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- A differentiated approach to the dream of automated driving -

To automate individual traffic is a major goal. In this context, many also think of central control – that, however, is a contradiction in itself. First, we need to rename, or at least to differentiate such traffic: into individual traffic proper on the one hand and transport traffic on the other hand. While it will be possible to automate transport traffic with intelligent coordination mechanisms – a fertile field for the application of game theory –, in the context of individual traffic, fundamental questions of the freedom of movement in our society arise. An essential restriction on automation must be that across-the-board central coordination of traffic *cannot* be a desirable goal in a free society. Or conversely: Any automation of road traffic will always have to be coordinated with the presence of individually controlled vehicles for whose drivers 'the journey is the destination'.

Already today, our roads are populated by two sorts of traffic participants with entirely different motivations:

On the one hand, we have those whose aim is exclusively to move themselves or goods or passengers from A to B. They don't care about the journey, the driver would rather ignore the trip as such, all that matters is getting there. This category without question comprises all **commercial traffic**, including heavy goods traffic, busses, taxis, and typically also their passengers.

On the other hand, however, there will always be traffic participants whose destination is not even quite determined yet when they set off – indeed, their destination may ultimately not be a 'place B' but the aim is rather just to enjoy their freedom of movement by means of a vehicle, e.g. checking out one's surroundings or going on a mystery tour. Hildegard Wortmann, head of brand communication with BWM, said in an interview about future mobility (Süddeutsche Zeitung online, January 1, 2018): "I want to decide during my trip when it's time to put my feet up and relax, and when I feel like actively conquering the road." This quote already reveals a major dilemma of the brand BMW, which until recently was totally committed to delivering 'driving pleasure' but now – driven (excuse the pun) by Tesla and wholly in line with the industry trend – suddenly subscribes to automated driving. However, there is more yet to the differentiation between pure transport traffic and **individual traffic** proper: It is about the ability to decide while on a trip to Italy, having crossed the Alps, to make a *spontaneous stop* and enjoy a cappuccino.

Please note that here we use a somewhat more nuanced definition of the familiar concept 'individual traffic'. Thus far, the term referred to *vehicles whose drivers can freely choose their destination*, e.g. cars as opposed to busses or rail traffic. In the future, however, we will have to get used to cars whose destination was selected at the start of the trip and which then operate fully automatically until they reach that destination. Does that then also count as individual traffic? We think that in times of fully automated cars, this concept will require a more fine-

grained definition, specifically in terms of vehicles whose occupants can *correct or re-select their destination at any time*. Can you see the difference?

Before going into more detail regarding the discussion about the meaningful organisation of autonomous driving for transport traffic and individual traffic, we would like to distinguish, also on the implementation side, two areas that are being discussed in the context of automating road traffic:

On the one hand, we have the **local automation** of individual vehicles, which manifests itself in ever more advanced driver assistance systems. This development already began decades ago with cruise control, really became elegant in the form of automatic distance control on motorways and is currently taking place in the field of lane-keeping assist and fully automatic parking across the distance of entire car park levels. Essentially anything may be envisaged, up to the complete self-regulation of driving by means of the vehicle's sensors and intelligent control. An essential contribution to the feasibility of this self-regulation provide certain since already twenty years available electronic stability control systems - which enjoyed its market breakthrough in the Mercedes A-class model thanks to the car famously capsizing during a moose test in 1997. The author was in his early thirties when, despite woefully undersized wheels, he had a ball taking one of the first rental A-class cars ploughing through the snow slush – some much at this point for the passion for driving, which will likely be denied to subsequent generations. This incidental remark is primarily intended to prevent the discussion below on the meaningfulness of fully automated driving from being understood as misguided scepticism of technological innovation per se. Our aim is rather the differentiated anticipation of the effects on society and on the individual freedom of movement – which in a certain sense already amounts to the application of game theory.

As part of the local automation of vehicles we will also consider the variant in which the car independently finds its way from A to B – as has long been the case with navigation systems. The increasing interconnection of the vehicle with other vehicles or with fixed infrastructure elements (traffic lights, etc.) will permit continued improvements to dynamic routing of the type we are already familiar with in the context of processing congestion data. The website of the German Association of the Automotive Industry, www.vda.de, lists numerous future technologies that appear viable today – and all of those we still count among local automation, so long as they 'only' concern very powerful ways of generating input for the local driver (where it actually makes little difference whether that 'driver' is an actual person or a program). The local automation of driving is ultimately characterised by the fact that the choice of the destination or of the next (intermediate) stop can be altered at any time by the driver's intervention – as required in the definition of individual traffic 'proper' we stated above. The program merely immediately optimises the route again given the new set of conditions.

A much more far-reaching scenario is the idea that vehicles might report their position and destination to a central **entity of coordination** and that they are then allocated the prescribed route in a sense as a 'travel slot'. The questions as to who is to control this entity and what mechanisms it is to apply will provide splendid opportunities for discussion. It immediately comes to mind that such a procedure could yield huge efficiency gains in terms of avoiding congestion

and the time wasted on finding a parking space. On second thoughts, however, we already see problems of allocation looming, which will necessitate a multitude of game-theoretic equilibrium solutions – as well as a delicate discussion about the allocation, price, bindingness and flexibility of slots for travel and parking, which the vehicle or its passenger is expected to actually use once they have made a reservation with the coordination system. The cappuccino beyond the alps then becomes distinctly more expensive – in terms of money or at least in the currency of *time* – if this means that the slot for driving to Italy must be postponed or booked anew.

Thus, for example, the problem of avoiding congestion in dense traffic constitutes a classic prisoners' dilemma, as already described in Section 4.1 of my book 'Game Theory Bargaining and Auction Strategies' (Palgrave Macmillan, 2015). Programs that optimise purely locally and are free of any influence of the human driver and his mind are all the more subject to this very dilemma. To avoid the dilemma, i.e. in this case to avoid a traffic jam, requires that all vehicles *firmly* abide by the coordinating entity, approaching the critical area more slowly or even bypassing it.

The issue of prioritisation in the case of a higher willingness to pay – who is required to bypass the area prone to congestion, and who gets to still use the shorter route? – may remind us of net neutrality, which is currently the subject of discussion in the context of data traffic via the web. Exactly the same discussion will be in order with respect to road traffic. However, if we think of the political debate about the introduction of a motorway toll in Germany, which seems trivial by comparison, concerns about the implementability of such ideas arise. It will be all the more important to choose the rules that underlie any automation and coordination – certainly not least new 'traffic rules' and laws – with care and especially with due regard to their efficiency and allocation effects. This in turn is the domain of mechanism design theory and game theory.

Local automation will improve efficiency *and* safety – at some point

A ubiquitous discussion concerns the fallibility of the human driver versus the reliability of automated control. At some point, it will probably indeed be possible to significantly reduce the number of traffic casualties by eliminating the human factor in traffic control or by at least reducing the influence of human error to a minimum by giving maximum scope to driver assistance systems. And yet the question about the driver's responsibility in case of an unavoidable accident – such as the famous trade-off between hitting the child or the grandmother, which creates interesting legal issues – arises exactly if the driver's attention is required only occasionally to choose the route while control over the vehicle itself has already been handed over entirely to the program – as we will assume here in the scenario 'local automation'. Besides pointing out the legal issue of responsibility and liability, which in our opinion so far completely lacks a satisfactory solution, we daresay that for the foreseeable future, the improvement in traffic safety thanks to full (local) automation can only be achieved at the expense of reduced efficiency.

For even with full automation of all vehicles, in the chaotic system that is road traffic, there will always be an individual equilibrium point for each vehicle in the trade-off between its speed and the risk of unforeseen events. And to surrender precisely this risk assessment to a program means to interpret the assessment strongly in favour of increased safety, i.e. reduced speed.

This is not to say that it might not be possible at some point to implement fully automated road traffic that runs at least as efficiently and at the same time more safely than what we have today. We just mean to remark that such a situation is likely much further off than appears to be commonly assumed – just think of roads that are slippery with rain or even snow and ice. Incidentally, without electronic stability control, automation would not stand even the slightest chance.

Furthermore, even with full automation there will always have to be overtaking: Due to different technical features, differences in loading and, indeed, differing interpretations of the risk assessment we mentioned – be it on the part of the driver or the manufacturer – different speeds will be selected. And this has nothing yet to do with the considerations of freedom we will hint at below, but simply with the efficiency of the dynamic system 'road traffic', which would collapse if the speeds of all vehicles were brought into line with the slowest one. This is why overtaking must occur even in a world of automated driving, and so we are back in the world of individual risk assessment, which is then, however, delegated to programs. It is no accident that calls have long been heard for the local automation of vehicles to be equipped with 'artificial intelligence'. Whether that AI will have to be of the *strong* type, i.e. whether it must feature true creativity and the ability to innovate, is a matter for a different discussion. If *weak* AI should suffice, it will have to be very powerful indeed, comprising for example neural networks capable of autonomous learning, and this program will then relieve the driver not only of the task of *quantifying* the risks but also of *evaluating* them in the sense of a trade-off. The program – however artificially intelligent it may be – *assumes the risk on behalf of the passenger*. Just to be aware of these considerations is what we would like to recommend to anyone who takes part in the discussion or dreams of automated driving. In a conceivable scenario, the risk preferences and thus ultimately the actual speed of the vehicle continue to be controlled by the occupant, within boundaries set both by external speed limits (e.g. by traffic rules or by some sort of binding coordination mechanism) and by what the car's program currently proposes as a safe speed (based on its assessment of local risks).

There is no question that even only local automation, i.e. the mere maximisation of all conceivable assistance systems up to the situation where the driver's only remaining task is to choose the route, will tend to first make road traffic either safer or more efficient, and at some point also more efficient *and* safer. This of course applies both to pure transport traffic and to individual traffic proper.

Central coordination of individual traffic would raise fundamental questions of freedom of movement and data protection

For many people, all they ask of their car is to take them from A to B without having to bother with the details of the ride. In times when our attention is constantly absorbed by our smartphones, autonomous driving would without doubt significantly improve traffic safety for many drivers. If we systematically develop this scenario further, we would even have to question the necessity for people to have their own car and driver's license. According to our classification from above, such traffic participants are in a sense already by definition no longer part of individual traffic proper; instead, they are typical users of public transport that offers the service of taking passengers from A to B.

We cannot speculate at this point as to what the share of individual traffic proper in the sense of our definition will still be in 10, 20 or 30 years. In all likelihood, its percentage of all traffic will be small – even weekend trips, vacation trips and purely private trips to the gym or to see friends or family can for the most part be organised as centrally coordinated traffic – that is, if we try to imagine that the central coordination does work well. However, in our opinion, the current discussion generally underestimates the demand for true freedom of movement with spur-of-the-moment decisions during the trip – and that underestimation likely also applies to many of today's consumers themselves. Here's what the scenario with full central coordination would realistically look like: You'll be sitting in a tin can, like a taxi without a driver, and any spontaneous stop or change of plan – perhaps because you suddenly need to relieve yourself or remember you left your wallet at home – will pose great difficulty to the central coordination mechanism. The decision to go to a different restaurant after all will be subject to the availability of a 'travel slot'. All of this is well familiar to us from today's public transport – which is exactly why already today, public transport isn't individual traffic.

At first glance, one might lump the passenger's changing his (intermediate) destination in with other unforeseen events such as congestion, weather-related obstacles or animals on the road. This would in a sense in fact apply to purely local automated control of the vehicle. However, in the case of coordination across several or indeed all vehicles, we are looking at the *internalisation* specifically of the destinations of all vehicles concerned. This means that the continued free choice of a destination stands in outright contradiction to (binding) coordination with all its potential efficiency benefits.

If we however assume that in true individual traffic, drivers will continue to demand the possibility to flexibly change their destination at any time and will ultimately refuse to have any data about themselves or their whereabouts sent to some central entity, it follows that *local* automation is the highest degree of automation that is viable for truly individual traffic. Whether the realisation of our free lifestyle even requires individual traffic at all is a question that will, in the future, too, likely be answered differently with respect to cities as opposed to rural areas.

The coordination of pure transport traffic will reduce gridlocks

Transport traffic virtually defines itself by the sole and stable goal of getting from A to B, which makes it naturally suited for (central) coordination to reap efficiency gains. Though it does happen occasionally that passengers in transport traffic need to get off urgently, this scenario rather constitutes an exception, and some solution can always be found. Trains have toilets for such occasions – and it may be necessary to consider miniature toilets in centrally coordinated cars as well. Most times, however, the passenger in transport traffic may be expected to keep quiet until he arrives at the agreed destination – he'll be busy with his smartphone all the time anyway.

Speaking of trains: As far as the reliability and punctuality of vehicles controlled by a central mechanism are concerned, we would like to point out that a traffic system has already been in existence for generations which with its tracks ideally lends itself to the automated movement of its vehicles – and which with its timetables is subject to maximum central coordination. Yet train

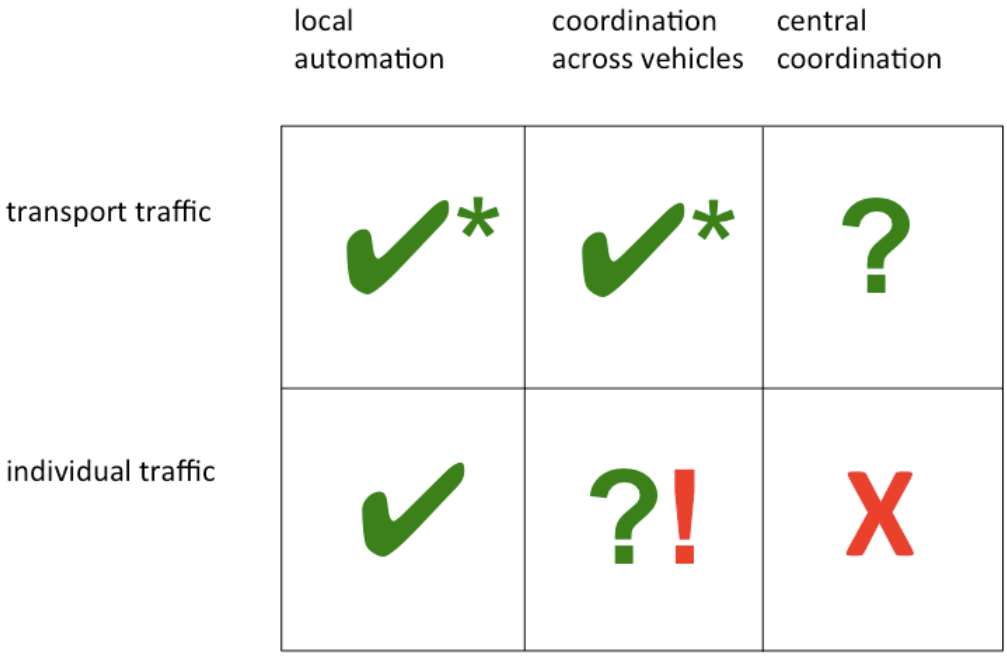
operators around the world share the phenomena that trains run late and that, with very few exceptions, human conductors are still required to deal with unusual situations and to bear responsibility in case of doubt. Perhaps we should first try to automate railway systems using modern communication, sensors and satellite positioning, and gain experience with central dynamic control in that sphere before we seriously venture to introduce such technologies to road traffic. By the way, subway trains have been running fully automatically for years in many cities, where the fact that they mostly operate underground with little interference certainly helps.

It is not just for the concern about jobs lost but for quite another reason that we would also like to question the scenario of entirely driverless transport vehicles: Realistically imagine being not the occupant of such a vehicle but being on the outside, encountering it. You might just be passing by, or you might be living across the street from where the vehicle is fully automatically looking for a place to stop to make a delivery. Unloading can be done by a robot, that is not the issue. But whom do you speak to if the vehicle is roaming about, if it has run into something or someone, if there is something wrong with it – in other words, if you need to contact whoever is responsible for the vehicle. Sure, the vehicle may have an intercom that will connect you to the operator's call centre, but – no offence – that's just naïve. We believe that here, too, not only are the legal questions in the context of driverless vehicles in road traffic entirely unresolved as yet, but that furthermore, we will have to come to terms with important issues of the freedom of movement – in this case, the freedom of the environment in which the fully automated vehicle operates. It is not for nothing that railroad tracks are strictly off limits, even though the trains do not even run fully automatically yet. Incidentally, similar and yet in detail quite different questions apply to the much-discussed 'delivery drone' – seeing that it will soon be off in the air again, where it is not bound to a one-dimensional road network and where it does not get in the way of the people on the ground – so long as there are not too many drones around.

But let us return to the automated coordination of road traffic. In reality, it will not be possible to implement such coordination overnight through some central entity; instead, it will develop as an evolutionary process from bilateral and multilateral cooperation across vehicles. For more than a hundred years, the use of indicators in conventional vehicles has been part of a coordination effort across individual vehicles that goes beyond the pure generation of input for local control: He who is about to turn actively provides a signal to facilitate traffic coordination. Other traffic participants rely on the indicating driver actually making the turn – and therefore so he should. And yet the traffic rules do not force vehicles to turn after use of the indicators – in case of doubt, a vehicle that fails to indicate correctly does not forfeit its right of way. Thus, this noncommittal type of coordination does not entail a temporary 'loss of freedom' for him who indicates – he may cancel the intended turn at any time. Here the legislator has consistently followed the philosophy of *local* control. It becomes evident, however, that automated control will work better the more firmly the signals sent by other partners in coordination can be interpreted. Similarly to the above discussion on the prisoners' dilemma in avoiding congestion, the situation of two cars approaching head-on can also be modelled as a standard of game theory: the 'chicken game'. Whether every turn and every encounter at a crossroads already constitutes a chicken game and what that implies for the use of the indicator is the beginning of an imminent game-theoretic discussion which is, however, beyond the scope of this Market Commentary.

The recent talk about vehicle-to-vehicle (V2V) communication concerns cross-vehicle coordination that we would place somewhere between what we have referred to as *local* automation on the one hand and *central* coordination on the other hand. The term 'local' becomes relative: The question is how far the driver's commitment to actually make the turn he indicated will / should / must carry. To develop the coordination mechanisms from the so far only local level into central coordination, to discuss and to establish them, taking account of the differentiation into transport and individual traffic: that is the foremost challenge of the automation of road traffic.

Suitable degree of automation in each traffic category



* *with a responsible person on board*

By way of summary, we would like to reiterate our core statements that there is ample scope for optimising pure transport traffic by means of (possibly central) coordination, which will however require solutions to the economic challenges of finding mechanisms to allocate travel and parking slots. Irrespective of their coordination, vehicles will be fully automated locally, imitating from the perspective of an outside observer the behaviour of a conventional driver – improvements in safety and reliability are to be expected. For reasons of law and indeed of social philosophy – after all, this is about how people encounter each other in the streets – full

automation will likely require declaring the routes intended for automated traffic off limits to pedestrians, as is already the case today on motorways and in some car parks.

Finally, there will always be a coexistence of the (partially centrally) coordinated transport traffic and some remaining individual traffic proper, with the latter comprising all degrees of automation down to the conventional driver. And this is not just a transition phase but indeed the target scenario in a society that continues to value its freedom of movement as afforded by individual traffic – if only to take the convertible for a ride across the alps for a cappuccino in Italy.

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