article can be described as misleading as it can be assumed that the author refers to fully autonomous vehicles due to the repeated use of the term "driverless cars," indicating that a human being present in the vehicle does not control the trajectory of the vehicle. According to the Department for Transport in the U.K. [2], fully autonomous vehicles refer to vehicles where a driver does not need to be present, while driver assistance systems refer to vehicles where the driver should be engaged or in the loop at all times. Consequently, it was unclear in the article as to what concepts or business models will be used for fully autonomous vehicles in urban systems. It was also implicitly assumed that these vehicles will be used to transport small numbers of people, similar to the way conventional human driven cars are used.

A Bold Vision Based on Some Crude Assumptions

Wiseman in his paper presents a very bold vision of the future of driverless cars, making rather controversial recommendations concerning transport policies in relation to rail. As with any futuristic vision, however, his approach is based on a number of assumptions. The explicit assumptions are rather crude, based on extrapolations of limited pieces of evidence or their incomplete interpretation. There are also a number of implicit assumptions, some of which we have spelled out and reflected on with our existing knowledge in transport systems operations. Based on this approach, we do not see a credible basis for accepting Wiseman's recommendations. We see the need for continuing efforts towards understanding how driverless vehicles, with their expected capabilities, can complement the broader socio-economic role of dynamic transport systems. We make this recommendation, bearing in mind that even driverless vehicles themselves can be subject to competition from other, also futuristic modes, e.g., autonomous passenger air vehicles (e.g., proposed by Boeing and Airbus), air-resistance-free transport (e.g., Hyperloop), or improved participation in services via digital means (e.g., virtual or augmented reality). In conclusion, we argue that an evolutionary approach to planning and management of transport systems is needed. Such an approach should explore emerging technologies and their application to transport, while leveraging extensive existing knowledge about travel behavior, safety, and environments, and of the socio-economic role of transport.

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Understanding the Full Range of Contextual Factors

Wiseman in his paper presents a vision that can be summarized with the following two sentences: "In the age of driverless cars, a means of transportation that takes many people from one central station to another central station has lost the justification for its existence," and "Driverless cars will gradually take control of the transportation market, and as more and more driverless cars are on the roads, trains will slowly but surely fade away from our lives."

In our opinion, these statements are extrapolated from a few factors and do not represent the direction that the mobility domain has been taking in recent years. His position is taken without fully understanding the full range of contextual factors, and social and environmental variables.

Coordination for Mobility as a Service is a mandatory requirement today to maintain a certain level of city sustainability (i.e., lower CO_2 emissions, more citizen participation and satisfaction, etc.). MaaS can be implemented on a spectrum, ranging from independent human or robotic agents interacting with users through market exchanges, to hybrid ensembles of hierarchies that lend themselves to mass transit, to fixed, military-style hierarchical control systems. Our opinion is that instead of implementing selfish mobility, there is a need to realize a collective and cooperative mobility where each MaaS provider sees in each single competitors a partner and not an adversary.

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