A GDP-weighted First-Order Approximation of Energy Equivalence of Safety Framework

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National Renewable Energy Laboratory (NREL)
TRB Annual Meeting
January 12, 2020

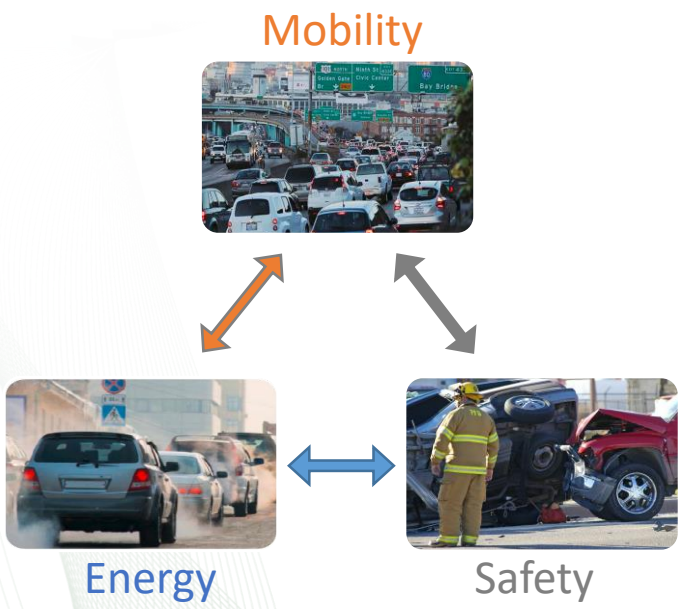
Outline

- Introduction
- Motor Vehicle Crashes and Impact
- GDP-weighted Energy Equivalence of Safety
- Results and Discussion
- Conclusions

Introduction

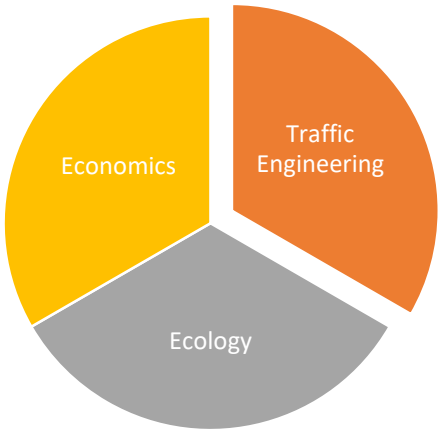
- Motor vehicle crashes lead to significant economic cost and societal harm
  - 6,453,247 crashes with 34,247 fatal crashes in 2017
  - direct economic cost of crashes accounted for about 1.6% (US$ 242 billion) of the U.S. GDP in 2010

- Almost 50% of crashes occur at intersections, where severe crashes are more likely to occur.
- A framework is needed
  - to understand long-term energy/fuel consequences
  - to be compatible with available economics, energy, and safety statistics
  - to strength the connection between safety and energy



Energy Equivalence of Safety Framework

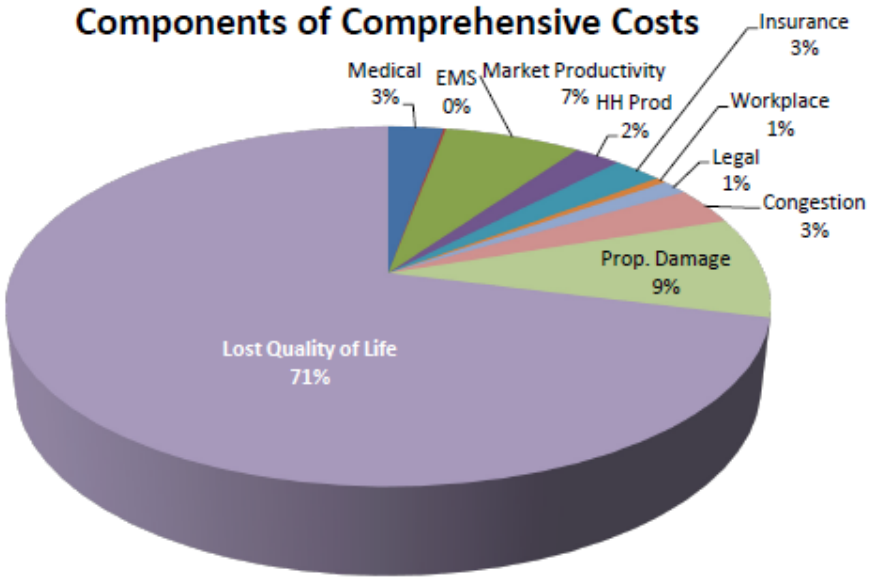
- Attempt for **a holistic view** of the long-term impact of motor vehicle crashes
  - Economics
    - Tangible losses: US GDP per capital in 2018: US$ 54,000 ➔60 year* of lost productivity mounts to US$ 3.4 million per fatality
    - Intangible losses: lost quality-of-life resulted from injury
  - Ecology
    - Embodied energy: all the available energy that has been used directed and indirectly to make an ecosystem component (e.g., human)
  - Traffic Engineering
    - Unify the multiple-dimensional assessment among the three pillars of modern transportation system: mobility, safety, and energy



* 2018 U.S. life expectancy: 78.7 yrs.

Energy Cost of Crashes

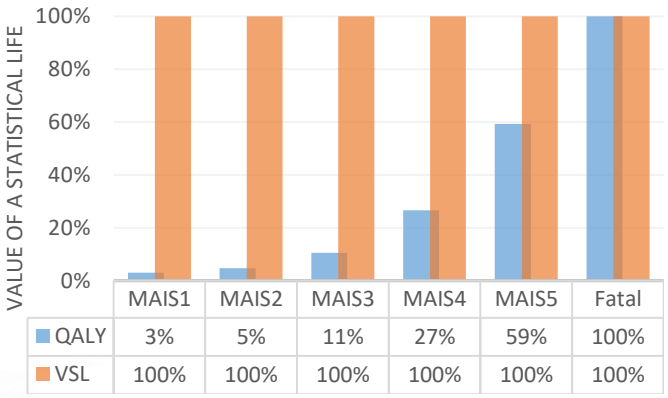
- Comprehensive costs in the Energy Equivalence of Safety (EES) framework
  - **Direct costs:** fuel wasted during induced congestion, energy impacts of medical rehabilitation, societal, legal, and lost productivity, etc.
  - **Indirect costs:** Lost quality of life energy cost: economic cost that society is willing to pay to reduce the risk of injury and fatality crashes.



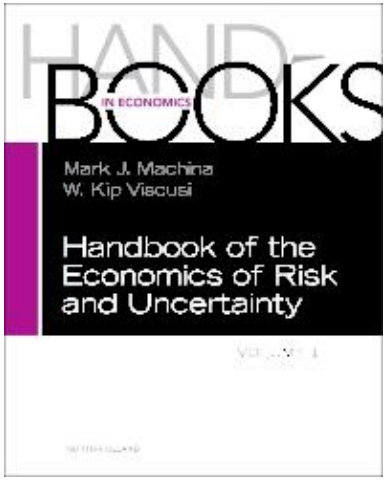
Source: NHTSA (Blincoe et al. 2015)

Indirect Cost -Value of a Statistical Life

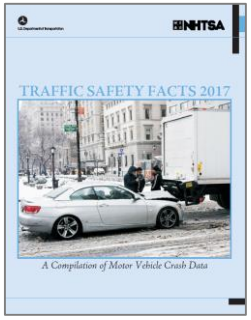
- The Value of a Statistical Life (VSL)
  - used by government agencies to value benefits for policy-making over the past three decades.
  - accounts for the largest component of all new regulation benefits
  - often **misinterpreted** as the "value of a life"
  - "value of mortality risk" or "value of risk

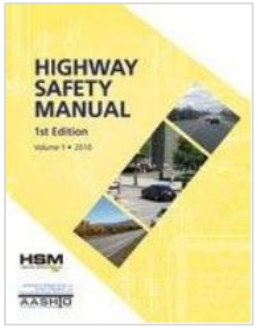


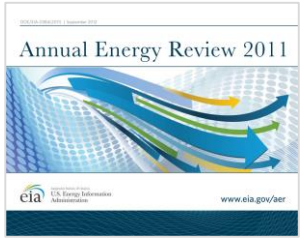
Policy	VSL Value ($2012)	Agency
1985 protective breathing equipment	US$ 1.3 million	FAA
2000 tire pressure monitoring systems regulation	US$ 4.2 – 6.6 million	NHTSA
2005 Final Clean Air Mercury Rule	US$ 7.5 million	EPA
2010 Hazard Communication Final Rule	US$ 8.7 million ($ 2009)	OSHA
2011 Hours of Service of Drivers	US$ 6.3 million	FMCSA



The Energy Equivalence of Safety Framework







From Economic Cost to Energy Cost?

NHTSA crash data

HSM crash cost

EIA energy consumption

National/regional economic statistics: GDP, CPI, MUWE index*

adjusting

Direct & indirect economic crash costs

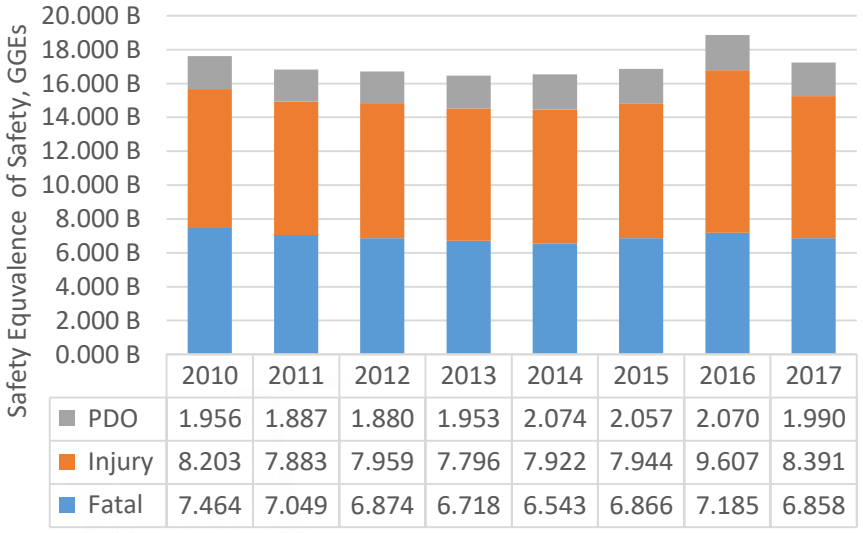
Energy equivalence rate (EER)

Energy equivalence of safety (EES) crash cost

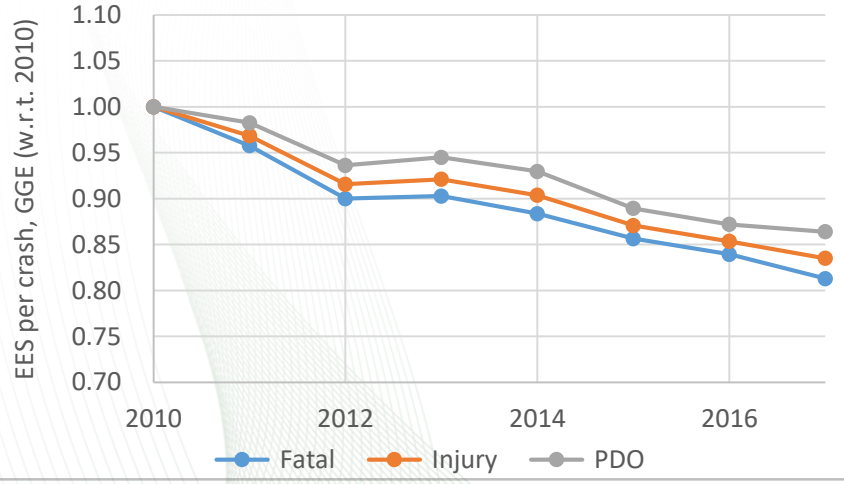
* Median usual weekly earning index

EES Analysis Results

- Total EES for crashes was at
  - 17.62 billion GGE in 2010
  - 16.46 billion GGE in 2013
  - 18.86 billion GGE in 2016
  - 17.24 billion GGE in 2017
- CRSS (Crash report Sampling System) scope expanded by NHTSA in 2016.
- Overall EER exhibits a decreasing trend from 2010 (0.057 GGE/$) to 2017.

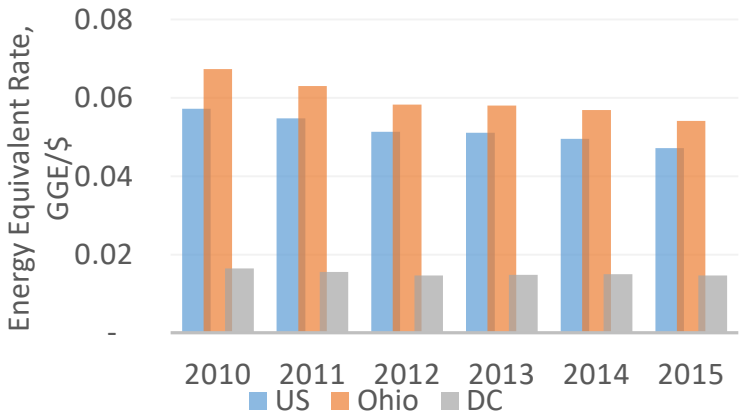


	2010	2011	2012	2013	2014	2015	2016	2017
PDO	1.956	1.887	1.880	1.953	2.074	2.057	2.070	1.990
Injury	8.203	7.883	7.959	7.796	7.922	7.944	9.607	8.391
Fatal	7.464	7.049	6.874	6.718	6.543	6.866	7.185	6.858



State and Local Level Applicability

- Applicable to state and local levels
- Significant role of EER in determining the value of EES
- Low EER by higher energy productivity efficiency
  - 30% employment from government sector
  - 2% employment from goods-producing sector



	Crash Number			EES per crash, GGE		
	Fatal	Injury	PDO	Fatal	Injury	PDO
2010	25	5,060	12,870	70,694	1,526	146
2011	27	5,210	12,714	66,981	1,463	142
2012	18	5,258	13,152	63,155	1,388	136
2013	29	5,358	14,069	64,462	1,420	139
2014	24	5,811	15,704	65,817	1,453	143
2015	26	6,215	18,024	65,582	1,440	141

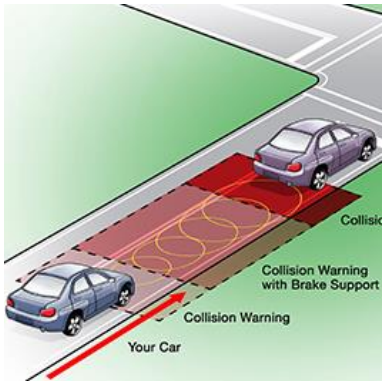
EES Analysis for DC

	Crash Number			EES per crash, GGE		
	Fatal	Injury	PDO	Fatal	Injury	PDO
2010	984	74,426	224,750	289,969	6,261	598
2011	942	73,771	223,118	271,376	5,926	575
2012	1,024	72,105	213,956	252,037	5,537	541
2013	918	69,104	199,056	252,558	5,564	546
2014	919	69,917	211,532	249,987	5,520	543
2015	1,029	75,107	226,169	241,912	5,310	518

EES Analysis for Ohio

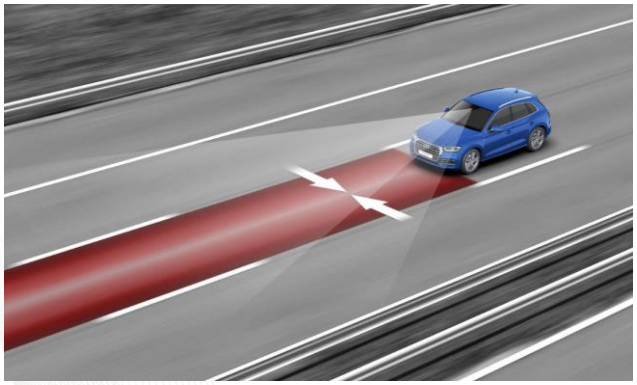
Reducing Crashes -Vehicle Side

- **Advanced technologies to reduce motor vehicle crashes**
  - Advanced Driver-assistance Systems (ADAS)
    - Forward Collision Warning (750 annual fatal crash reduction*)
    - Lane Departure Warning (9000 annual fatal crash reduction*)
    - Blind Spot Monitoring (280 annual fatal crash reduction*)
  - Highly-automated Vehicles (SAE Lv. 4 or 5)



Forward Collision Warning

Blind Spot Monitoring

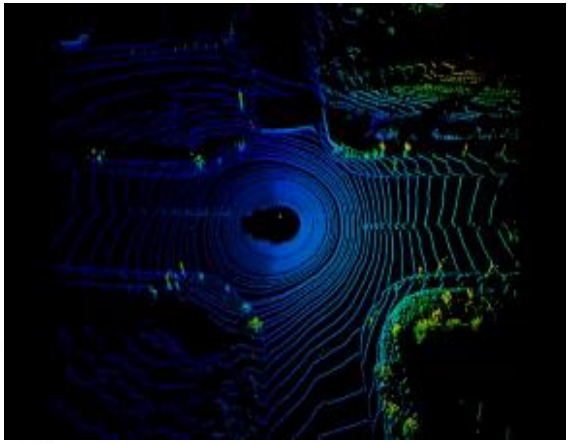


Lane Departure Warning

* Harper, C. D., Hendrickson, C. T., & Samaras, C. (2016).

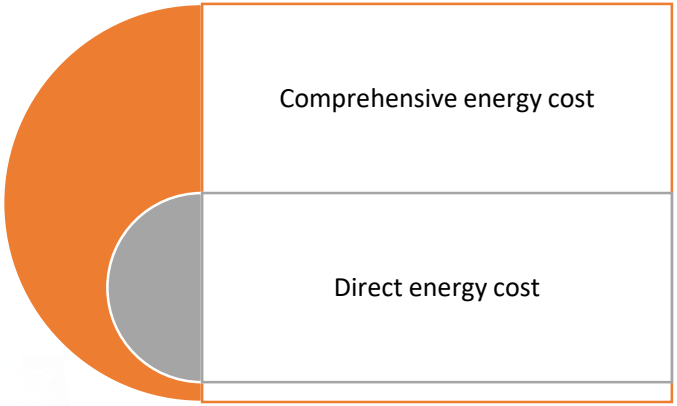
Reducing Crashes -Infrastructure Side

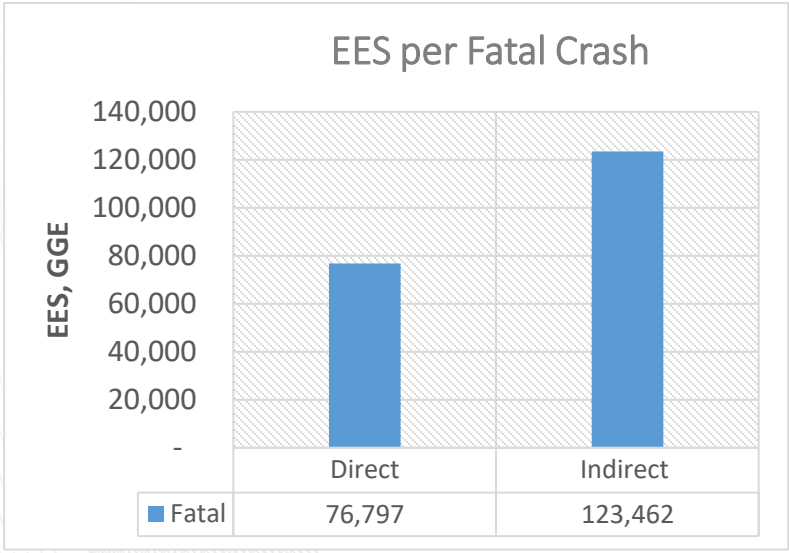
- Advanced spatial sensing technology
  - Advantages
    - Tracks all objects (vehicles, bicycles, pedestrians, animals)
    - High-resolution data
    - Day and night, all conditions
    - More cost-effective
  - Applications
    - Impending safety hazards (red-light running) protection
    - Eco-approach/driving
    - Traffic flow optimization



Conclusion

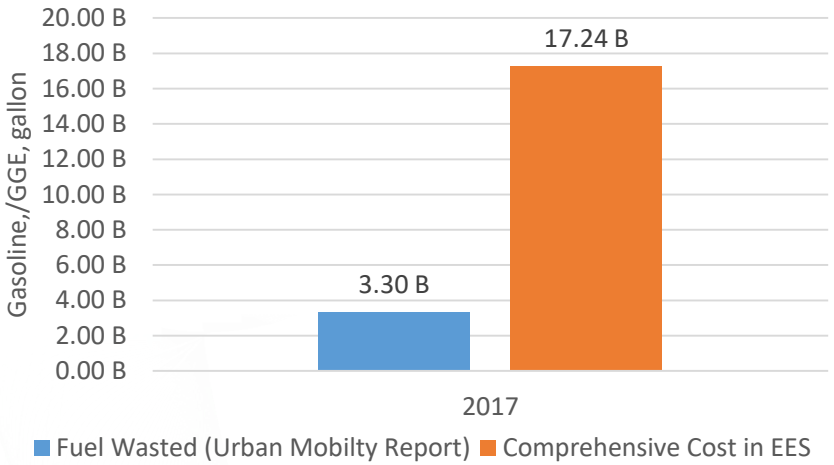
- This study offers a framework of GDP-weighted energy equivalences of safety (EES) that
  - provide a holistic view of the value of safety
  - compatible to available economics, energy, and safety statistics
  - applicable to national, state, and local levels crash analysis
  - consider the economic composition of analysis regions
- The total GDP-weighted EES for U.S. is estimated at 17.24 billion GGE in 2017.
- The energy costs per fatal crash is valued at 200,259 GGE in 2017.





Final Thoughts

- Magnitude of the comprehensive crash cost
- VSL value: US$ 2.7 million for fatality compared to 9.6 million as recommended by USDOT in 2016
- Contentiousness of converting crash cost to energy



*"While **economists** ignored nature, **ecologists** pretended humankind did not exist. Rather than sully their science with the uncertainties of human affairs, they sought out pristine patches in which to monitor **energy flows** and population dynamics."*

-J. R. McNeil, professor, environmental historian

	Direct Cost, GGE	Comprehensive Cost, GGE	Ratio
Fatal	76,797	200,259	2.6
Injury	2,729	4,442	1.6
PDO	395	439	1.1

Unit EES Cost for Crash Type

Thank you!
Q&A
Contact: zijia.zhong@nrel.gov

EES Calculation

- $Direct\ cost_{\ 201x} = Direct\ cost_{2001} \times \frac{CPI_{\ 201x}}{CPI_{\ 2001}}$ (1)
- $Indirect\ cost_{\ 201x} = Indirect\ cost_{2001} \times \frac{MUWE_{\ 201x}}{MUWE_{\ 2001}}$ (2)
- $Economic\ cost\ \ of\ Crashes(\$) = Direct\ cost\ (\$) + Indirect\ cost(\$)$ (3)
- $EER = \frac{Energy\ consumption}{GDP}$ (4)
- $EES = Economic\ cost\ of\ safety\ (\$) * EER\ \left(\frac{GGE}{\$}\right)$ (5)