TomTom

Mapping the Road to Autonomous Driving

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List of MAIN speakers	Company	Job title
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Thank you

Willem Strijbosch
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I still remember very vividly the first time I stepped into an autonomous vehicle. The engineer opened the door and said, ‘You go sit behind the steering wheel’. So I sat there and he instructed me to drive to a highway stretch and he said, ‘Now you press these two buttons and you can let go of the steering wheel’. And that's when the magic happened. That's when I knew this was going to be something, right?

Mapping the road to autonomous driving Slide #1

This was fantastic. Within minutes I was talking very excited to the engineer in the back who urged me to look to the front of the car again, because it wasn't that safe yet that I could be talking to him all the time.

So autonomous driving is, you know, if you've experienced it, you know it’s going to be huge, right? The benefits of it are just enormous. So I'll talk a bit about autonomous driving today. Then I’ll ask one of our partners Erik Coelingh from Zenuity to come on stage to explain some of the elements that we don't make and then I dive a bit deeper in what the role of maps is. How we make those maps, and I guess you're dying to hear what the market size is of this opportunity. So I'll dive into that as well. So a few months actually, after that experience in that vehicle, I was leading the autonomous driving unit of TomTom.

AUTONOMOUS DRIVING IS HAPPENING Slide #2

Autonomous driving: It is happening. The societal benefits are so big; the investments are so big; so huge. It is happening. The safety advantages are enormous, right? Every day 3,000 people dying across the world and a multitude of that are getting injured because of vehicle accidents. It gives us comfort, right? If we have truly autonomous vehicles, we can actually look at our smartphone. We can work in a car. We can sleep. So it gives us back time that we're losing out on now in our commute or on holiday, right? Wouldn't it be great if you sort of step into your vehicle, you drive it to the highway, you press the activate function. You drive to the South of France and you turn around your chair and play games with your kids. So that's the comfort part. And the efficiency part: It will change our cities. It will get to lower fuel consumption. All of that stuff. So it’s happening.

The pillars of autonomous driving Slide #3

What do you need for it? Well, you need four things to make it happen. First one is mapping.

IMAGE Slide #4

No surprise there. It's a very important element, and the higher the automation level, the more important maps become. You also need sensing. So you need sensors like cameras and you need laser scanners, or lidars. You need radar to see what is around you and compare that to the map.

You need a driving policy. Meaning software that takes the decisions to go left or right or to overtake and you need actuators that actually replace your foot and your hands on the gas pedal and the brake and steering wheel.

TomTom maps for ADAS & AD Slide #5

So if we now dive a little deeper on maps. Which maps do we make for autonomous driving? Well, they've been mentioned today. We make the ADAS map and the HD map and I've plotted them here against the six levels of automation: level zero through to level five, where level zero is that a human controls everything in the car, but it can get warnings from sensors and maps like you're driving over the speed limit, to level five where you can tell by the symbol, where you don't need a steering wheel, where you don't need a gas or brake pedal, it's all gone. That's still a little while away. We're now in mass production at level two. A Tesla autopilot is an example, as is the Volvo system. They can all keep lane and adjust speed. So they do, in technical terms, lateral and longitudinal control. So that's the level two. The level one is typically an adaptive cruise control where you still have to hold the steering wheel.

Our ADAS map is used for the lower levels of automation: levels zero, one, two. And our HD map is used for level two, three, four, five. And you see that there is an overlap in level two because we actually see both. We saw both. We have level two systems on the road with an ADAS map. We have a level two systems coming up with an HD map in production vehicles.

To explain the difference very briefly. So ADAS map, it has been mentioned many times in the presentation, an ADAS map is a road level map. So if you have a five-lane highway, it's seen as one road. It will have a lane count. It will have one speed limit. It will have one curvature, one gradient or slope, whereas an HD map is a centimetre level accurate lane-level map.

So actually you know everything for each lane. If there is an exit lane, then that exit lane can have a separate speed limit. Like in Germany that happens. So road-level map for us is a centimetre-level, lane-level map.

The perception challenge for automated vehicles Slide #6

So what's the role of maps? There are three roles that maps play in the car: One is perception, which is shown here and I'll explain the picture. One is localization, and one is path planning.

So how does a map help a car understand the environment around it? Here's one example: Let's say this is a picture from a front-facing camera in a car and the car now has to decide, 'am I allowed to drive or not?' It sees this bunch of red lights and it has to make up its mind, right? How do you interpret this picture? Well a map will help the car determine this.

It will tell you in which lane are you today and are you now. If you're in that lane then it's that traffic light that applies. So it can tell the camera actually, 'look at that set of pixels because that's where you're going to find the traffic light that you need to read and applies to your particular position'. So it will tell you, 'actually, it is OK to drive'. It finds the green traffic lights.

The localization challenge for automated vehicles Slide #7

Localization is the second element, the second function of a HD map in a vehicle. So localization is needed because GPS, which is traditionally used to put yourself in a map is not precise enough. It's not good enough. You need more. So we add special localization attributes to the map. Things that a camera can see, or that a lidar can see. The radar can see. We add that to the map and that can be compared to sensor readings. And if you then do the math, you can find out in which lane you are, which is a kind of important. And once you know in which lane you are, you can also determine in which lanes the other vehicles are. That is not always trivial to determine, but quite important for decisions, right? If you're driving much faster than the vehicle next to you like what would happen in Germany and you're entering a curve, then it's quite hard to see whether the car ahead of you is in your lane or not, but with a map you can get a much greater certainty that you can continue speeding, and you can safely pass the vehicle that is driving slower. That's an example.

The path planning for automated vehicles Slide #8

The third element where an HD map comes in his path planning. Erik already mentioned some examples and a simple example is if you're on a five-lane highway or four-lane highway here, and it's, you know, a lot of traffic. Then you want to know kilometres ahead actually that you need to start merging into the lanes to the right. And that's where an HD map can help you do that type of path planning. It plots all the vehicles, or the system can plot all the vehicles around you on that map and it can see very far ahead; much further than the cameras can, because it knows in two kilometres you need to be on the exit lane.

How do we make HD maps? Slide #9

So that was how a map was used in a vehicle. I've spoken about autonomous driving and the pillars of autonomous driving and then the roll of HD maps. So how do we make those maps? Just, you know, very briefly. We mastered this, as you have heard Alain say. We can build on a very long experience and a very wide experience as well, right? We master all the technologies that are needed. So what does it take?

Centimeter-level accuracy + Millions of sources Slide #10

It takes centimetre-level accuracy. It takes ultimately millions of sources. So sources can be our own survey vehicles, or moma vehicles, mobile mapping vehicles as Alain was calling them. They can be Zenuity cameras. It can be other cameras. In the end it will add up to millions of sources that are all differently calibrated and are made by different vendors and create different types of data. So millions of sources.

Centimeter-level accuracy + Millions of sources + Real-time processing Slide #11

And we have to do that in real time, as fast as possible, because the faster we can reflect changes in reality, that in the car in a map, the safer the whole experience will be and the better the user experience will be in the end. So if we go into a couple of examples on each of these. So first, this: This is not a map. This is somewhere halfway through our production process, right? So we get a bunch of raw sensor data in. Then somewhere halfway we’re here and then we abstract this into a map. Now why is this special? If you look at this, you can see that you cannot get this from one drive. You cannot send out a survey vehicle or any other car and drive this in one go and have it all sort of fit. It takes many drives to do this. You can also see that there are no shadows in this. And if you have many drives, you need to combine them right? And that needs to be at centimetre-level accuracy. You can't have two lantern poles right next to each other where in reality there's only one. You can't have two traffic signs and all of that. So that's what we're able to do at scale.

And this is really leading edge, state-of-the-art application of technologies. This has been done scientifically on small areas, but never at the scale of the world, and we're doing it at the scale of the world. Centimetre-level accuracy.

IMAGE Slide #12

Then, there's millions of sources. Here's one example: In the top left. Yeah, it’s left for you guys as well. Top left, you see a video image from a car driving. In this particular case it is in Japan in the area where the Olympics will be held, Odaiba, and so you see a car driving there with a camera and it is registering information, much like Erik was also describing. It is registering road edges in purple. It is registering solid lines and dashed lines that are on the driveable surface in pink. And then below that video, you see how that is stored all the time and that creates a roadogram. That information if you combine all together, essentially creates a roadagram. And that's what we do with multiple partners, including Zenuity; to close that loop and get information about what’s changing, as quickly as possible. Millions of sources.

AutoStream Slide #13

And finally, there's the real time element of it. One part of being real-time is that you actually need to be able to stream maps to the vehicle and that's what we do with AutoStream. It's like Netflix or Spotify, but then safe for maps for autonomous vehicles. So here's what it does. We're planning a route. This all happens on the navigation map. We’re planning a route from Las Vegas to San Francisco, and that route is planned and is handed over to the autonomous driving system. And this takes you through the configuration. A driver in a car would not do this, but this is how you would configure what data is then streamed. Because bandwidth is a concern.

So obviously we want the road elements; we want traffic signs for localization. We call our localization products Road DNA. So the traffic signs were going to put in, Road DNA signs, so that they can be compared with the camera and we can localise. We are going to put speed restrictions in because we want to know that we're not autonomously driving over the speed limit. We’re going to put another localization attribute in that works particularly well with radar, which we call Road DNA roadside, which is that sort of Minecraft blocks next to the side of the road. And we're going to put in jam tail warnings; live data plus explicit curvature and gradient. An HD map is so precise that you can calculate any curvature you want, but sometimes OEMs want that to be explicit so they don't have to calculate it in the vehicle.

Now we're going to start and download only the relevant tiles that we need. So these are all the tiles between Las Vegas and San Francisco. And because the system is very smart and keeps a persistent cache, we can actually look for differences and only download where there have been changes, again, to save bandwidth and to gain speed. The less you have to download, the faster you can actually start driving which is happening here.

So we’ve developed this. It's called AutoStream. When we started, people said that's not possible, right? An HD map is much bigger than a navigation map and how on Earth can you stream that? And we can't be dependant for safety critical function on a cellular connection, but we managed to address all of those problems and created AutoStream which is going to be in a production vehicle next year. So that's AutoStream. So that's the centimetre-level accuracy. Millions of sources in real time.

Large opportunity, first in private vehicles, later in robotaxi Slide #14

So then we move to the final bit, I promised, which was euro numbers. How big is this market? What I'm showing here is multiple opportunities, so vertically you see private vehicle automation. That's the level two and three and a little bit of level four in the future for private vehicles. Vehicles that all of us who would buy.

Then there's robotaxi or shared vehicles automation, different market, different business models, partially different technologies, but very similar maps. And there's one example of ‘other’. There is actually a larger category called ‘other’, but this is one example: Asset management for government, right? If you have all this very detailed data, you can actually also add and find things like lantern polls in a map. You can find electricity cabinets; all that stuff. And that is of interest for municipalities and other governments.

And then you see 2020, 2025, 2030. If we look at private vehicle automation: In our own market model, we see that the market in 2020 is roughly 0.1 billion. This is what the model gives us. I’ll explain a bit about that in a minute. By 2025 and has grown 0.8 billion. And by 2030 it has grown to 3 billion. So there's an enormous growth in the private vehicle automation market.

If we look at robotaxis. We think it looks like this: A similar size 0.1 billion in 2020. In 2025, not yet very big; 0.3 billion. A lot smaller than a private vehicle automation. And then it'll go in 2030 when all of those difficult technology nuts have been cracked and there has been time for scaling, it'll be around 5 billion. Government Asset Management, a smaller market; a few hundred million.

Everything we do, and it's important to understand that everything we project, is only based on private vehicle automation. That's what we focus on. That's the business where we are leading. That's where we want to win. And that's what's driving all of our decisions. Robotaxis will come, but it's upside in all of our projections. So if we go a little bit deeper into private vehicle automation.

Rising volumes in levels of automation Slide #15

Then this is part of our market model. So let me explain this to you. You see horizontally the years. On the left axis you see tens of millions, or 20 million, 40 million cars that have a particular function and on the right-hand side you see percentages with attach rate. So how many of these cars will have an AS map or on HD map? Those are the two lines. And then the colours in the graph, light blue, medium blue and dark blue are level zero and one, combined level two and three, combined level four and five combined.

And what you see is that there's already on the road next year more than 60 million vehicles with level zero and one functions, but often they don't use a map, right? The attach rate of maps is around 20% of AS map. As we see higher and higher automation coming in at a level two, three functions, we see also the attach rates of maps growing, with HD map growing faster than the AS map. And ultimately by 2030, we expect to see, or actually the analysts that we've based this model on expect to see a level four or five private vehicles again. So these are not the robotaxis, being meaningful as well. Being a meaningful percentage of the total amount of vehicles. And you basically also see that nearly all vehicles will have some form of automation, because we sell in the world about 100 million cars a year. That will grow a bit.

So that has gone in to those market estimates that I just gave; 0.8 billion in 2025 for private vehicles is based on these take rates and these volumes.

Now what does that mean if we split it out? This is the ADAS map market. So you see again, same time scale. You see the total market value and you see that by 2030 this is around half a billion. So you see all the way on the right-hand side. Not all of that is addressable. Part of it is in China, which we can't address, and that's the dark red part. And this grows about 20% per year, we expect in ADAS map market value.

If we do the same for HD map it looks like this: We actually see it starting from a small base. We see a 60% growth over the next decade, at 60% CAGR over the next decade with a very large part, nearly 2 billion by 2030 addressable for us.

This is what we work for every day. And this is what we try to capture as much of as possible. So where do we stand today? The numbers have been mentioned before today.

Competitive advantage Slide #16

If you look at what got us here, it is our competitive advantage. We have experience with dealing with automotive customers, customer experience, customer intimacy through our automotive sales force. Everything that Antoine is doing through our cumulative domain knowledge. Our global presence. We are everywhere in both mapmaking as well as in sales. And if we're not there, we travel.

Our independence: the Switzerland of maps, as Harold said in his introduction. That's one element of our competitive advantage in this space. Then we have leading technology. A lot has been said about that as well. Our transactional mapmaking applies equally well to our ADAS map and our HD map, that's delivering shorter cycle times. And, we build up a lot of technology over the years in artificial intelligence, computer vision, and what have you. That's also, all in all, giving us a leading technology position.

And finally, we have a very complete, the most complete product portfolio in this space. You've seen Cees talk about integration with navigation. We have the SD map. You need an SD map to be able to make an ADAS map. An ADAS map is a road-level map and we attach attributes to that. You need an SD map. If you don't have that, you can't play. We have AutoStream, I mentioned that. We have services, they have been mentioned.

And we actually can help to integrate all of those products into the vehicle, by working with partners where we do pre-integration. We have our own integration services. So all this together gives us a very strong competitive position. Nobody has the same sets. We are better than HERE in many of these things and we're better than Google in many of these things.

TomTom ADAS Map Slide #17

And that is translating into market share. More than 1 million vehicles, level one and two, mostly level two actually, on the road today as we speak, powered by our ADAS map.

We're learning from that every day. We get feedback from the free OEMs. They tell us what they like about the map and what they would like to be improved. And we work with that and we bring that in.

TOMTOM LEADS IN HD MAPS Slide #18

In HD map we are the current leader, we are the market share leader, the market leader also in technology.

IMAGE Slide #19

This is expressed as a market share of 60% out of all rewarded deals. Between, call it a year ago, 18 months ago and two years from now, every single OEM will have made their HD map selection decision. At the point in time where we are now, we are at 60% market share based on awarded deals.

That doesn't come out of nothing. It comes out of our competitive advantage that I just described and out of working with all of these OEMs for a long time. Erik also mentioned how long we've already been working with Zenuity, even before Zenuity existed. We've been working with four of the top five global OEMs when they were developing their test vehicles and there R&D vehicles. We gave them map samples. That has translated, for some of them, into wins.

We're the only company with a self-driving stack, the cars outside. We test our own map. We eat our own dog food, as they like to say on the West Coast. And we have many firsts in HD mapping. We were the first to file patterns in 2009, the first to provide samples in 2013, the first to provide a country in 2015 and the first to cover the highways of the world. At least where those vehicles will drive in 2017.

Thank you Slide #20

Yeah, so with that, I would like to thank you for your attention and I think it's time for questions now.