# A Data-Driven Tool for Estimating Safety Benefits of CAV Deployment

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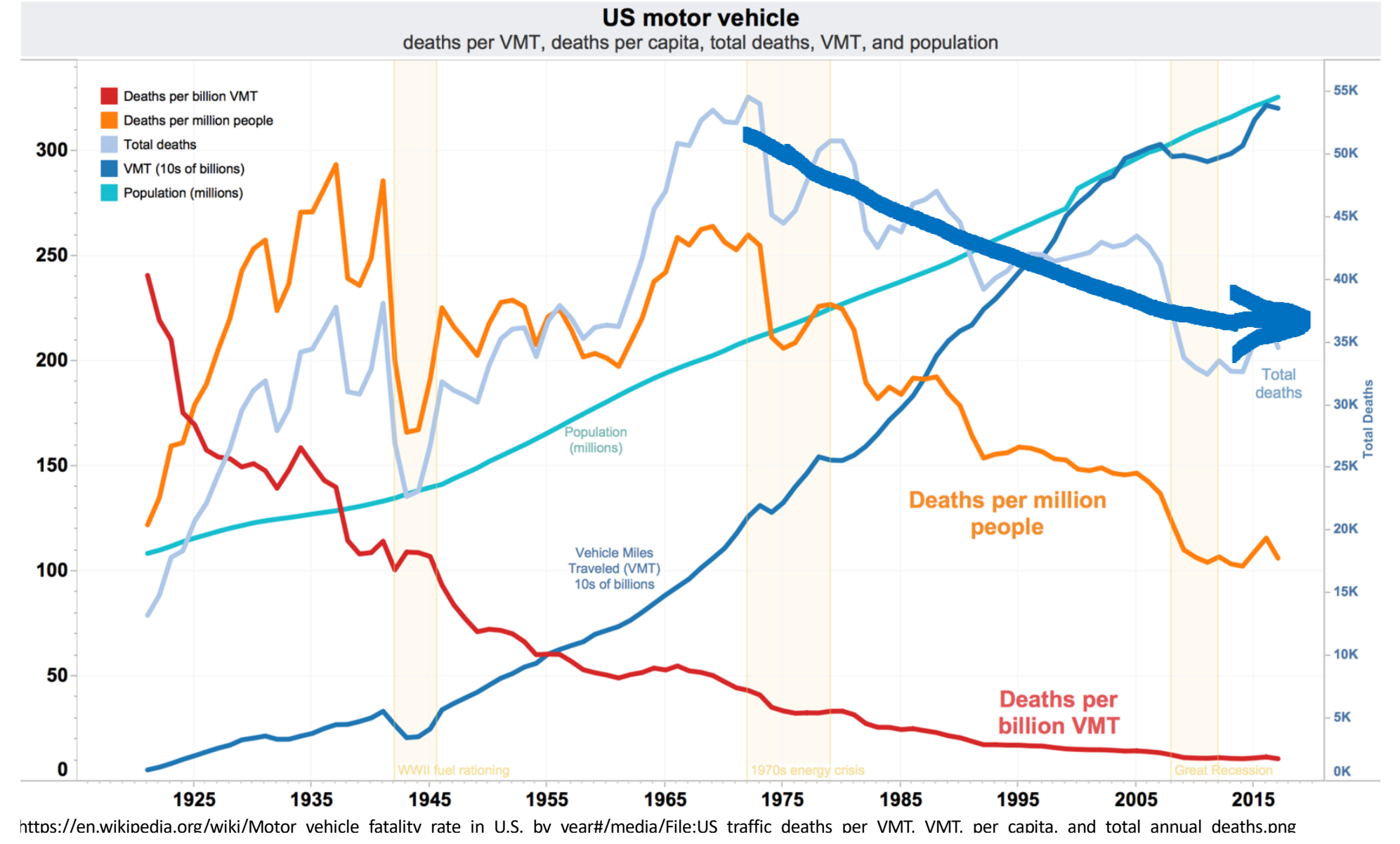
## ABSTRACT

It is widely held that connected and autonomous vehicle (CAV) technologies will reduce highway crashes. That some 94% of all crashes are due to human error is often held as the principal rationale for this projection. The 94% figure is controversial and probably an upper bound and includes human error by pedestrians, bicyclists and motorcyclists. For automated vehicles, the statistic may remain at 94% due to at least two factors: risk compensation and the interaction of CAVs with human driven cars. These factors make estimating the safety improvements during the transitional period difficult. It is even possible that some safety degradation will take place, and this degradation may disproportionately affect certain driver populations and crash types. The study analyzes the potential safety benefits and the implications for certain driver populations and crash types. The study examines crash causal factors, harmful events, trends, site characteristics, driver and vehicle characteristics, and other factors affecting or affected by the introduction of CAVs. Decomposing crash reports and analyzing crash data allows matching levels of vehicle automation to the types of crashes that will be affected, allowing more detailed predictions of safety effects. Results are examined through the lens of technology deployment analysis, reflecting growth and decline of various trip types enabled by these new technologies. In addition to safety benefits and costs of CAVs during transition, the project identifies crash types and conditions where targeted engineering, education, enforcement, and emergency response countermeasures may be required. Future benefits of this study will be the ability to identify trade-offs where certain populations, crash types and even modes get safer while others potentially get less safe, or, at least, do not benefit as greatly. A user-friendly spreadsheet tool allows estimation of crash reductions due to the implementation of AVs and CAV technologies. These estimations are supported by real data on crashes, road types, and travel trends.

The University of Kentucky

The Kentucky Transportation Center


US motor vehicle
deaths per VMT, deaths per capita, total deaths, VMT, and population

https://en.wikipedia.org/wiki/Motor_vehicle_fatality_rate_in_U.S._by_year#/media/File:US_traffic_deaths_per_VMT,_VMT,_per_capita,_and_total_annual_deaths.png

## SAFETY THE PROBLEM, AVS THE SOLUTION?

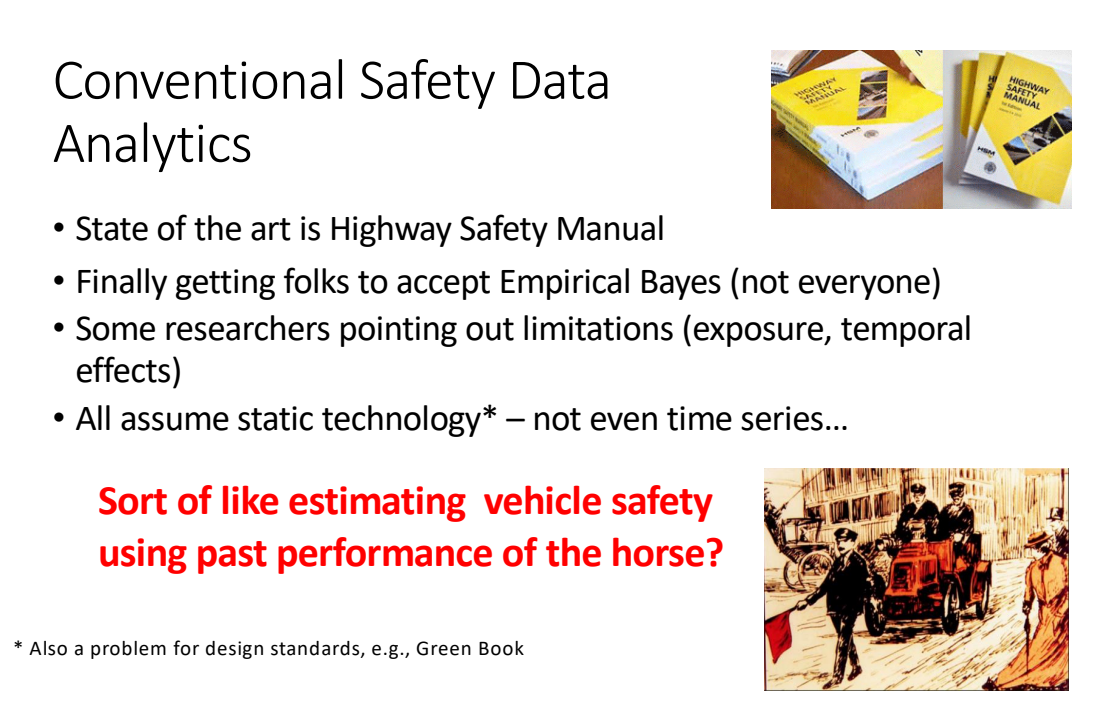
- 35,000 deaths per year in the US
- Initially, mixing in AVs may make things worse (for some crash types)
- Money spent on AVs could be spent on less-expensive "safer" cars
- Money spent on making the infrastructure work with AVs and CAV-tech enabled cars could be spent making roads safer for non-CAVs*
- Interactions between AVs and non-CAVs may be more dangerous than a driver-operated system
- Effectiveness requires proper use, can be a distraction, users compensate for risk
- In the long run even, some things might be worse

* *some improvements may help both types of cars*

## EFFECTIVENESS

Effectiveness is the degree of safety success from the vehicle technology compared to level 0. Effectiveness is broken down into five groups, as each group has different technology with different amounts of safety benefits.

| Level 1 | Level 2&3 | Level 3.5 | Level 4 | Level 5 |
|---|---|---|---|---|
| Use Percentage | Crashes Potentially Mitigated | Crashes Potentially Mitigated | Crashes Potentially Mitigated | Risk of Software Malfunction |
| Distraction Factor | Percentage of Time Working with Level 5 Technology | Percentage of Time Working with Level 5 Technology | Percentage of Time Working with Level 5 Technology | Effectiveness on Roadways |
| Risk Compensation Factor | VMT Where Technology works (Interstates & Divided Highways) | VMT Where Technology works | | |
| VMT | | | | |
| Crash Percentage with Technology Prevention | | | | |


Conventional Safety Data Analytics

- State of the art is Highway Safety Manual
- Finally getting folks to accept Empirical Bayes (not everyone)
- Some researchers pointing out limitations (exposure, temporal effects)
- All assume static technology* – not even time series…

Sort of like estimating vehicle safety using past performance of the horse?

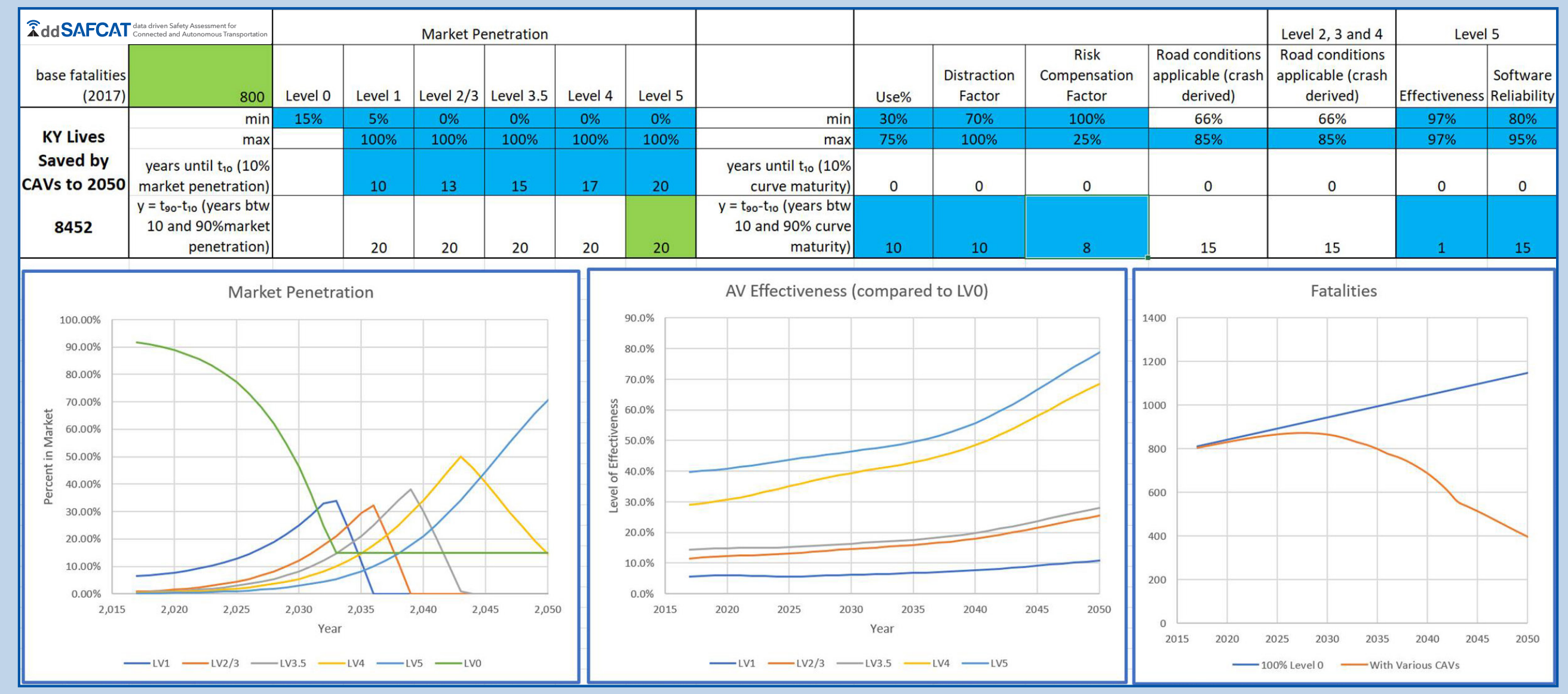
* Also a problem for design standards, e.g., Green Book

RAND Corporation (2017) explored relations between CAV deployment and highway fatalities. Their scenario generator simulates the effect of market penetration rate on total highway deaths, and provokes thinking about the effect of this rate. ddSAFCAT embraces this thinking, and takes the concept to another level, using crash and traffic data to inform the forecast.

## MARKET PENETRATION

ddSAFCAT addresses market penetration of technology by SAE level. Level 5 is considered the market "driver" as level 5 cars, once deployed, are not likely to be replaced by lower level vehicles. However, it is likely that lower level vehicles will penetrate the market faster. Level 0 share is considered as the remaining vehicles on the roadways. Technology penetration is also considered to be a function of fleet turnover rate, a function of how long cars last on the road. Although the tool provides suggested starting points, the user has the ability to change these numbers to test different future scenarios. As the tool "learns" (real data are used to inform inputs) the results become less speculative, and more data driven. This learning will be incorporated into the tool in two ways: better starting and ending point estimations, and more "dials" to allow different components to be taken into consideration.

# ddSAFCAT data driven Safety Assessment for Connected and Autonomous Transportation

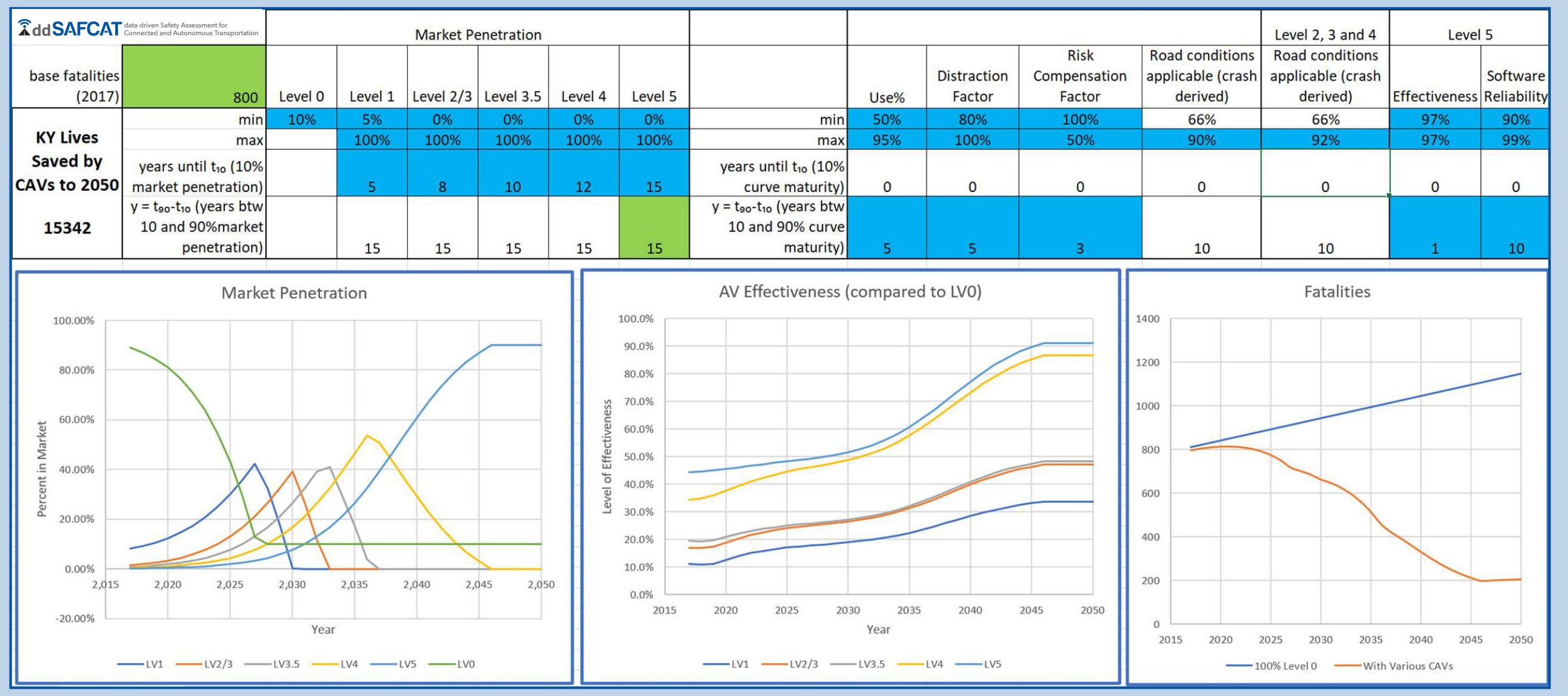

ddSAFCAT data driven Safety Assessment for Connected and Autonomous Transportation

| | | Market Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| base fatalities (2017) | 800 | Level 0 | Level 1 | Level 2/3 | Level 3.5 | Level 4 | Level 5 |
| KY Lives Saved by CAVs to 2050 | min | 15% | 5% | 0% | 0% | 0% | 0% |
| | max | | 100% | 100% | 100% | 100% | 100% |
| | years until $t_{10}$ (10% market penetration) | | 10 | 13 | 15 | 17 | 20 |
| 8452 | $y = t_{90}-t_{10}$ (years btw 10 and 90%market penetration) | | 20 | 20 | 20 | 20 | 20 |

| | Use% | Distraction Factor | Risk Compensation Factor | Road conditions applicable (crash derived) | Level 2, 3 and 4 Road conditions applicable (crash derived) | Level 5 Effectiveness | Level 5 Software Reliability |
|---|---|---|---|---|---|---|---|
| min | 30% | 70% | 100% | 66% | 66% | 97% | 80% |
| max | 75% | 100% | 25% | 85% | 85% | 97% | 95% |
| years until $t_{10}$ (10% curve maturity) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y = t_{90}-t_{10}$ (years btw 10 and 90% curve maturity) | 10 | 10 | 8 | 15 | 15 | 1 | 15 |

### Less Aggressive

Forecast presents a substantial amount of time for CAV technology to penetrate the market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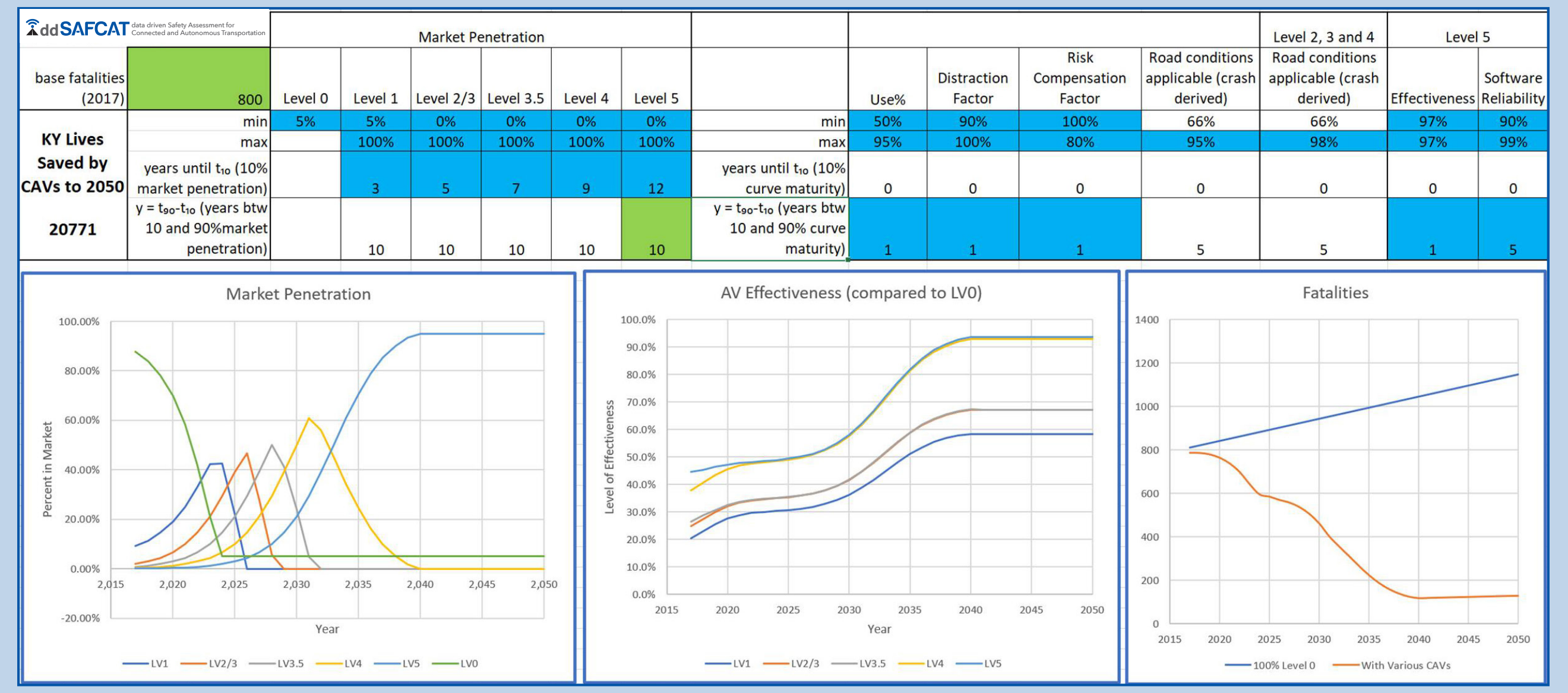
| | | Market Penetration | | | | | |
|---|---|---|---|---|---|---|---|
| base fatalities (2017) | 800 | Level 0 | Level 1 | Level 2/3 | Level 3.5 | Level 4 | Level 5 |
| KY Lives Saved by CAVs to 2050 | min | 10% | 5% | 0% | 0% | 0% | 0% |
| | max | | 100% | 100% | 100% | 100% | 100% |
| | years until $t_{10}$ (10% market penetration) | | 5 | 8 | 10 | 12 | 15 |
| 15342 | $y = t_{90}-t_{10}$ (years btw 10 and 90%market penetration) | | 15 | 15 | 15 | 15 | 15 |

| | Use% | Distraction Factor | Risk Compensation Factor | Road conditions applicable (crash derived) | Level 2, 3 and 4 Road conditions applicable (crash derived) | Level 5 Effectiveness | Level 5 Software Reliability |
|---|---|---|---|---|---|---|---|
| min | 50% | 80% | 100% | 66% | 66% | 97% | 90% |
| max | 95% | 100% | 50% | 90% | 92% | 97% | 99% |
| years until $t_{10}$ (10% curve maturity) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y = t_{90}-t_{10}$ (years btw 10 and 90% curve maturity) | 5 | 5 | 3 | 10 | 10 | 1 | 10 |

### Best "Guess"

The "most likely" scenario of what is already in the market as well as the anticipated rates of penetration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| | | Market Penetration | | | | | |
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| base fatalities (2017) | 800 | Level 0 | Level 1 | Level 2/3 | Level 3.5 | Level 4 | Level 5 |
| KY Lives Saved by CAVs to 2050 | min | 5% | 5% | 0% | 0% | 0% | 0% |
| | max | | 100% | 100% | 100% | 100% | 100% |
| | years until $t_{10}$ (10% market penetration) | | 3 | 5 | 7 | 9 | 12 |
| 20771 | $y = t_{90}-t_{10}$ (years btw 10 and 90%market penetration) | | 10 | 10 | 10 | 10 | 10 |

| | Use% | Distraction Factor | Risk Compensation Factor | Road conditions applicable (crash derived) | Level 2, 3 and 4 Road conditions applicable (crash derived) | Level 5 Effectiveness | Level 5 Software Reliability |
|---|---|---|---|---|---|---|---|
| min | 50% | 90% | 100% | 66% | 66% | 97% | 90% |
| max | 95% | 100% | 80% | 95% | 98% | 97% | 99% |
| years until $t_{10}$ (10% curve maturity) | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y = t_{90}-t_{10}$ (years btw 10 and 90% curve maturity) | 1 | 1 | 1 | 5 | 5 | 1 | 5 |

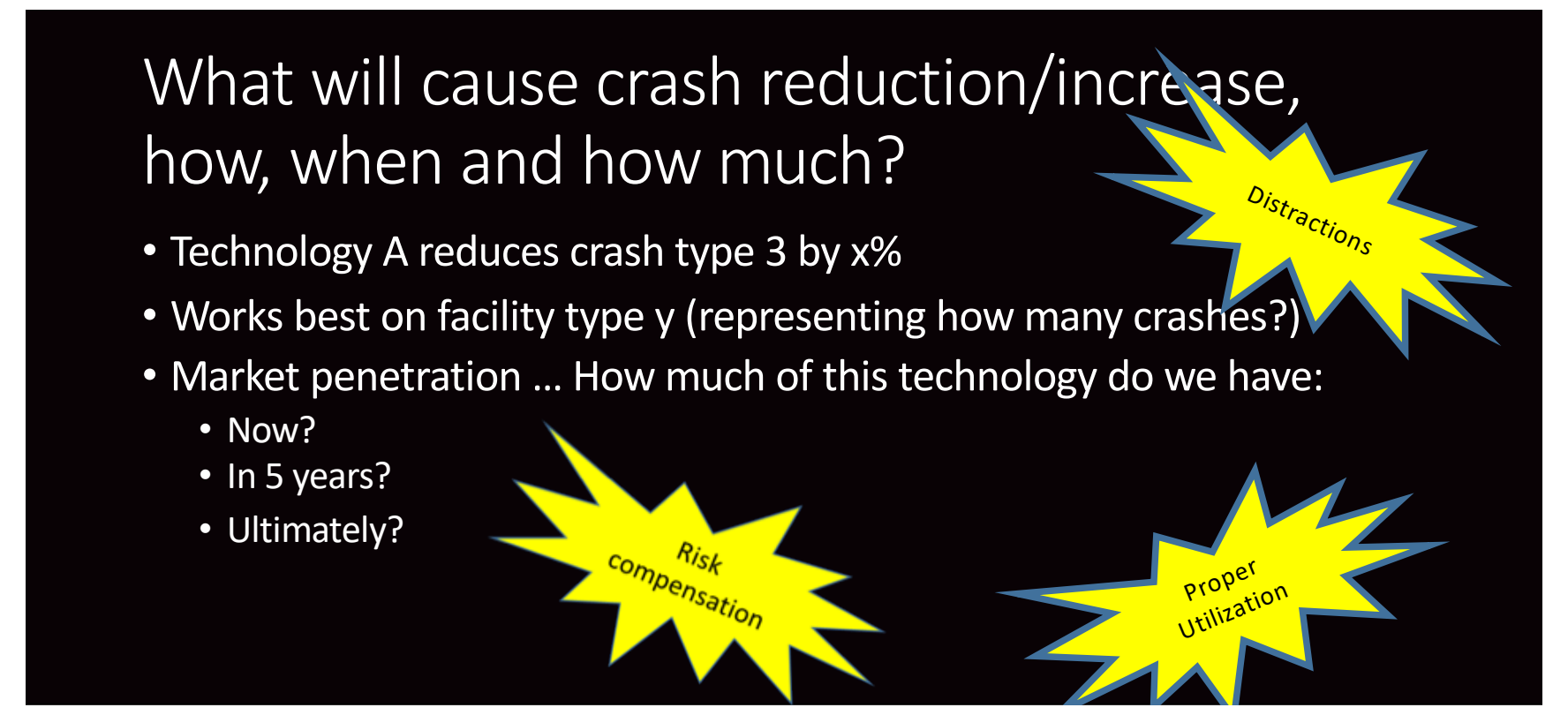
### More Aggressive

A display of what would occur if society and policy makers fully embrace autonomous vehicles

How 'bout some more dials?

**LOGISTIC FUNCTION** $Y(t)=A+\frac{K-A}{1+e^{-B(t-M)}}$

A is the lower limit
K is the upper limit
B is the growth rate
t represents the current year
M represents the year of 50% "penetration"


What will cause crash reduction/increase, how, when and how much?

- Technology A reduces crash type 3 by x%
- Works best on facility type y (representing how many crashes?)
- Market penetration … How much of this technology do we have:
  - Now?
  - In 5 years?
  - Ultimately?

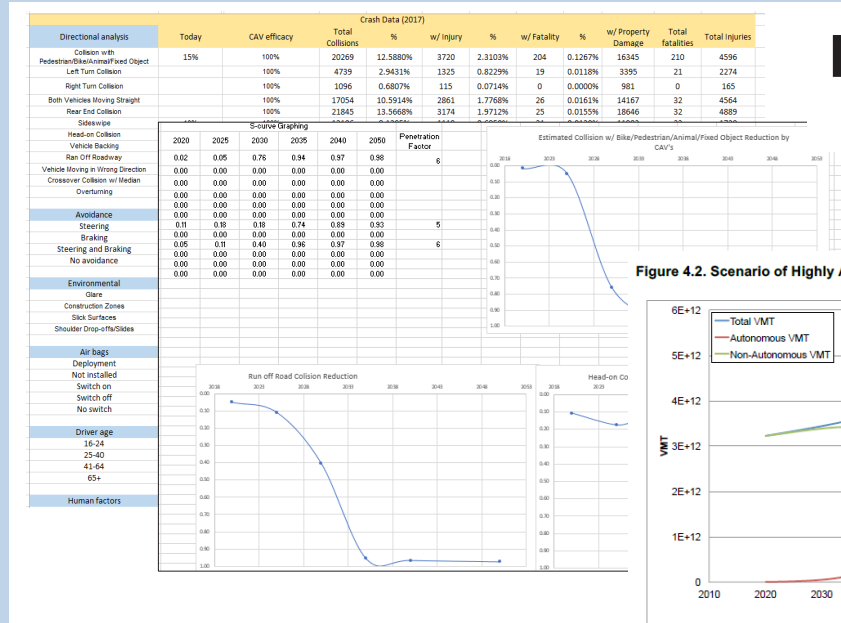
## FATALITIES

Fatalities are estimated for two scenarios. First, a baseline estimate, informed by current fatality levels and VMT growth assumes only level 0 technology. A second scenario incorporates the eventual deployment of the higher levels of CAVs. The baseline for fatalities in Kentucky is 800 (2017 annual total).

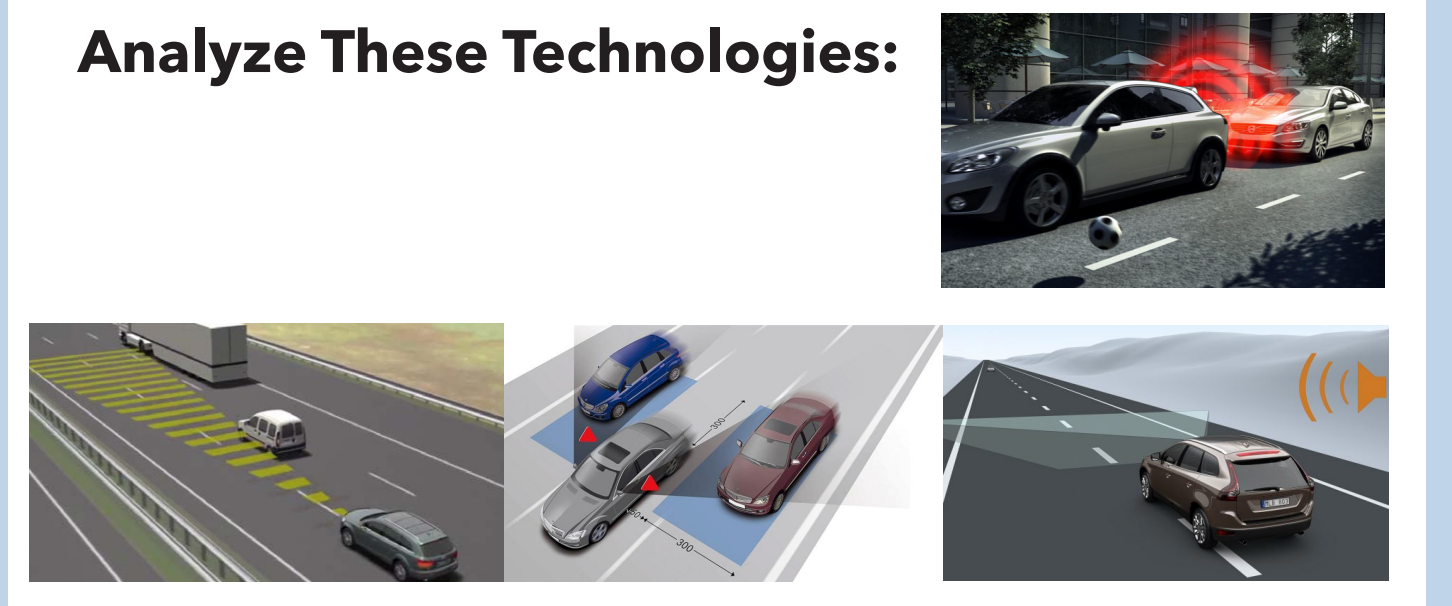
## NEXT STEPS

- Market penetration and staging (not currently well informed)
- Driver/crash type interaction
- Impact on Engineering: Countermeasure analysis/CMF modification
- Impact on other modes
- Impact on education, enforcement, and emergency response
- Explore impact of various functional forms or deployment curves

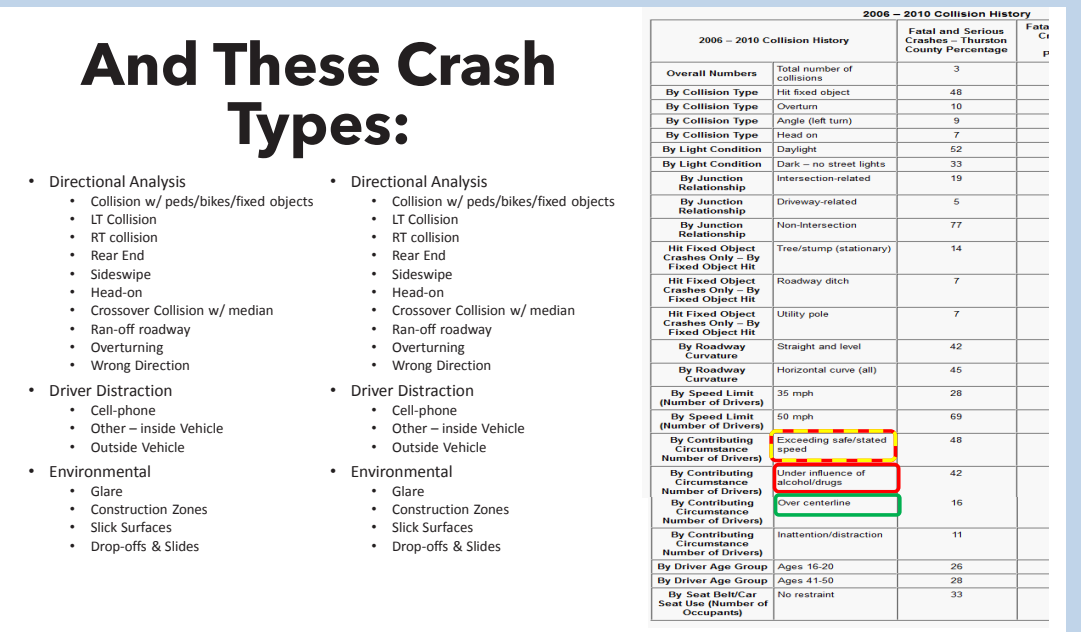
### Learn from Others



### Analyze These Technologies:



### And These Crash Types:


- Directional Analysis
  - Collision w/ peds/bikes/fixed objects
  - LT collision
  - RT collision
  - Rear End
  - Sideswipe
  - Head-on
  - Crossover Collision w/ median
  - Ran-off roadway
  - Overturning
  - Wrong Direction
- Driver Distraction
  - Cell-phone
  - Other – inside Vehicle
  - Outside Vehicle
- Environmental
  - Glare
  - Construction Zones
  - Slick Surfaces
  - Drop-offs & Slides

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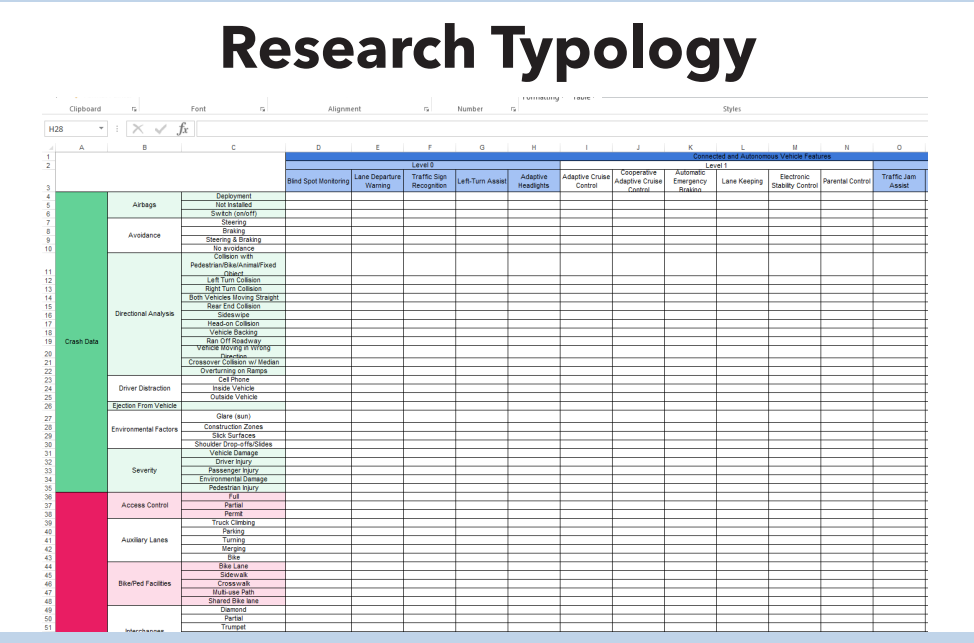
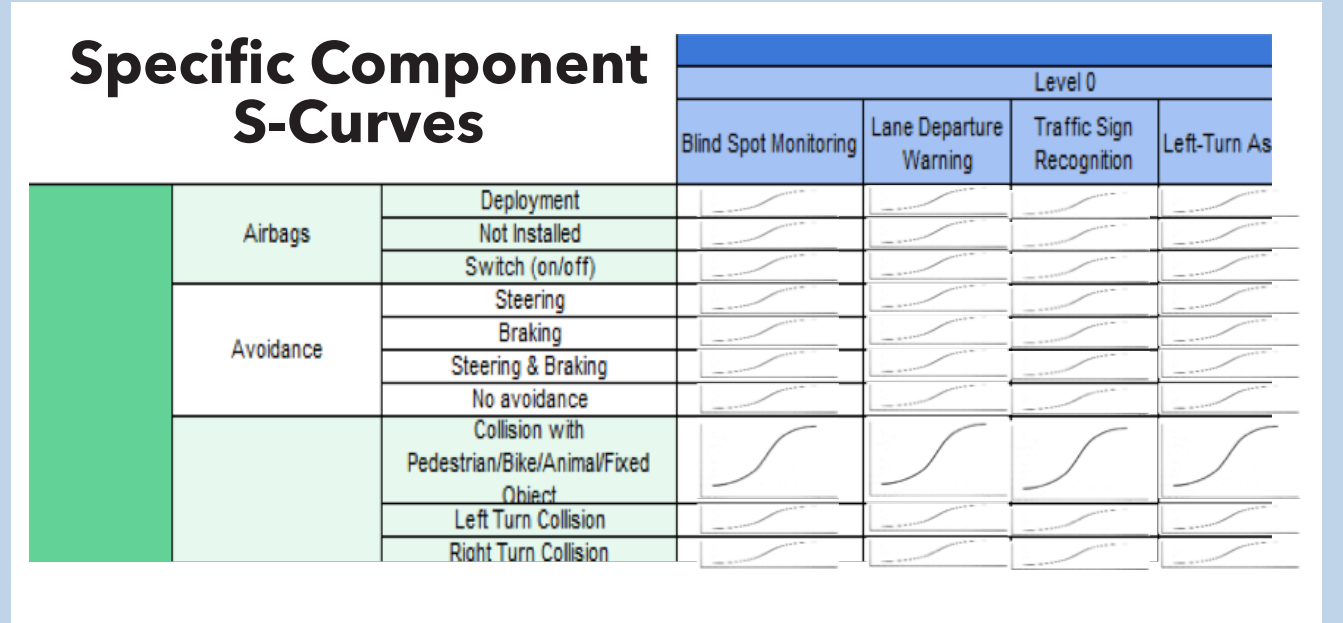
### In the Context of These Facility Characteristics:

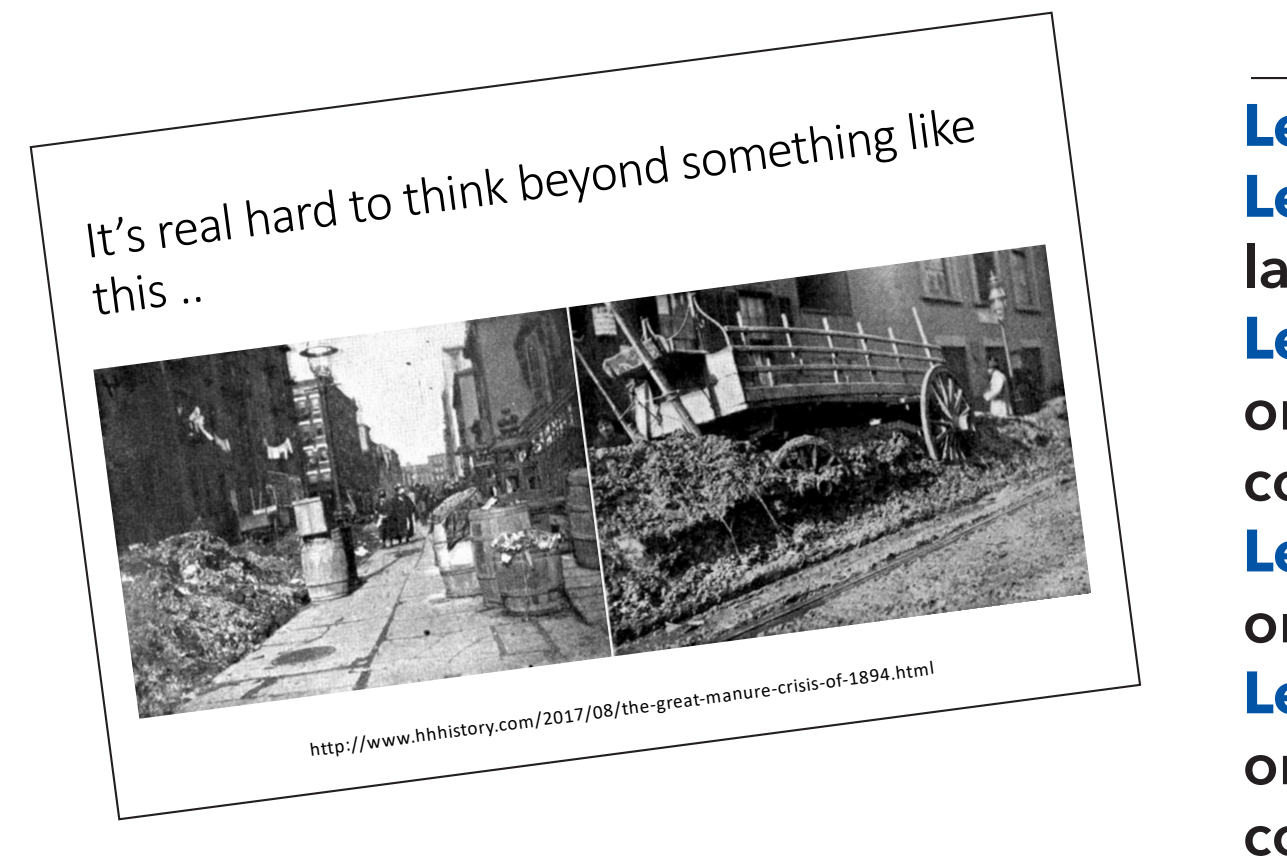
- **Access Control**
  - Full Access
  - Partial Access
  - Permitted Access
- **Auxiliary Lanes**
  - Truck Climbing
  - Parking
  - Turning
  - Merging
  - Cycling
- **Bike/Peds**
  - Cycling lane
  - Sidewalk
  - Crosswalk
  - Multi-use path
  - Shared lanes
- **Interchanges**
  - Diamond
  - Double diamond crossover
  - Partial
  - Trumpet
  - Cloverleaf
  - Displaced LT
- Pavement
  - Unimproved/ primitive
  - Graded & Drained
  - Soil/Gravel/Stone
  - Highly Flexible
  - Concrete
  - Composite
- **Operation Type**
  - One-way
  - Two-way

### Research Typology



### Specific Component S-Curves




It's real hard to think beyond something like this ..

http://www.hhhistory.com/2017/08/the-great-manure-crisis-of-1894.html

## CAV LEVELS

**Level 0** – No vehicle control
**Level 1** – Adaptive cruise and/or lane keeping
**Level 2 & 3** – Fully Autonomous on some roads under certain conditions
**Level 3.5** – Fully Autonomous on certain roads in all conditions
**Level 4** – Fully Autonomous on all roads under certain conditions
**Level 5** – Fully Autonomous


FROM SLATE, NEW AMERICA, AND ASU

Self-Driving Cars Will Make Organ Shortages Even Worse

We need to prepare for that now.

By Ian Adams and Anne Hobson

A pilot model Uber self-driving car on display on Sept. 13 in Pittsburgh.

## ASSUMPTIONS

- Development and deployment of technology follows a logistic function (s shaped curve)
- Vehicle fleet turnover = average max time vehicles remain on the road, 15 years.
- User inputs time to 10 and 90% market penetration
- Safety effectiveness of levels 1-4 are informed directly by level 5 effectiveness:
- Level 1 effectiveness is half that of level 5
- Levels 2-4 effectiveness same as level 5, but under certain conditions or for certain road types
- 50% of current crashes involve only one vehicle

### AVERAGE LIFESPAN FOR U.S. VEHICLES

Number of Vehicles on the Road in the United States: 253 Million (increased

Average Lifespan: 13 - 17 Years

Average age: 11.5 Years

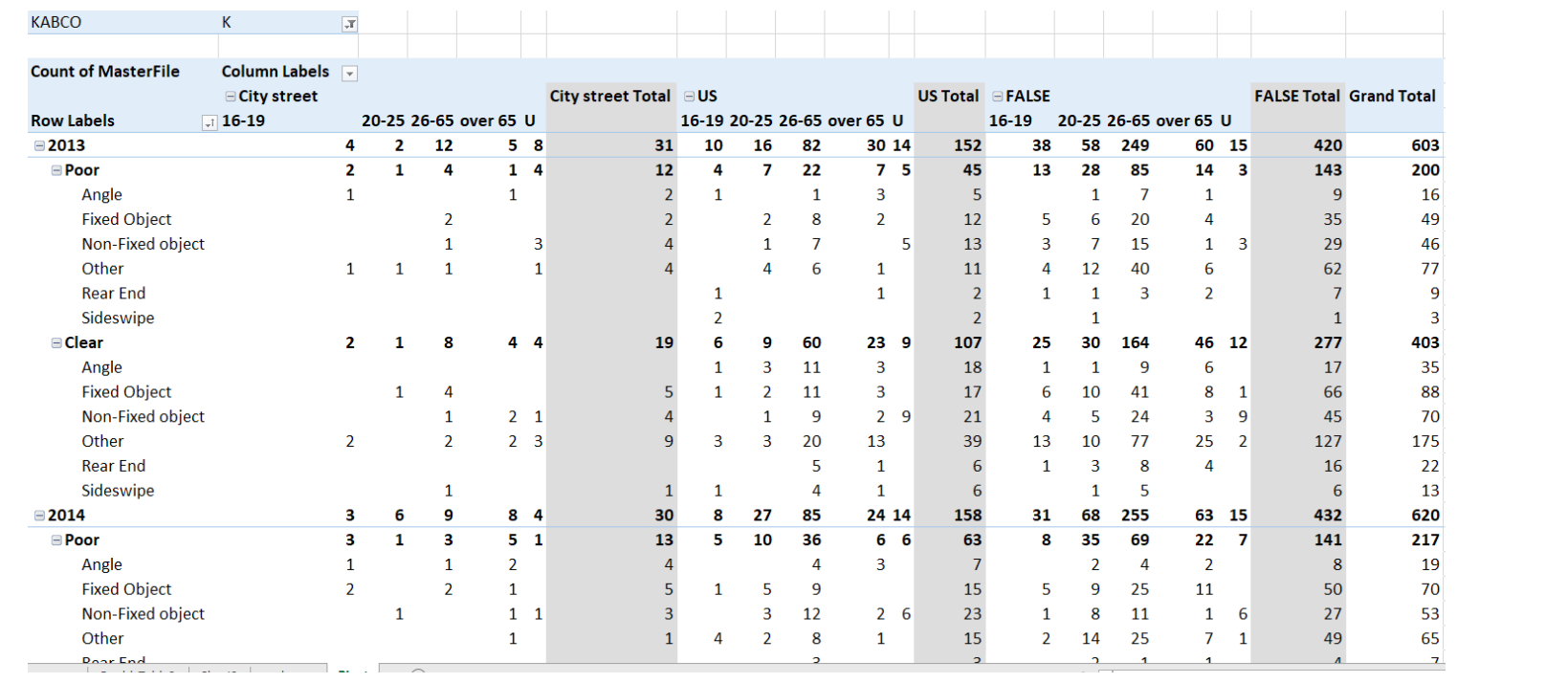
Source: https://berla.co/average-us-vehicle-lifespan/

| | Market Penetration | Effectiveness | Average |
|---|---|---|---|
| Level 0 | 3.5 | 4 | 3.75 |
| Level 1 | 3.5 | 3 | 3.25 |
| Level 2-3 | 2 | 2.5 | 2.25 |
| Level 3.5 | 1.5 | 2.5 | 2 |
| Level 4 | 1 | 2 | 1.5 |
| Level 5 | 1 | 1 | 1 |
| | | Average | 2.29 |
| Key | 1 - Complete Speculation | | |
| | 4 - Data Driven | | |

### Speculation Meter

## DECOMPOSITION

We examine crash causal factors, harmful events, trends, site characteristics, driver and vehicle characteristics, and other factors affecting or affected by the introduction of CAVs. Decomposing safety into components allows data to inform forecasts. For example, crash data supports matching levels of vehicle automation to the types of crashes that are most likely affected. ddSAFCAT's initial decomposition separates the effects of market penetration from technology effectiveness. The tool considers road types and conditions where the technology is most effective.



| KABCO | K | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Count of MasterFile | Column Labels | | | | | | | | | | | | | | | | |
| | City street | | | | | City street Total | US | | | | | US Total | FALSE | | | | FALSE Total | Grand Total |
| Row Labels | 16-19 | 20-25 | 26-65 | over 65 | U | | 16-19 | 20-25 | 26-65 | over 65 | U | | 16-19 | 20-25 | 26-65 | over 65 | U | | |
| 2013 | 4 | 2 | 12 | 5 | 8 | 31 | 10 | 16 | 82 | 30 | 14 | 152 | 38 | 58 | 249 | 60 | 15 | 420 | 603 |
| Poor | 2 | 1 | 4 | 1 | 4 | 12 | 4 | 7 | 22 | 7 | 5 | 45 | 13 | 28 | 85 | 14 | 3 | 143 | 200 |
| Angle | 1 | | | 1 | | 2 | 1 | | 1 | 3 | | 5 | | 1 | 7 | 1 | | 9 | 16 |
| Fixed Object | | | 2 | | | 2 | | 2 | 8 | 2 | | 12 | 5 | 6 | 20 | 4 | | 35 | 49 |
| Non-Fixed object | | | 1 | | 3 | 4 | | 1 | 7 | | 5 | 13 | 3 | 7 | 15 | 1 | 3 | 29 | 46 |
| Other | 1 | 1 | 1 | | 1 | 4 | | 4 | 6 | 1 | | 11 | 4 | 12 | 40 | 6 | | 62 | 77 |
| Rear End | | | | | | | 1 | | | 1 | | 2 | 1 | 1 | 3 | 2 | | 7 | 9 |
| Sideswipe | | | | | | | 2 | | | | | 2 | | 1 | | | | 1 | 3 |
| Clear | 2 | 1 | 8 | 4 | 4 | 19 | 6 | 9 | 60 | 23 | 9 | 107 | 25 | 30 | 164 | 46 | 12 | 277 | 403 |
| Angle | | | | | | | 1 | 3 | 11 | 3 | | 18 | 1 | 1 | 9 | 6 | | 17 | 35 |
| Fixed Object | | 1 | 4 | | | 5 | 1 | 2 | 11 | 3 | | 17 | 6 | 10 | 41 | 8 | 1 | 66 | 88 |
| Non-Fixed object | | | 1 | 2 | 1 | 4 | | 1 | 9 | 2 | 9 | 21 | 4 | 5 | 24 | 3 | 9 | 45 | 70 |
| Other | 2 | | 2 | 2 | 3 | 9 | 3 | 3 | 20 | 13 | | 39 | 13 | 10 | 77 | 25 | 2 | 127 | 175 |
| Rear End | | | | | | | | | 5 | 1 | | 6 | 1 | 3 | 8 | 4 | | 16 | 22 |
| Sideswipe | | | 1 | | | 1 | 1 | | 4 | 1 | | 6 | | 1 | 5 | | | 6 | 13 |
| 2014 | 3 | 6 | 9 | 8 | 4 | 30 | 8 | 27 | 85 | 24 | 14 | 158 | 31 | 68 | 255 | 63 | 15 | 432 | 620 |
| Poor | 3 | 1 | 3 | 5 | 1 | 13 | 5 | 10 | 36 | 6 | 6 | 63 | 8 | 35 | 69 | 22 | 7 | 141 | 217 |
| Angle | 1 | | 1 | 2 | | 4 | | | 4 | 3 | | 7 | | 2 | 4 | 2 | | 8 | 19 |
| Fixed Object | 2 | | 2 | 1 | | 5 | 1 | 5 | 9 | | | 15 | 5 | 9 | 25 | 11 | | 50 | 70 |
| Non-Fixed object | | 1 | | 1 | 1 | 3 | | 3 | 12 | 2 | 6 | 23 | 1 | 8 | 11 | 1 | 6 | 27 | 53 |
| Other | | | | 1 | | 1 | 4 | 2 | 8 | 1 | | 15 | 2 | 14 | 25 | 7 | 1 | 49 | 65 |

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