Mobileye in Numbers

EyeQ Shipped

EyeQs shipped to date

- 54M

Globally across 26 OEMs

- 47 Running Programs
  - Globally across 26 OEMs

Over

- 54M EyeQs shipped to date

In 2019:

- 46% CAGR
  - In EyeQ shipping since 2014

- 33 Design Wins
  - 28M units over life
  - 4 high-end L2+ wins with 4 major EU and Chinese OEMs

- 16 Product Launches
  - Industry first 100° camera with Honda
  - VW high-volume launch (Golf, Passat)
Mobileye Solution Portfolio
Covering the Entire Value Chain

**Today**
- **L1-L2 ADAS**
  - Driver assistance
  - Front camera SoC & SW: AEB, LKA, ACC, and more

**L2+/ L2++ (Conditional Autonomy)**
- Scalable proposition for:
  - Front vision sensing
  - REM HD map
  - May also include:
  - Driver monitoring, surround vision, redundancy
  - “Vision Zero” - RSS for ADAS

**2022**
- **L4/ L5 Mobility-as-a-Service**
  - Full Autonomy
    - Full-Service provider owning the entire MaaS stack
    - SDS to MaaS operators
    - SDS as a Product

**2025**
- **L3/4/5 Passenger cars**
  - Consumers Autonomy
    - SDS to OEMs
    - Chauffeur mode
    - Scalable robotaxi SDS design for a better position in the privately owned cars segment

**REM® Data and Mapping**
- Crowdsourcing data from ADAS for:
  - HD mapping for AV and ADAS
  - Providing smart city eco system with Safety/Flow Insights and foresights
The ADAS Segment Evolution
L2+ - The Next Leap in ADAS

L2+ common attributes

- Multi-camera sensing
- HD maps
- Multi-camera front sensing to full surround

L2+ functionalities range from

- Everywhere, all-speed lane centring
- Everywhere, all-speed conditional hands-free driving

The opportunity

L2+ global volume expectation (M)

Source: Wolfe research, 2019

- 3.6
- 63% CAGR
- 13

2021 2022 2023 2024 2025

- L2+ - significant added value in comfort, not only safety
- Higher customer adoption and willingness to pay
- Significantly higher ASP- 3-15x more than legacy L1-L2
- System complexity leads to high technological barrier
Mobileye Scalable Solution for L2+

Camera-based 360° sensing is the enabler for the next leap in ADAS

360° cameras sensor suite
- Affordability allows mass adoption in ADAS
- Full 3D environmental model
- Algorithmic redundancy

REM™ HD Maps
- First in the industry to offer:
  - "HD Maps Everywhere"
  - High refresh rate

Lean compute platform
- Entire system running on 2x EyeQ® 5H
- 3rd party programmability
- 46 TOPS, 54W

Driving Policy layer
- RSS-based
- Formal safety guarantees
- Prevention driven system for ADAS
More than 70% of the L2+ systems running today are powered by Mobileye’s technology

For example:

Nissan ProPilot™ 2.0  
VW Travel Assist™  
Cadillac Supercruise™  
BMW KaFAS 4

Additional 12 active programs with L2+ variants and 13 open RFQs
Next Generation ADAS
Unlocking “Vision Zero” with RSS for Humans Drivers

ADAS Today
AEB, LKA | Emergency driven
ESC/ESP | Prevention driven
Application of brakes
longitudinally & laterally

ADAS Future Potential
AEB, LKA, ESC | All in one
Prevention driven system
Formal Guarantees

Scalable surround CV system
RSS Jerk-bounded braking profile
longitudinal & lateral

Standard fitment/Rating

Vision Zero
Under the Hood of Mobileye’s Computer Vision
# The Motivation Behind Surround CV

## The goal
- Full stack camera only AV
- $10^{-4}$ MTBF for sensing mistake leading to RSS violation (per hour of driving)

## Why
- $\sim 10^{-4}$ Humans probability of injury per hour of driving
- $\sim 10^{-6}$ Humans probability of fatality per hour of driving

- $\sim 10^{-7}$ **The sensing system desired MTBF** (with safety margins)
  - Driving 10M hours without a safety critical error

To meet the $10^{-7}$ MTBF, we break it down into two independent sub-systems:

$$\text{MTBF} 10^7 \approx \text{MTBF}_1 10^{3.5} \cdot \text{MTBF}_2 10^{3.5}$$

Critical MTBF of $10^4 \approx 10,000$ (with safety margins) hours is plausible.

## The challenge
- $10^{-4}$ MTBF still requires an extremely powerful surround vision
- Equivalent to driving 2 hours a day for 10 years without a safety critical sensing mistake
Mobileye’s Sensing has Three Demanding Customers

- Sensing state for Driving Policy under the strict role of independency and redundancy.
- Smart agent for harvesting, localization and dynamic information for REM based map
- ADAS products working everywhere and at all conditions on millions of vehicles
Comprehensive CV Environmental Model

Four General Categories

Road Users
360 degrees detection of any movable road-user, and actionable semantic-cues these users convey (light indicators, gestures).

Road Geometry
All driving paths, explicitly / partially / implicitly indicated, their surface profile and surface type.

Road Boundaries
Any delimiter/3D structure/semantics of the drivable area, both laterally (FS) and longitudinally (general objects/debris).

Road Semantics
Road-side directives (TFL/TSR), on-road directives (text, arrows, stop-line, crosswalk) and their Driving Path (DP) association.
Redundancy in the CV Subsystem

In order to satisfy an MTBF of $10^{-4}$ hours of driving of the CV-Sub-system:

Multiple independent CV engines overlap in their coverage of the four categories.
Object Detection

Generated and solidified using 6 different engines
2D to 3D Process

Generated and solidified using 4 different engines

Measurements

VIDAR

Visual road model

Range Net

Map world model (REM)
Full Image Detection

Two dedicated 360-stitching engines for completeness and coherency of the unified objects map:

- Vehicle signature
- Very close (part-of) vehicle in field of view: face & limits
Inter-cameras tracking
Object signature network
Range Net

Metric Physical Range estimation
dramatically improve measurement quality using novel methods
Pixel-level Scene Segmentation

- Redundant to the object-dedicated networks
- Catches extremely-small visible fragments of road users;
- Used also for detecting “general objects”.

![Pixel-level Scene Segmentation](image1)

![Pixel-level Scene Segmentation](image2)
Surround Scene Segmentation with Instance
Road Users – open door

Uniquely classified, as it is both extremely common, critical, and of no ground intersection.
Road Users - VRU

Baby strollers and wheel chairs are detected through a dedicated engine on top of the pedestrians detection system.
**Parallax Net**

Parallax Net engine provides accurate structure understanding by assessing residual elevation (flow) from the locally governing road surface (homography).
VIDAR

“Visual Lidar”: DNN-based Multi-view Stereo

- Redundant to the appearance and measurement engines
- Handling “rear protruding” objects – which hover above the object’s ground plane.
VIDAR Input

Front left

Main

Front right

Rear left

Parking left

Parking right

Rear right
VIDAR Output
DNN based multi-view stereo
VIDAR Output
DNN based multi-view stereo
Road Users from VIDAR

Leveraging Lidar Processing Module for Stereo Camera Sensing – “VIDAR”

Dense depth image from VIDAR
High-res Pseudo-Lidar
Upright obstacle ‘stick’ extraction
Object detection
Obstacle Classification

**Obstacle classification**
e.g., how to differentiate a double parked car from a traffic jam

**Using cues from the environment**
- Behavior of other road users
- What’s in front of the object
- Object location
- Opened door
- Emergency lights
Road Users Semantics

- Head/pose orientation
- Pedestrians posture/gesture.
- Vehicle light indicators
- Emergency vehicle/Personnel classification.

Emergency vehicle, light indicators

Pedestrian understanding
Come closer

You can pass

Stop!

On the phone
The full unedited 25min ride is available at Mobileye’s YouTube Channel

https://www.youtube.com/watch?v=hCWL0XF_f8Y&t=15s
REM Mapping and Data
REM Process

1. Harvesting
   Collecting road and landmarks through EyeQ-equipped vehicles

2. Anonymizing and encrypting REM data

3. Aggregation
   Generating HD crowdsourced RoadBook for autonomous driving

4. Map tile distributed to the car

5. Localizing
   Localizing the car within 10cm accuracy in the road book.

Also available via retrofit solutions
REM Volumes

Harvesting agreements with 6 major car makers

**Harvesting:**
- Over 1M Harvesting vehicles in EU by 2020
- Over 1M Harvesting vehicles in US by 2021
- Collecting 6 million km per day from serial production vehicles such as: Volkswagen Golf, Passat, BMW 5 series, 3 series, Nissan Skyline, and more

**Localization:**
- Programs for using Roadbook™ for L2+:

  - 2 OEMs
  - 2 OEMs
  - 2 OEMs

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**Harvesting volumes**

- 3 additional major OEMs

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**Timeline:**

- 2018
- 2019
- 2020
- 2021
- 2022
REM Milestones

- Mapping most of the US by end 2020
- Mapping all of Europe by Q1 2020
REM for Autonomous Driving

Already operational and is proving to be a true segment game changer

For roads above 45 Mph

- Maps created in a fully automated process TODAY
- Contains all static, dynamic, and semantic layers to allows fully autonomous drive

45 Mph

For roads below 45 Mph

- Semi-automated process
- Full automation in 2021

Las Vegas Fwy, interstate 15 REM map
Data harvesting agreements in China complying with regulatory constraints

Strategic collaboration with SAIC Motor for REM data harvesting
Accelerate the AV development for passenger vehicles in China

Harvesting data in China as part of a collaboration with NIO on L4 synergy for Robotaxi and consumer AV

JV agreement with Unigroup to enable the collection, processing, and monetization of data in China
The Smart Cities Opportunity
Mobileye Data Services

Product Portfolio

**Infrastructure Asset Inventory**
- Automated, AI-powered road asset surveying
- Efficient asset management, precise GIS data and change detection
- Strategic collaboration with Ordnance Survey (UK)

**Pavement Condition Assessment**
- Automated surveying & assessment of road conditions
- Efficient road maintenance with precise GIS data of surface distress

**Dynamic Mobility Mapping**
- Near real-time & historical data on movement in the city; dynamic mobility GIS datasets
- Evidence-based urban planning improvements
Infrastructure Asset Inventory
Pavement Conditions Assessment

5 levels score

0 – Excellent conditions - requires no repair
Pavement Conditions Assessment

Cracks and potholes harvester in action

Road Conditions Score – Poor (5)
Pavement Conditions Assessment

Road Conditions Score – Poor (5)
Pavement Conditions Assessment

Cracks and potholes harvester in action
RSS Driving Policy and Driving Experience
The Driving Policy Challenge

- Do we allow an accident due to a “lapse of judgement” of Driving Policy?
- Should the occurrence of “lapse of judgement” be measured statistically?

Safety is a technological layer living outside of Machine Learning. It is like “Ethics” in AI - a set of rules.

- It all boils down to a formal definition of “what it means to be careful”

There is a need for “regulatory science and innovation”. Technological innovation is not sufficient.
What is RSS?
A formal model for safety, that provides mathematical guarantees for the AV to never cause an accident

On a Formal Model of Safe and Scalable Self-driving Cars
Shai Shalev-Shwartz, Shaked Shammah, Amnon Shashua
Mobileye, 2017

Abstract
In recent years, car makers and tech companies have been racing towards self-driving cars. It seems that the main parameter in this race is who will have the first car on the road. The goal of this paper is to add to the equation two additional crucial parameters. The first is standardization of safety assurance — what are the minimal requirements that every self-driving car must satisfy, and how can we verify these requirements. The second parameter is scalability — engineering solutions that lead to unassembled costs will not scale to millions of cars, which will push interest in this field into a niche academic corner, and drive the entire field into a “winter of autonomous driving”. In the first part of the paper we propose a white-box, interpretable, mathematical model for safety assurance, which we call Responsibility-Sensitive Safety (RSS). In the second part we describe a design of a system that adheres to our safety assurance requirements and is scalable to millions of cars.

http://arxiv.org/abs/1708.06374

The Method

01 Defining reasonable boundaries on the behavior of other road users

02 Within the boundaries specified by RSS, one must always assume the worst-case behavior of other agents

03 The boundaries capture the common sense of reasonable assumptions that human drivers make

04 Any action beyond the defined boundaries is not reasonable to assume
For Example

Ego car \( A \) is following car \( B \) on a single-lane straight road.

\[
\begin{array}{c}
\text{A} \\
\downarrow \\
\text{B}
\end{array}
\]

Safe distance for \( A \) to not hit \( B \) in the worst-case – under a reasonable assumption on \( V_{\text{b max brake}} \).

The Goal

Efficient policy for \( A \) that guarantees not to hit \( B \) in the worst-case.

The Implementation

Safe distance for \( A \) to not hit \( B \) in the worst-case.

The Policy

- Define **Dangerous Situation** - a time is dangerous if the distance is non-safe.
- Define **Proper Response** - as long as the time is dangerous, brake until stop.

The Guarantees

- Proof by induction.
- More complex situations (\( n \) agents) need to prove “no conflicts” (efficiently verifiable).
More Complex Situations

RSS sets the boundaries of reasonable assumptions for all driving scenarios

What is reasonable to assume on B in the scenarios below

**Multiple Geometry**

If B can brake at $B_{min\text{-}brake}$ without violating right-of-way, B will brake, otherwise A must stop.

**Lateral Maneuvers**

If B can brake at $B_{lat\text{-}min\text{-}brake}$, B will brake laterally, otherwise A must brake laterally.

**Occlusions**

Assuming the max velocity of B dictates the max speed for A.
In Summary

Assuming **cooperative behavior on the roadway** is the key for drivability and "human-like" driving

Formal definition of the “reasonable assumptions” provides **mathematical guarantees for safety**

The parameters dictates the **cautiousness and utility tradeoff** and allow transparent and concise regulatory framework

The RSS adheres to 5 principles:

01 **Soundness**- full compliance with common sense of human driving

02 **Completeness**- covering all driving scenarios by always assuming the worst case under the reasonable assumptions

03 **Usefulness**- Policy for efficient and not overly-conservative driving

04 **Transparency**- The model should be a white-box

05 **Efficiently Verifiable**- proof of guarantee by induction, insuring no butterfly effect
Industry Acceptance

The RSS is gaining global acceptance as an Automated Vehicle Safety Standard

Previously announced adoptions of RSS:

Safety First for Automated Driving (SaFAD)

Companies involved are:
BMW, Daimler, Audi, VW, FCA, Aptiv, Continental, here, Baidu, Infineon

Together with 11 industry leaders, we established an industry-wide definition of safety with the SaFAD white paper, based on RSS definitions

IEEE to define a formal model for AV safety with Intel-Mobileye leading the workgroup

The new standard will establish a formal mathematical model for safety inspired by RSS principles
Industry Acceptance

The RSS is gaining global acceptance as an Automated Vehicle Safety Standard

China ITS Industry Alliance (C-ITS) to formally approve an RSS-based standard

The standard, “Technical Requirement of Safety Assurance of AV Decision Making”, has been released to public and will take effect on March, 2020

- The world’s first standard, based on RSS
- Proof point that RSS can handle one of the world’s most challenging driving environments: China
- The world’s first proposed parameter set that defines the balance between safety and usefulness
The Path to Becoming an End-to-End Mobility-as-a-Service Provider
Mobileye is forging driverless MaaS as a near term revenue-generating channel

- The JV to bring robotaxi MaaS to Tel-Aviv is officially signed
- Deploying and testing in Tel-Aviv during this year
- Establishing the regulatory framework in Israel

RATP and Mobileye partnered with the City of Paris to deploy a driverless mobility solution
- The first EU city where testing with Mobileye’s AV will start this year

This year Mobileye will start using Nio ES8 for AV testing and validation
- In 2022 launching a next-gen platform with Mobileye’s L4 tech offered to consumers in China
- Robotaxi variant will be launched exclusively for our robotaxi fleets

Daegu City and Mobileye announce today a partnership to start testing robotaxi MaaS in South Korea this year
- Deployment during 2022
Our Self-Driving-System

HW Generations

- **EPM 52**
  - In deployment
  - Up to 2x EQ5H
  - Up to 7x8MP + 4x1.3MP
  - Up to 48 TOPs

- **EPM 59**
  - Deployment in Q2 2020
  - Up to 6x EQ5H
  - Additional 2-3 for FOP
  - E2E support in all aspects - fusion, policy, control
  - Up to 216 TOPs

- **EPM 6**
  - Deployment in 2023
  - Single EQ6H to support E2E functionality
  - Additional EQ6H FOP
  - Up to 220 TOPs
**Main Takeaways**

01. L2+ a growing new category for ADAS where Surround-CV unlocks considerable value at volume production cost.

02. Realization of (safe) L4 and unlocking the full potential of L2+ requires Surround-CV at a standalone (end-to-end) quality.

03. L2+ required HD-map-everywhere at growing use-case (types of roads) → L4 requires HD-maps → Consumer-AV requires HD-maps-everywhere → Automation at scale is enabled by crowd-sourced data (REM).

04. Crowd-sourced data from ADAS-enabled vehicles (REM) unlocks great value for Smart Cities.

05. To unlock the value of automation there is a need for “regulatory science” (RSS).

06. The road to Consumer-AV goes through Robotaxi MaaS.
Thank You!