Patience
CONSULTING
Perception for Movement Automation

Company Profile

Patience Consulting Background

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"Our mission is to empower our customers realize the best solutions for perception and movement automation"

We provide customized technical, business and operational consulting services in the area of perception, sensing, optics and LiDAR

- Market analysis
- Technology evaluation
- Strategy development
- Manufacturing partnerships

Patience Consulting is led by Sabbir Rangwala

- 30 years experience in optics with innovations in telecom, automotive and sensing
- Led automotive LiDAR business at Princeton Lightwave
  - *Successful exit with sale to Argo.ai for $52M in October 2017*
- Leadership positions in product development, operations, marketing, sales and business management in large and small companies
- Rich personal network across automotive, technology, optics, LiDAR communities

Recent Events

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1. **Waymo powering ahead with > 10M AV miles to date**
2. **GM is also progressing and is the leading OEM in AV efforts**
   - OEMs clearly feel cost pressure developing AV technology
   - Pushing external investments and partners – Softbank and Honda invest $5B
3. **Ford is also looking for external investors for AVs – still far behind**
4. **Uber planning IPO at $120B valuation in 2019**
5. **AI companies pulling in significant funding – Helm, Deepscale, Aurora**
6. **Zoox and Nuro building own vehicles and partnerships**
7. **China active – Baidu-BMW, Alibaba, Pony.ai**
8. **US DOT issues guidance document for AV – hands-off approach**
9. **Safety in AVs increasingly important after Uber accident**
10. **LiDAR players looking to integrate more than raw sensor capability – fusion, perception, software, low power consumption, efficient computing**
11. **Recent large LiDAR fundings – Blackmore (BMW, TRI), Luminar (Volvo), Aeva, Robosense, Innovusion**
12. **Acceptance that LiDAR needs to move from Silicon Valley to automotive maturity – role of Tier 1s becoming increasingly significant**
    - Velodyne-Veoneer, Innoviz-Magna

Ecosystem for Driverless Car Based Transportation

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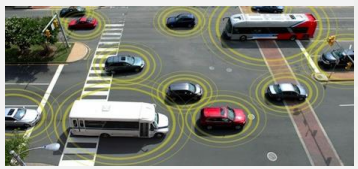
Sensors
- Radar
- Cameras
- Ultrasonic
- IMU
- LiDAR

Knowledge or Deep Learning Based Sensor Fusion

Perception Map
- Object ID
- Object location
- Object tracking
- Road markings
- Traffic signs



Driving decision making & control
- Localization
- Scene understanding
- Behavior prediction
- Obstacle avoidance
- Path planning
- Control

Perception
Multiple Players – Sensor Providers, Techs, OEMs

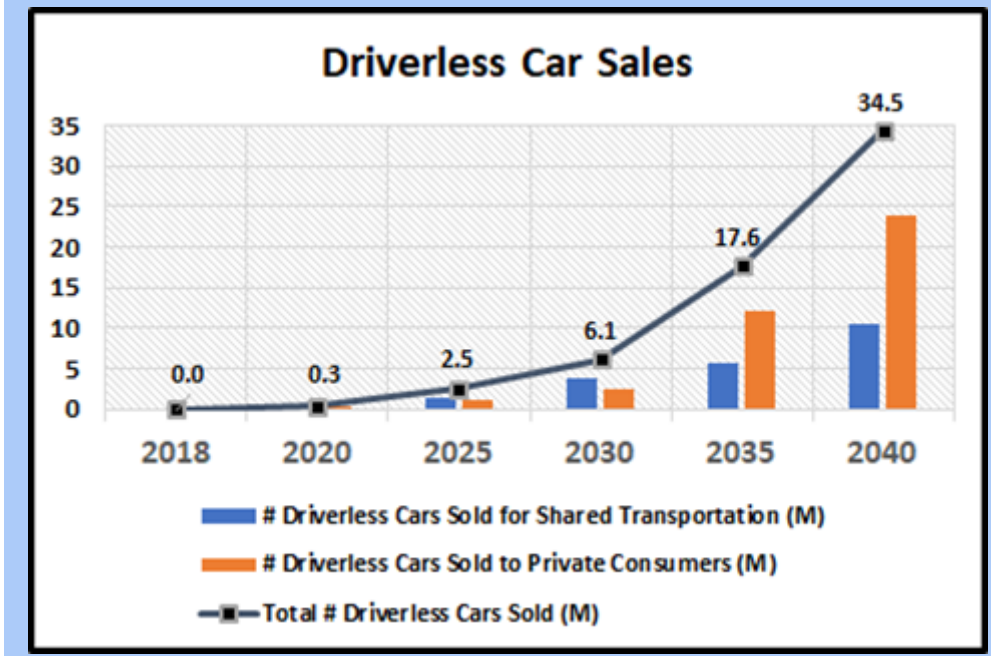
Driving Control
OEM/Tech. Focus

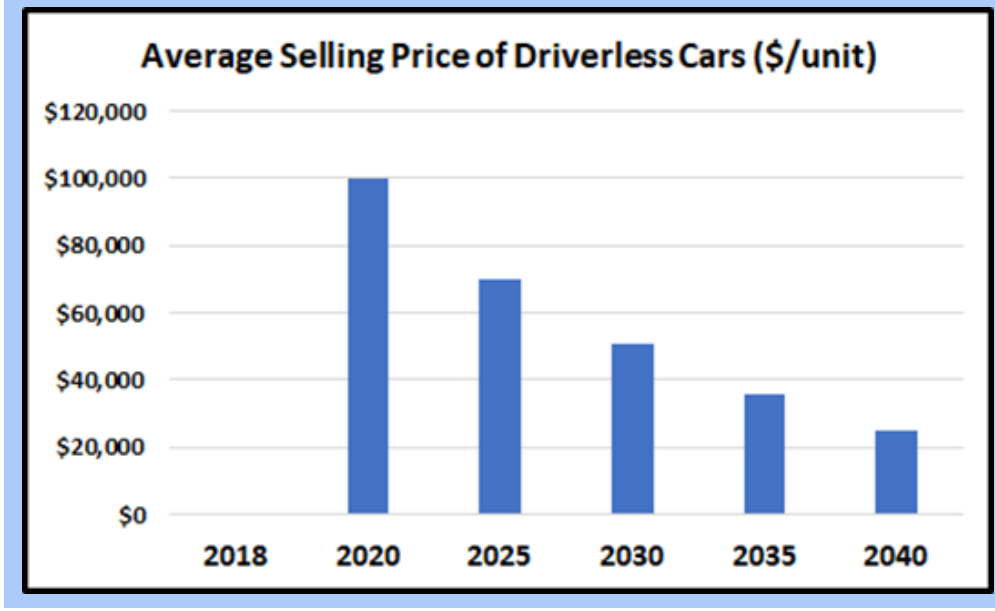
Consumer Car Sales	Manufacturing Driverless Cars	Fleet management services	On-demand shared transportation services
OEM	OEM	OEM/Rental Co.	OEM/Tech.

Shared Transportation and Driverless Cars

Market Size

1. **$1T recurring revenues in 2030 from shared transportation services ($30B today) [1]**
   - Ride sharing, fleet management, data monetization
   - Driverless cars enable attractive margins (15%)
2. **OEMs ideally placed to deliver & manage driverless fleets**
3. **6M driverless cars in 2030 in 100 global urban areas**
   - ASP $50K/car, 3 year replacement cycle
4. **Sales of driverless cars ramps from $30B (2020) to $175B (2030)**
5. **Shared transportation dominates until 2030**
6. **> 2030, economies of scale and lower ASP drives penetration into consumer market**





[1] Ref: Automotive revolution – perspective towards 2030 (McKinsey 2016), Rethinking Mobility (Goldman Sachs 2017)

Market Opportunity

Perception Systems

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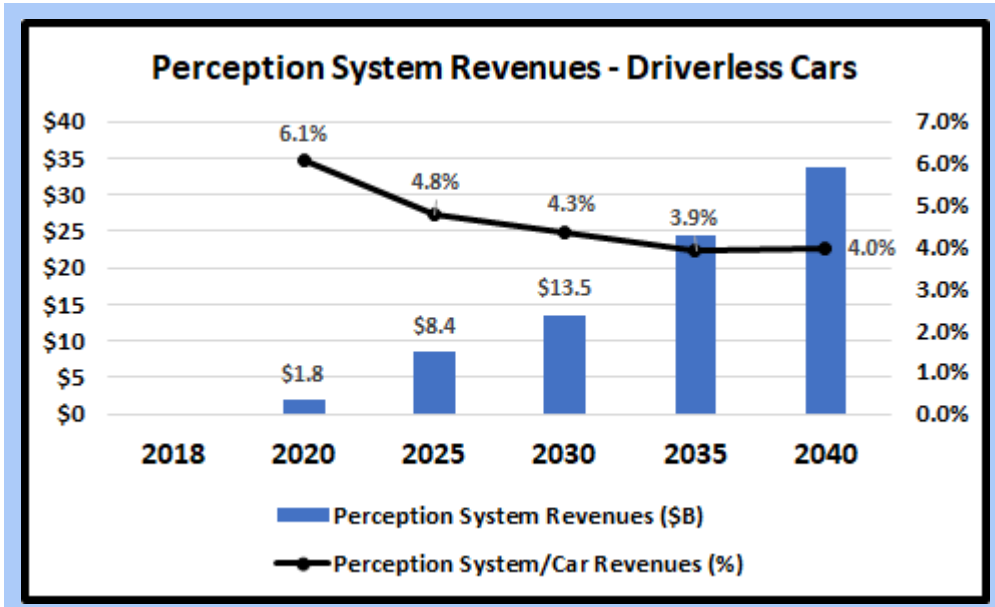
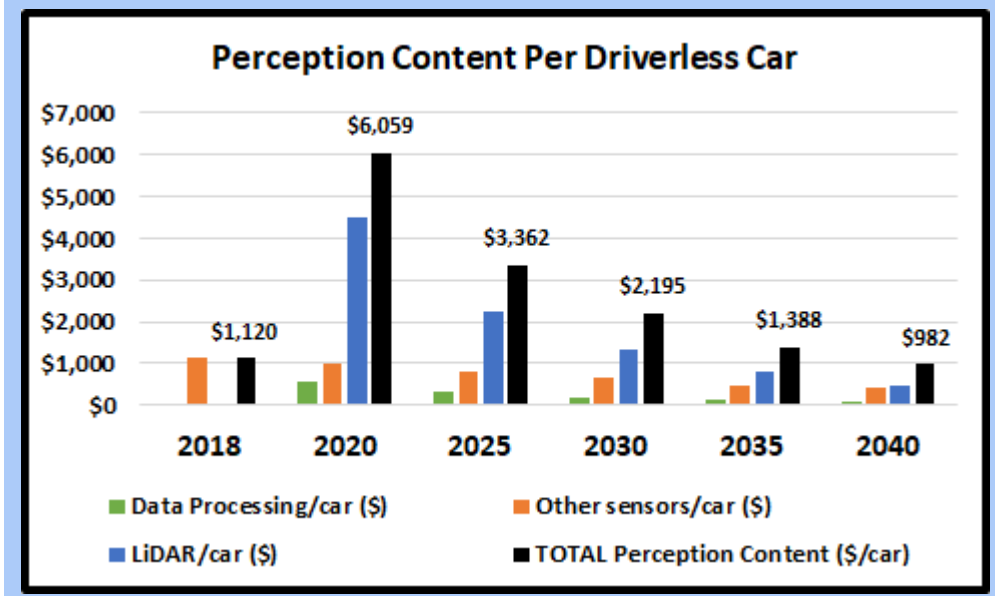
1. **Perception revenues at 5% of car revenues**
   - Reasonable considering the driverless function viewed as a high end option could demand 10% of car cost
2. **As driverless car ASP reduces, perception content/car reduces from $6K/car in 2020 to $3.4K by 2025**
3. **Perception revenues include sensor hardware and software**
   - Sensors include ultra-sonics, radar, and LiDAR
   - Costs based on [2], customer and supplier discussions
   - **Software revenues projected to approach 30% of total revenues[3], we assume 10% as conservative estimate**
4. **Revenues grow from $1.8B in 2020 to $8.4B in 2025, with LiDAR contributing about 70%**



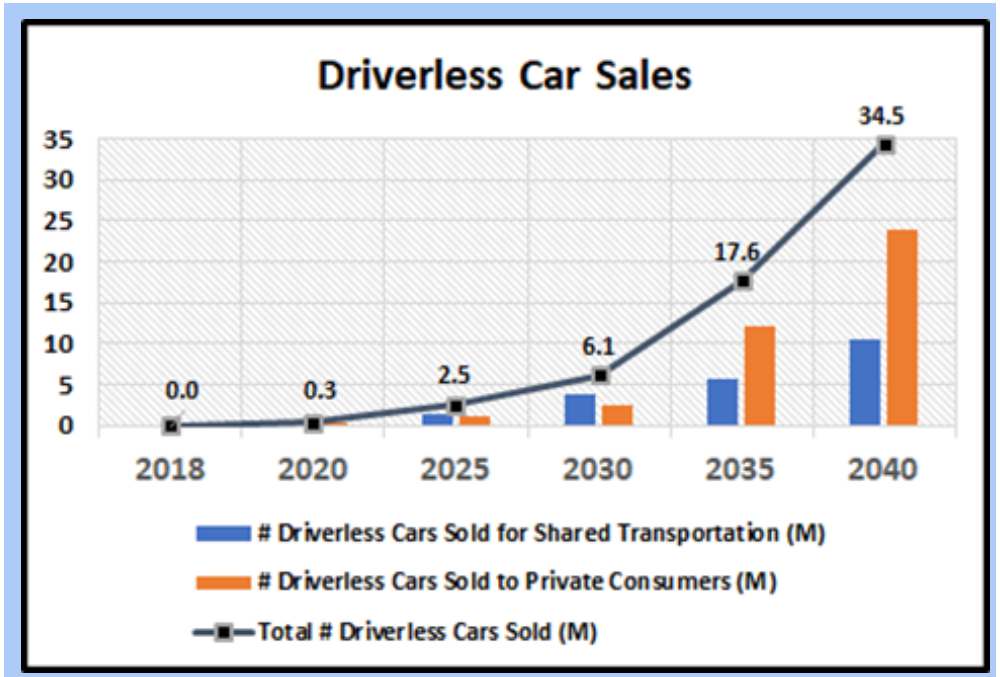


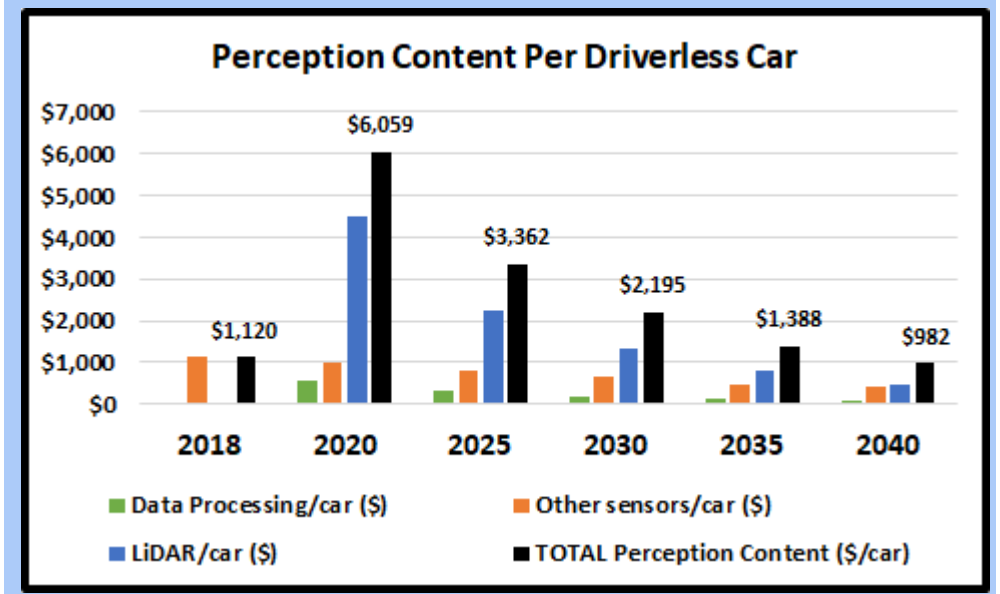
[2] Ref: Car of the Future 3.0 (Citibank, 2016)

[3] Ref: Rethinking Car Software and Electronics Architecture (McKinsey 2018)

Driverless Cars, Perception, LiDAR

Business Opportunity	2020 ($B)	2030 ($B)
Recurring Revenues from Shared Transportation Services[1]	35	1500
Driverless Car Sales[2]	30	300
Perception System Sales[2] [3]	2	13
LiDAR System Sales [4]	1.4	9





[1] Automotive revolution – perspective towards 2030 (McKinsey 2016), Rethinking Mobility (Goldman Sachs 2017)

[2] The Driverless Car Revolution Creates Massive Opportunities For Optics (April 2018, Sabbir Rangwala, Photonics Online

[3] Ref: Car of the Future 3.0 (Citibank, 2016), Rethinking Car Software and Electronics Architecture (McKinsey 2018)

[4] The Automotive LiDAR Market, Yole Consulting – WCP, April 2018

Automotive LiDAR Requirements & Suppliers

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Nominal and Ideal Requirements for stand-alone LiDAR (Level 4 and 5)

No.	Description	Nominal Requirements	Ideal Requirements
1	Eye Safety	Class 1 Eye Safe (IEC 60825 or ANSI Z136)	Same
2	Imaging Range (10% reflectivity)	150 m	300 m
3	Angular Resolution	2 mrad	1 mrad
4	Image Resolution	30 cm	Same
5	Range Accuracy	20 cm	10 cm
6	Horizontal Field of View	240°	360°
7	Vertical Field of View	+/- 10°	+20° to -10°
8	Range Imaging Rate	10 Hz	60 Hz
9	Velocity Imaging Rate	10 Hz	30 Hz

Classification of LiDAR suppliers by LiDAR type and wavelength

	8XX-9XX nm	15XX nm
ToF	❶ Velodyne, Innoviz, Leddartech, Ouster, Tetravue, Phantom, Infineon, Robosense, Valeo, Ibeo, Cepton, Hesai, Quanergy	❷ Aeye, Continental, Luminar, Argo, Waymo ?, Uber ?
FMCW	Not feasible	❸ Strobe, Aeva, Analog Photonics, Blackmore

ToF = Time of Flight

FMCW = Frequency Modulated Continuous Wave

1. **Over 50 LiDAR companies focused on automotive LiDAR today with different approaches**
2. **Requirements not standardized and vary across OEMs and technology companies**
3. **FMCW players (❸) guided by 2 main imperatives**
   - Implementing "chip scale" LiDAR with Si Photonics based scanning and integration
   - Providing fast velocity measurements
4. **FMCW at 8XX-9XX nm does not seem to be an approach at present**
   - Single mode coherent lasers with frequency control not developed
   - Si waveguides do not work optimally at these wavelengths – chip scale potential difficult

Predictions – 2020 to 2025 timeframe

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1. Number of LiDAR companies will reduce to < 10 (currently > 50)
2. Need for LiDAR will be dominated by ride sharing applications
3. Waymo and their LiDAR implementations likely to succeed for Waymo fleets
4. General Motors, Ford and Uber develop internal LiDAR solutions
5. ToF LiDAR most likely to be deployed in this time frame
6. FMCW implementations using opto-mechanical scanning will also be deployed
7. 9XX and 15XX nm wavelength solutions will be deployed
8. LiDAR and optics company collaborations with Tier 1 suppliers will mature

Predictions – > 2025 timeframe

1. Level 4 and 5 deployment will move towards private car sales
2. Volumes increase, price and styling become critical
3. Silicon photonics fabrication technology becomes automotive mature
4. Chip scale LiDAR feasible
5. 15XX nm wavelength solutions will rule; 9XX nm solutions will be limited
6. Successful LiDAR manufacturers will need to master optics and materials technologies, partners and suppliers

Disruptions to watch for

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1. **Frequency Modulated Continuous Wave (FMCW) LiDAR kicks in earlier than expected**
   i. Essentially, all LiDAR companies today are working on TOF, intensity based LiDAR
   ii. FMCW LiDAR using hybrid integration and opto-mechanical scanning or mechanical rotation could provide a performance disruption
2. **Solid state scanning and higher levels of photonic integration kicks in earlier than expected**
   i. Elegant concept which currently is not mature, and does not provide Level 4 and 5 performance
   ii. With more focus, funding and breakthroughs can disrupt cost, size and power consumption performance
3. **Imaging Radar eliminates need for LiDAR**
   i. Traditional LiDAR used for automotive does not have adequate resolution to enable object recognition and path planning required for Level 4 and Level 5 driving
   ii. Current investments in metamaterials based radar antennas can eliminate need for LiDAR
4. **Cameras with advanced AI algorithms and adaptive headlights eliminate need for LiDAR**
   i. Stereo camera capable of providing 3D range information today for 50 m range
   ii. Mono cameras with certain cues can be used to extract depth information
   iii. Adaptive headlights can minimize sensitivity issues with cameras
   iv. AI algorithms which better mimic human vision and depth perception become feasible


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We look forward to working with you to make movement automation a reality