平時時の交通と安全 ~交通安全の変遷と展望~

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「これからの交通安全」
“Traffic Safety in the Future”
Session by IATSS Symposium Department

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Transportation Safety and Operator Fatigue: Where Biology Needs Technology
Four key points

I. Transportation systems involve continuous operations.

II. Healthy sleep is essential to operate a motor vehicle safely.

III. Driving sleepy is common and a risk to transportation safety.

IV. Driver incapacitation from sleep loss requires novel solutions.
I. Transportation systems involve continuous operations.

A. 24-hour operations in transportation modalities

B. Inadequate sleep has been associated with major transportation accidents

C. The commute conundrum: Evidence that time spent driving can affect sleep time
Contributors to human behavior 24/7

- global economy (investment markets, banking, etc.)
- proliferation of around-the-clock industries
- widespread use of nonstop automated systems
- increased exposure to night shift work
- growing trend toward prolonged work hours
- overnight and just-in-time delivery
- emergency operations
- physical access to entertainment, shopping, etc.
- internet access around the clock
- early school start times coupled with later bed times
- life style chronic sleep restriction
- 24-h vigilance by police and military
- increased international commercial aviation

Human activity often exceeds human sleep requirements

Commercial airplane flights in a 12-h period—each yellow dot is an airplane

Earth is rotating on its axis from left to right.
Driving with inadequate sleep results in fatigue, sleepiness, and drowsiness that pose a significant risk

- Fatigue can be a risk to safety in general, and driving in particular. (Mitter et al., 1988; Dinges, 1995; Lyznicki et al., 1998; Stutts et al., 2003; Barger et al., 2005)

- Fatigue is the physiological consequence of inadequate sleep. (Dinges et al., 1997; Belenky et al., 2003; Van Dongen et al., 2003; Banks et al., 2010, 2011)

- Sleep loss degrades the ability to remain awake, alert and reactive. (Lim & Dinges, 2008, 2010; Basner & Dinges, 2011; Roehrs et al., 2011)

- Sleep loss induced performance deficits equivalent to alcohol limits. (Dawson & Reid, 1997; Williams & Feyer, 2000; Williams et al., 2001; Roehrs et al., 2003).

- Driving drowsy is common and frequently results in injury and fatality. (Pack et al., 1995; Philip et al., 2001; Connor et al., 2002; Flatley et al., 2004).

- Driving drowsy had a 4-6 times higher crash risk relative to driving alert, and a higher crash risk than distracted driving. (Klauer et al., 2006)

Excessive sleepiness is a common and serious problem due primarily to life style decisions and secondarily to medical disorders and medications

- Most common cause—Insufficient sleep syndrome

- Shift work and jet lag disorders

- Obstructive sleep apnea syndrome

- Narcolepsy and hypersomnolence syndromes

- Certain insomnias
II. Healthy sleep is essential for the alertness required to operate a motor vehicle

A. Evidence for the biological basis of sleep need

B. Evidence on how acute and chronic sleep loss affect alertness and performance

C. Evidence that sleep need can pose a performance risk equivalent to alcohol
Sleep has not been eliminated by evolutionary adaptation. It is ubiquitous in the animal kingdom when defined by behavioral criteria (sans EEG).

- behavioral quiescence
- stereotypical posture
- reduced response to stimulation
- spontaneously reversed in <24h
- resists deprivation
- increased following deprivation
- no EEG criteria required

On the basis of these criteria, we can conclude that "sleep" is present throughout the animal kingdom. It has been identified in alligators, turtles, lizards, frogs, salamanders, bees, wasps, flies, dragon flies, grasshoppers, butterflies, scorpions, and the primitive invertebrate sea hare. Its presence in simpler animal models (C. elegans, Zebrafish, Drosophila melanogaster).

Sleep continuity, intensity and duration provide the "recovery" that restores alertness: Sleepiness increases when any of these aspects are denied.

During sleep the brain is dynamically reorganizing. Abrupt awakenings at these times reveals an inability to use cognitive functions such as working memory.

- waking EEG
- sleepy (eye closed; 8-12 cps)
- stage 1 non-REM (3.5-7 cps)
- stage 2 non-REM (some 0.5-3 cps)
- stages 3+4 slow wave sleep (SWS) (0.5-3 cps)
- rapid eye movement sleep (REM)
Earth’s orbital mechanics are instantiated in (and entrain) a circadian genetic “clock” and sleep need in the human brain.

Genes enforce the imperative of daily sleep and its timing.

**Melatonin receptor binding on the human suprachiasmatic nucleus (SCN)**

**The SCN is the master biological (circadian) clock**

Our circadian clock also has strong influence over the timing of our sleep periods (sleep duration)

Circadian timing from home dictates sleep duration in long-haul pilots.

Duration of 247 layover sleeps in long-haul commercial pilots flying Pacific routes

Rosekind et al. (1994)

Meta-analysis of the impact of 24-48h total sleep deprivation on cognitive performance

Impact of 48h total sleep deprivation on speed and accuracy measures in 6 cognitive categories:

70 articles (147 cognitive tests) met inclusion criteria.

Both speed and accuracy were affected across cognitive domains.

Effect sizes were largest for lapses in simple attention, and smallest (nonsignificant) for reasoning accuracy

<table>
<thead>
<tr>
<th>Outcome variable</th>
<th>Combined effect size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple attention</td>
<td>-0.762***</td>
</tr>
<tr>
<td>Lapses</td>
<td>-0.732**</td>
</tr>
<tr>
<td>Reaction time</td>
<td>-0.479**</td>
</tr>
<tr>
<td>Complex attention</td>
<td>-0.312**</td>
</tr>
<tr>
<td>Accuracy</td>
<td>-0.245</td>
</tr>
<tr>
<td>Reaction time</td>
<td>-0.302**</td>
</tr>
<tr>
<td>Processing speed</td>
<td>-0.555**</td>
</tr>
<tr>
<td>Accuracy</td>
<td>-0.515**</td>
</tr>
<tr>
<td>Reaction time</td>
<td>-0.383*</td>
</tr>
<tr>
<td>Working memory</td>
<td>-0.378*</td>
</tr>
<tr>
<td>Accuracy</td>
<td>-0.125</td>
</tr>
<tr>
<td>Reasoning</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td></td>
</tr>
</tbody>
</table>

*p<.01,   **p<.001

Lim & Dinges (2010)
No matter what humans are doing—sleepiness can intrude into wakefulness even in highly motivated and well trained individuals engaged in safety-sensitive activities. B747 transoceanic flights: EEG microsleeps from TOD to landing; No in-flight nap; 40-min in-flight nap. Illustration of wake state instability due to sleep loss: PVT lapses of attention and uneven performance. Stable responses after an 8-hr sleep opportunity; instability = 0 lapses. Unstable responses after a night without sleep; instability = 33 lapses.
Drowsy driving crash risk varies across the day in a manner reflecting (nonlinear) circadian and sleep need dynamics.

USA National Highway Traffic Safety Administration (NHTSA) estimates driver fatigue annual costs to be:

- $12.5 billion
- 100,000 police-reported crashes
- 1,550 deaths (4% of fatalities)
- 71,000 injuries

Lapses are errors of omission and when they occur errors of commission can increase.

Neuroimaging evidence shows lapses when sleepy involved distributed brain areas.

Time of day of 4,333 highway crashes in which the driver was judged to be asleep but not intoxicated.

(Pack et al., 1995)
A drowsy driving crash requires a lapse of only a few seconds to result in a crash.

Sleep loss is cumulative and people are often not aware of how much it is affecting alertness and performance.

Vigilance lapses occur more frequently with each day of sleep duration below 7 hours.

Vigilance lapses increased across days of sleep restriction, but ratings of fatigue changed much less.

Coefficients for cognitive functions were near linear.

Coefficients for subjective impressions were saturating.
Studies equating the effects of alcohol on performance to those of time awake on performance have found 18h awake ≈ 0.05 g%

(8 other studies also equate prolonged wakefulness with BAC >0.04 g%)

In the USA fall asleep crashes are often as lethal as alcohol crashes

Dawson & Reid (1997)

Pack et al. (1995)

III. Driving sleepy is common enough to be a concern in transportation safety

A. Evidence that driving sleepy is common

B. Evidence that driving sleepy increases crash risk
USA National Survey of Distracted and Drowsy Driving Attitudes and Behaviors: 2002

- Telephone interviews with nationally representative survey of 4,010 drivers (age ≥ 16 yr)
- 37% of the driving population reports having nodded off or fallen asleep while driving at some time in their life. Males (49%) are more likely to report this than female drivers (26%).
- About 22% of male drivers who have nodded off at the wheel report having done so within the past month, compared to 19% of females.
- Among drivers who had a drowsy driving event in the past 6 months
  - 28% reported it occurred between midnight and 6:00 a.m.
  - 35% reported it occurred between 6:00 a.m. and 5:00 p.m.
  - 17% reported it occurred between 5:00 p.m. and 9:00 p.m.

Submitted to the National Highway Traffic Safety Administration by The Gallup Organization.
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National Survey of Distracted and Drowsy Driving Attitudes and Behaviors: 2002

- Average of 6 hours sleep reported the night prior to a drowsy driving experience
  - 24% reported having just ≤4 hours of sleep the prior night
  - 26% reported having 6 hours sleep the prior night
  - 33% reported having ≥7 hours of sleep the prior night

- Drowsy drivers under age 30 reported an average of 5.5 hours of sleep the night before they nodded off at the wheel. The average sleep time of drowsy drivers increased with age. Those ≥ 65yr reported episode after an average of 7.7 hours of sleep

- Relatively few drivers who nod off at the wheel report having had consumed alcohol (2%) or allergy or other medications (12%) prior to their trip

Submitted to the National Highway Traffic Safety Administration by The Gallup Organization.
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When feeling sleepy while driving, 43% say they pull over and nap (especially males); 26% open a window to get air; 17% get a coffee or soda to drink; 14% turn on the radio or increase its volume; 3% sing/talk

92% of drivers who have nodded off while driving within the past 6 months report that they startled awake.
- 33% wandered into another lane or onto the shoulder
- 19% crossed the centerline
- 10% ran off the road

While it happened in only about 2% of the most recent drowsy driving episodes, it is estimated that approximately 292,000 drivers were involved in some type of crash within the past six months as a result of nodding off at the wheel.

NHTSA (2002)
“NHTSA data indicate that in recent years there have been about 56,000 crashes annually in which driver drowsiness/fatigue was cited by police. Annual averages of roughly 40,000 nonfatal injuries and 1,550 fatalities result from these crashes. It is widely recognized that these statistics underreport the extent of these types of crashes. These statistics also do not deal with crashes caused by driver inattention, which is believed to be a larger problem.”

NHTSA (2002)
While the proportion of drivers involved in a crash as a result of nodding off at the wheel is very small, the actual numbers of drivers involved in such crashes over the past five years is sizable. An estimated 1.35 million drivers have been involved in a drowsy driving related crashes in the past five years (270,000 crashes annually). About seven in ten of these drivers, or 972,000 were males, while 379,000 were females.
Driving sleepy has been found to be a significant factor in injury-related and fatal crashes in many countries

- **New Zealand**: “There was an eightfold increased risk if drivers reported sleepiness and almost a threefold risk for drivers who were driving after five hours or less of sleep.” (Connor et al., 2002)

- **France**: A survey of 67,671 crashes in France determined 10% were fatigue related. (Philip et al., 2001)

- **United Kingdom**: The authors of a recent study that examined 1828 crashes in the UK reported that 17% of the accidents resulting in injury or death were sleep related. (Flatley et al., 2004)

Drowsy driving in metropolitan Washington, DC, USA was found to be as common as distracted driving, and it occurred more often during daylight/lighted conditions.

“It appears driving drowsy during the daylight may be slightly riskier than driving drowsy in the dark. While it is commonly thought that most drowsiness-related crashes occur at night, a majority of the drowsiness-related crashes in this study occurred during the daytime in heavy traffic (during morning and evening commutes). Thus, the risks of driving drowsy during the day may be slightly higher than at night due to higher traffic density.” (p. 41)

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People often believe they can drive and work (even on safety-sensitive tasks) when they have a sleep debt.

Drowsy driver crashes cost $12 billion and contribute to a third of the ~4,000 annual truck driver deaths in the US.

Study of 406 commercial truck drivers found increases in subjective sleepiness (ESS), MSLT, and performance (PVT, DADT) were linearly associated with shorter sleep durations, but associations with severity of sleep apnea were not as robust and not strictly monotonic. Severe sleep apnea (AHI >29/h) was found in 4.7% of drivers, while sleep duration <5h/night was found in 13.5% , and these conditions were similar in their impact on objective sleepiness.

Pack A. et al. Impaired Performance in Commercial Drivers: Role of Sleep Apnea and Short Sleep Duration; AJRCCM, 174:446–454, 2006

Truck drivers are at risk for drowsy driving crashes from sleep disorders and work-rest schedules.

Pennsylvania, USA (2000)

Hazmat crash (sulfuric acid)

Closed one of the busiest highways in the US for 24 h
UK (2001): A motor vehicle operator who had been awake all night began driving his Land Rover at 05:00 h. He fell asleep at the wheel, veered off the motorway and lodged his vehicle on the southbound East Coast railway line. After exiting his vehicle, a commuter train traveling 125 mph smash into his vehicle. The southbound train was derailed, only to collide with a northbound freight train running at 60 mph. The crash killed 10 and injured >60. The driver was convicted of 10 counts of causing death by dangerous driving.

Bus drivers are at risk for drowsy driving crashes from sleep disorders and work-rest schedules

Bus driver with sleep debt and untreated sleep complaint (could sleep only 3-4h)
Pennsylvania, USA (1998)
7 killed, 16 injured

Bus driver had <4h sleep in 51h, stayed awake to gamble,
New York, USA (2002)
5 killed, 42 injured

Sleep-related crash involving two modes of transportation
Sleep loss has contributed to serious maritime catastrophes

People have difficulty believing that a human can make a fatigue-related error while performing an over-learned task under highly motivated (even life-threatening) conditions. But it happens because fatigue is a risk state that degrades behavioral efficiency. These maritime allisions illustrate this point.

Using technology to help manage fatigue

IV. Are there solutions to driver incapacitation from sleep need?

A. Is education to avoid sleepy driving likely to be effective?

B. Are increased rest stops a cost-effective solution without unintended consequences?

C. Are vehicle technologies feasible that safely inform, warn and/or alert sleepy drivers?
Maintaining Human Behavioral Capability: Where Biology Needs Technology

Why technologies can help humans cope behaviorally

- Performance is dynamically nonlinear (C+S)—work rules aren’t
- Large differences among people in neurobehavioral vulnerability
- Lack of awareness of relationship between “fatigue” and risk
- Need to inform people of when recovery is essential & how much

Accurate feedback regarding an individual’s sleepiness level
  - evaluate clinically for treatment needs
  - to prevent/reduce imminent risk
  - to manage fatigue from life style

Sleep and circadian drives in the brain interact to control performance and alertness: Mathematical models attempt to predict this performance timing

Two-process model: oscillator interacting with a quasi-linear process

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Tracking astronaut alertness with the **PVT-B (Reaction Self Test)** during 6-month missions on the International Space Station (ISS)

Study of effects of feedback on driver sleep and sleepiness

- **WRAIR SleepWatch**
- **SafeTRAC lane-tracking monitor**
- **CoPilot infrared retinal reflectance monitor**
- **PVT-192**
- **Howard Power Center Steering System**
- **Eye images from CoPilot**

Dinges DF et al (2005)
During night driving, fatigue feedback decreased lane tracking variability (p < 0.0001)

Expected “alertness” decreased after hour 8 of night driving.
Feedback improved lane tracking at night in commercial truck drivers

Feedback by driving time interaction was significant $P<0.0001$


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Drowsiness has a characteristic neurobehavioral profile

PERCLOS refers to the percent of time slow eyelid closures cover the pupil. PERCLOS was the best predictor of PVT lapses of attention.

Changes in neurobehavioral markers can reflect sleepiness—tracking ocular sleepiness

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Pack et al. (1995)

Dinges et al. (1998); Dinges et al. (2002)
Measure of sleepiness based on optical computer recognition (OCR) of eyelids (levator palpebrae superioris muscle)

No sleep deprivation
PVT lapses = 0 in 1-min video below
4 in 20-min test bout
Eyes closed epochs = 125 (4.1 sec)
Avg. blink duration = 132 ms

Sleep deprivation
PVT lapses = 4 in 1-min video below
42 in 20-min test bout
Eyes closed epochs = 308 (10.2 sec)
Avg. blink duration = 205 ms (+54%)

Research supported by:
USA National Institutes of Health (NINR, NHLBI, NCRR)
NASA & National Space Biomedical Research Institute
Department of Transportation; Department of Defense

Colleagues, collaborators, trainees and technical staff

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Prof. Ekkehard Brühning / Germany

Traffic Safety in Japan and Germany – Success, Deficiencies, Future Potentials
Traffic Safety in Japan and Germany – Success, Deficiencies, Future Potentials

Director and Professor a.D.
Dr.-Ing. Ekkehard Brühning

Similarities in motorization and road safety in 2010

<table>
<thead>
<tr>
<th>Japan</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital: Tokyo</td>
<td>Capital: Berlin</td>
</tr>
<tr>
<td>128 million inhabitants</td>
<td>81.8 million inhabitants</td>
</tr>
<tr>
<td>646 vehicles / 1000 inh.</td>
<td>614 vehicles / 1000 inh.</td>
</tr>
<tr>
<td>5,745 road fatalities</td>
<td>3,648 road fatalities</td>
</tr>
<tr>
<td>4.5 fatalities / 100,000 inh</td>
<td>4.5 fatalities / 100,000 inh</td>
</tr>
</tbody>
</table>

IRTAD (2011)
Reasons for safety improvements

- **Engineering**
  (road, vehicle, traffic planning, ...)
- **Legal measures**
  (speed, alcohol, safety belt, ...)
- **Education**
  (driver training, pedestrian behaviour, ...)
- **Enforcement**
  (police ...)
- **Emergency Medical Service at road accidents**

### Downward trend in fatality figures

<table>
<thead>
<tr>
<th></th>
<th>1990</th>
<th>2010</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatalities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>14595</td>
<td>5745</td>
<td>- 60 %</td>
</tr>
<tr>
<td>G</td>
<td>11046</td>
<td>3648</td>
<td>- 67 %</td>
</tr>
<tr>
<td>Fatalities / 100 000 inhabitants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>11.8</td>
<td>4.5</td>
<td>- 62 %</td>
</tr>
<tr>
<td>G</td>
<td>14.0</td>
<td>4.5</td>
<td>- 68 %</td>
</tr>
<tr>
<td>Fatalities / billion vehicle-km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>23.2</td>
<td>7.7</td>
<td>- 67 %</td>
</tr>
<tr>
<td>G</td>
<td>20.0</td>
<td>5.2</td>
<td>- 74 %</td>
</tr>
<tr>
<td>Motorization (mot. veh. / 1000 inh.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>216</td>
<td>646</td>
<td>+ 299 %</td>
</tr>
<tr>
<td>G</td>
<td>529</td>
<td>614</td>
<td>+ 116 %</td>
</tr>
</tbody>
</table>

IRTAD (2011)
The German Road Safety Programme 2011 requires for Rural Roads

- Preventing accidents involving a collision with a roadside obstacle
- Motorcycle-friendly safety systems
- Providing additional overtaking lanes to prevent overtaking accidents
- Enhancing road safety at junctions
- Deploying speed monitoring at accident blackspots
- Evaluating measures to prevent accidents involving wildlife
Tree-lined roads in Germany

Example: Dangerous road segment

- Before treatment
- After treatment

Fatally injured pedestrians and cyclists by age group in 2010

<table>
<thead>
<tr>
<th></th>
<th>under 65</th>
<th>65-74</th>
<th>75 and older</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian - J</td>
<td>28.4</td>
<td>22.2</td>
<td>49.5</td>
</tr>
<tr>
<td>Pedestrian - G</td>
<td>52.1</td>
<td>14.9</td>
<td>32.8</td>
</tr>
<tr>
<td>Cyclist - J</td>
<td>37.7</td>
<td>27.2</td>
<td>35.1</td>
</tr>
<tr>
<td>Cyclist - G</td>
<td>48.3</td>
<td>27.6</td>
<td>24.1</td>
</tr>
</tbody>
</table>

National Police Agency (2011)
Statistisches Bundesamt (2011)

Proportion of driving license holders by age and gender

Japanese data derive from 2010 (Ministry of Health, Labour & Welfare/National Police Agency)
Germany data derive from 2004 (Kalinowska et al, 2007) (Okamura, 2011)

Bicycle crossing at a main arterial street in Tokyo
The Japanese Traffic Safety Programme has 3 strategic objectives and 8 pillars.

The 3 strategic objectives are:
1. Safety for the elderly and children,
2. Pedestrian and bicycle safety,
3. Ensuring safety on roads serving the community and on main roads.

Among the 8 pillars are:
1. Improvement of the road traffic environment,
2. Dissemination and reinforcement of traffic safety messages,
3. Safe driving.

There are a great number of possible measures outlined in detail.

Improving road traffic environment
Small streets in a residential area nearby a school

Photos: Nishida (2012)
Fatalities caused by alcohol-impaired drivers

Alcohol is tolerated in most countries/societies – in Germany and Japan, too

Alcohol-related road fatalities

J - 6.0% of all fatalities in 2010
G - 9.4% of all fatalities in 2010
Alcohol-impaired drivers (involved in crashes) per 1,000 driving licenses

Japan in 2006

Germany in 2005

Trend in number of convicted alcohol-impaired drivers

National Police Agency (2011)
Statistisches Bundesamt (2011)
Emergency service at road accidents in Germany

- Arrivals of ambulance vehicle on the accident spot average = 9.0 min
  95 % < 18.4 min
- Arrival of rescue physician on the spot by vehicle average = 12.0 min
  95 % < 26.6 min
- HEMS – Helicopter Emergency Medical Service at 2.5% of road accident emergency cases

Unfallverhütungsbericht Straßenverkehr 2008/2009
HEMS: Helicopter Emergency Medical Service

Ca. 100 air rescue helicopters in G
for medical emergencies of any kind
System established in the 1970s and 1980s
HEMS provided by different organizations

HEM Net (2012)

30道府県
35箇所

30 Prefectures
35 Locations

HEMS: Helicopter Emergency Medical Service

Approximately 100 air rescue helicopters in Japan
for medical emergencies of any kind
System established in the 1970s and 1980s
HEMS provided by different organizations

HEM Net (2012)
Progress in vehicle safety

- Great success in the past through improvements in passive safety

- New horizons through accident avoiding electronic (driver) assistance systems

Passive safety – state of the art

- Stiff Passenger Compartment Cell
- Belt Pretensioner
- Belt Load Limiter
- Multi-Stage Airbags
- “Soft“ Interior Design
- Crash-Design: “Self Protection“
Pre-Crash-Safety
(Crosslinking with systems of the Active Safety)

Benefit for Passive Safety:
  – Collision mitigation
  – Time for optimization of parameters
  – Pre-deployment of airbag

Conclusion:

Future Improvements of Passive Safety – significant, substantial improvement, but not a new “dimension“
Evaluation of (driver) assistance systems

For many years on the market:
- Anti-lock Braking System (ABS)
- Electronic Stability Control (ESC)
- Brake Assist System (BAS)

Evaluation of (driver) assistance systems – Reduction of serious injuries in the EU

TRACE (2009)
“Forward collision avoidance systems, particularly those that brake autonomously, show some of the biggest crash reductions.”

IIHS (2012)

How to increase the market penetration of driver assistance systems?
Mandatory Fitment Requirements for Active Safety Systems in the EU

<table>
<thead>
<tr>
<th>Year</th>
<th>System</th>
<th>Type approval for</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>ABS</td>
<td>Anti-lock Breaking System</td>
</tr>
<tr>
<td>2009</td>
<td>BAS</td>
<td>Brake Assist System</td>
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<tr>
<td>2011</td>
<td>ESC</td>
<td>Electronic Stability Control</td>
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<tr>
<td></td>
<td>DRL</td>
<td>Daytime Running Light</td>
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<tr>
<td>2012</td>
<td>TPM</td>
<td>Tire Pressure Monitoring System</td>
</tr>
<tr>
<td>2013</td>
<td>AEBS</td>
<td>Advanced Emergency Breaking System</td>
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<td>LDWS</td>
<td>Lane Departure Warning System</td>
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<tr>
<td>2014</td>
<td>ESC</td>
<td>Electronic Stability Control</td>
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<td>2016</td>
<td>AEBS</td>
<td>Advanced Emergency Breaking System</td>
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<tr>
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<tr>
<td></td>
<td>AEBS</td>
<td>Increased speed reduction</td>
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<tr>
<td>2016/17?</td>
<td>ABS</td>
<td>Anti-lock Breaking System</td>
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(EU Directives / Regulations)

Euro NCAP Driver Assist
(Decision of 12 June 2012)

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<th>Fitment requirements in EU</th>
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<td>Electr. Stability Controle (= EU Regulation, 2011)</td>
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<td>Advanced Emergency Braking (Inter Urban &gt; 40km/h)</td>
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Euro NCAP (2012)
Arigato / Acknowledgements

for close co-operation and valuable assistance to
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- Nobuaki Takubo, PhD, National Research Institute of Police Science (Kashiwa)
Prof. Werner Brilon / Germany
Reliability of Motorway Operations
1.1. Introduction: What is reliability? Why do we use this term?

2.2. How do we describe reliability?

3.3. How to improve reliability?

4.4. What is the advantage of reliability concepts?
Reliability of Motorway Operation

1. Introduction:
   What is reliability? Why do we use this term?
2. How do we describe reliability?
3. How to improve reliability?
4. What is the advantage of reliability concepts?
Traditional objectives for highway design and operation:

- Safety
- Traffic efficiency
- Economic efficiency
- Environmental compatibility

accident cost rates
speed
ratio: benefit / costs
miscellaneous indicators
Classic macroscopic description of traffic flow: q-v-diagram

- **Average Speed (km/h)**
- **Volume (veh/h)**

**Capacity**

*Example: German HBS 2001: 3-lane freeway*

Traditional objectives for highway design and operation:
- Traffic efficiency
- Speed
- Safety
- Economic efficiency
- Environmental compatibility
- Miscellaneous indicators
Limitations of traditional analysis:

- A single peak hour cannot reflect the whole life cycle of a road infrastructure.
- Highest demands are not considered.
- No assessment of overloaded conditions (LOS F).
- Average speed is not of too much importance to the drivers.
- Small increase of speed does not produce economic benefit.
- Only applicable for proper operation; no consideration of disturbance due to work zones, accidents, incidents, weather.

Consequences:

- We need a modified scale to evaluate traffic performance.
- This concept should be interrelated with traffic safety.
- The concept should focus on the intrinsic purpose of the highway infrastructure.
- The concept must consider incidents, accidents, work zones, etc.

Traditional:

Choice of a specific single peak hour (e.g., 30th hour).
Comparison of this traffic demand and capacity to assess the quality of traffic flow.

Source of pictures: FHWA
Limitations of traditional analysis:

• A single peak hour cannot reflect the whole life cycle of a road infrastructure.
• Highest demands are not considered.
• Average Speed is not of too much importance to the drivers.
• Small increase of speed does not produce economic benefit.
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• The concept should focus on the intrinsic purpose of the highway infrastructure.
• The concept must consider incidents, accidents, work-zones, etc.
• This concept should be interrelated with traffic safety.
Disfunctioning of motorways

Potential reasons for breakdowns on motorways:

• failure of infrastructure
• accidents
• incidents (vehicle malfunction, road closure, …)
• demand exceeds capacity
• work-zones with reduced capacity
• bad weather (storm, snow, heavy rain, bad visibility …)
• other events: like festivals, sporting events, catastrophes, …

Observed reasons for breakdowns on motorways:

More timely Approach to express Traffic Efficiency

Objective of the road user (both passengers and cargo):
• to arrive within a time margin which can reasonably expected.

Scale for traffic efficiency important to the road user:
• risk of a remarkable delay.

→ Reliability

Future Parameters of Traffic Performance

Reliability =
Probability that the motorway operates at a performance level better than a defined minimum standard (i.e. a still satisfactory service quality; e.g. LOS D)

Indicators for reliability:
probability of congestion
delays per year due to freeway overload
duration of all congestions during a year
ratio of real travel time to average travel time
….
Disfunctioning of motorways

Potential reasons for breakdowns on motorways:

- failure of infrastructure
- accidents
- incidents (vehicle malfunction, road closure, ...)
- demand exceeds capacity
- work-zones with reduced capacity
- bad weather (storm, snow, heavy rain, bad visibility...)
- other events: like festivals, sporting events, catastrophes, ...

Disfunctioning of motorways

Observed reasons for breakdowns on motorways:

- Work-zone: 35%
- Overload: 39%
- Accident: 26%
Reliability is a function of:

- basic capacity of the infrastructure
- maintenance of the infrastructure
- performance of control systems
- qualification of operational staff
- quality of vehicles
- behavior of drivers
- weather
- ...

Two basic features of transportation systems:

1. Non-linearity
   - Up to \( \approx 60\% \) of capacity traffic systems are not sensible to moderate disturbances.
   - at-capacity: Small incidents cause severe congestion.

![Graph showing delay vs. degree of saturation](image)
Two basic features of transportation systems:

2. Normal operation (like designed) is happening very seldom. (always more than 10 % of the network are work-zones.)

2. How to measure reliability?

- variability of travel times
  - variance of travel times
  - 95th percentile of travel time
  - travel-time index (TTI) \[ \frac{\text{average travel time}}{\text{travel time (free flow speed)}} \]
  - planning time index (PTI) \[ \frac{95\% \text{ travel time}}{\text{travel time (free flow speed)}} \]
  - buffer index \[ \frac{\text{expected max. lost time}}{\text{average travel time} \cdot 100} \]
- percent of on-time arrivals
- lost times due to congestion
- probability that a driver experiences congestion; i.e. percent failure based on a target minimum speed.
Randomness of Capacity

Pattern over time for traffic volume and speed (1-minute-intervals) for a whole day with several breakdowns.
Randomness of Capacity

Variability of traffic volumes preceding a breakdown

Intervals just before the breakdown

SV-Anteil [%]: 20  10  0
dreistreifig, außerhalb von Ballungsräumen, s ≤ 2%

Pattern over time for traffic volume and speed (1-minute-intervals) for a whole day with several breakdowns
**Randomness of Capacity**

![Graph showing average speed and volume on a freeway with conditions ranging from fluent to congested, and a question mark indicating uncertainty or a query.]

**Deterministic versus Stochastic Capacity**

**Weibull-Distribution for the Breakdown Capacity**

**Density function**

\[
f(x) = \frac{\alpha}{\beta} x^{\alpha-1} e^{-\left(\frac{x}{\beta}\right)^{\alpha}}
\]

**Distribution function**

\[
F(x) = 1 - e^{-\left(\frac{x}{\beta}\right)^{\alpha}}
\]

\(\beta = \) scale parameter \quad \(\alpha = \) form parameter

**Maximum-Likelihood Estimation with Weibull-distribution**

\[
L = \prod_{i=1}^{n} \left[ \alpha \cdot \beta^{-\alpha} \cdot q_i^{-1} \cdot e^{-\left(\frac{q_i}{\beta}\right)^{\alpha}} \right]^{\delta_i} \cdot e^{-\left(\frac{q_i}{\beta}\right)^{\alpha}}
\]

\(\delta_i = \) indicator function
Distribution Function of Freeway Capacity (3 Lanes, 5-Minute Intervals)

- Maximum-Likelihood (Weibull)
- Product-Limit estimation

Deterministic versus Stochastic Capacity

- Maximum-Likelihood (Weibull)
Whole year analysis (WYA) of traffic performance

A year is generally long enough to capture nearly all of the variability caused by various kinds of breakdown and, thus, to represent also longer periods:

Congested situations:
- How often?
- Worst situation to be expected?
- Total impacts?
Whole year analysis (WYA) of traffic performance

Taken into account:
- random variation of capacity and of demand
- capacity drop
- accidents and incidents
- wet road surface capacity reduction

Method:
Monte-Carlo-simulation with multiple evaluation of delays etc. for a whole year
+ subsequent calculation of expectations
Whole year analysis (WYA) of traffic performance

Results:
- duration of congestion
- sum of all delays
- number of vehicles involved
- percentage of vehicles involved
- economic value of delays (all as expectation per year)
- Travel time index, Planning time index, Buffer-index...

can be combined with evaluation of ecological parameters (e.g. fuel consumption,...)

Whole year analysis (WYA) of traffic performance

Number of oversaturations per year

O.1 * ADT / capacity

no. of congestions due to traffic overloads per year

0 0.2 0.4 0.6 0.8 1 1.2
0 100 200 300 400 500 600 700 800 900 1000
Whole year analysis (WYA) of traffic performance

Results from with/without analysis:
- effects of accidents + incidents
- effects of traffic control devices
- effects of organizational improvements
  (fast accident removal, work-zone management,...)
- effects of structural improvements

3. How to improve reliability?
- capacity and infrastructure
  - adequate infrastructural capacity
  - active traffic control
  - temporary hard-shoulder running
  - work-zone management
  - emergency management (accidents & incidents)
  - high-quality construction of infrastructure \rightarrow less maintenance
Adequate capacity of the infrastructure

Example: restructuring of an urban motorway (A620):
- justifies an investment of reduced cost of time: 570,000 €/year
- reduced delays: 76,600 veh/h/year
- improved safety

New layout

Existing infrastructure

Value of travel time [€/year]

Direction MA

Direction Lux

Active traffic control

Motorway traffic control center (with manpower, video supervision, …)

Mandate to take action

(Police, emergency services, traffic control devices, road workers)

Adequate capacity of the infrastructure

Classical capacity

Maximum efficiency in veh*km/h

Average speed [km/h]

Volume [veh/h]

Optimization of efficiency [veh*km/h]

Maximum efficiency is achieved at 90% of the classical capacity

Classical capacity
Appraisal of motorway design schemes by WYA

**example: restructuring of an urban motorway (A620):**

- Reduced cost of time: 570,000 €/year
- Reduced delays: 76,600 veh·h/year

justifies an investment of 8.4 Mio €

+ improved safety

---

**Active traffic control**

Motorway traffic control center
(with manpower, video supervision, ...)

+ mandate to take action
(police, emergency services, traffic control devices, road workers)
Temporary hard shoulder running

- only during peak hours
- always with a speed limit of 100 km/h
- + 25 % capacity
- no additional risks

Work-zone management

Work-zones reduce capacity \rightarrow reduced reliability
Freeway Sections with work-zone (5-Minute Intervals)

Freeway A3, 4+2 scheme

Freeway A5, 5+1 scheme

Median Capacity -9.4%

Median Capacity -16.7%

Standard deviation is significantly lower

Median of capacity distribution of a construction zone (3-lane carriageway) is in the range of 6000 to 6300 veh/h

Work-zone management

a) timing of construction works and maintenance
   (e.g. during holiday season; in off-peak periods;…)

b) reduction of work-zone duration
   by rewarding construction firms for work acceleration

to be tested by WYA
3. How to improve reliability?

- Time dependent tolls
- Demand management (e.g., rewards for off-peak travel; (e.g., NL: Sitsmijden))

Seattle freeway reliability scheme

Source of picture: WS-DOT

Emergency management (incidents & accidents)

- Less accidents → More reliability

  Everything which avoids accidents will improve the reliability of the system.

- Reduction of the duration of lane closures due to accidents
  - Modified strategies for the police
  - Presence of tow-trucks during peaks at bottlenecks

- Charging drivers (accidents & incidents) according to the degree of congestion caused (conceptual)
3. How to improve reliability?

- **Demand**
  - time dependent tolls
  - demand management
    (e.g. rewards for off-peak travel; (e.g. NL: Sitsmijden)
    better information about expected travel times, …)

Seattle freeway reliability scheme

source of picture: WS-DOT

---

3. How to improve reliability?

**Best time to leave**

Where are you starting from:  
Seattle

Where are you going?  
Redmont

When do you need to et there?  
8:25

Your 95% travel time is 31 minutes.
95% of the time
you would need to leave at 7:54 AM to arrive by 8:25 AM.

source of picture: WS-DOT
3. How to improve reliability?

- Smoothening traffic flow
  - Traffic adaptive speed control
  - Truck overtaking restrictions (above specified levels of traffic flow)
  - Ramp metering
  - Integration of in-vehicle and stationary guidance systems
  - Driver education

Active adaptive speed control

With additional temporary truck overtaking prohibition
Impact of dynamic speed control

- 40% of delays per year

Impact of dynamic speed control on safety

Accident rate: before/after analysis at 10 traffic actuated speed control sites (Siegener et al. 2000)
Travel time indication by navigation systems teaches drivers that aggressive driving does not save travel time.

**Ramp metering**
- Bochum / Germany
- UK

**Travel time indication**
- Frankfurt / Germany
- Paris
Travel time indication by navigation systems teaches drivers that aggressive driving does not save travel time.

Traditional concept

Reliability concept

source of pictures: FHWA
Conclusions

Safety is target #1 beyond safety the central objective for motorway design and operation. Reliability is key to reliability management. WYA (whole year analysis) is an adequate method for analysis in addition to infrastructure organizational (soft) measures. Reliability and safety complement each other: they are two sides of the same medal.

Advantage of Reliability Concepts

- Reliability is more important than speed both for travelers and cargo.
- Reliability paves the way towards traffic performance based on:
  - infrastructure improvements
  - traffic control measures
  - organizational input
- Full integration of overloaded situations (LOS F) into the system of performance assessment.
- More reliability → more safety
- These integrated concepts meet today’s necessities
Conclusion

- Safety is target #1
- Beyond safety the central objective for motorway design and operation → Reliability
- Mathematical description of breakdown probabilities = key to reliability management
- WYA (whole year analysis) = adequate method for analysis
- In addition to infrastructure organizational (soft) measures provide a significant contribution to improved reliability.
- Reliability and safety complement each other: = 2 sides of the same medal.

Thank you for listening
Dr. Dominique Fleury / France
交通安全への地域的アプローチに関する研究
Research on the territorial approach to safety
The trend of safety in France: from 8,253 deaths in 2001 to 3,963 in 2011

Research on the territorial approach to safety

• The evolution of the territorial approach to safety
• Safety as an area of complex system management.
• The conditions for improvement
I - The evolution of the territorial approach to safety

How safety had structured traffic network design

• 19th century: the development of motorised transportation has a tremendous impact.
• Great specialisation of traffic areas (according to speed)

Cerda, Henard, Le Corbusier, ..

Principles of segregating modes of transportation and the hierarchy of roads

How safety had structured traffic network design

• Buchanan

Principle of environmental area

• The SCAFT guide of 1968

- Reduce traffic by localising activities
- Separate modes of transportation
- Differentiate the network by functions
- Differentiate the various traffic flows
- Clarify, simplify and standardise the design
- Design a safe road side
How safety had structured traffic network design

The "Woonerf" in the 70's

Integrating modes and functions
"traffic calming" principles

The dynamic of design resulting from an “Island Strategy”

Controversies

30-km/h city
- In Great Britain, Living Streets has launched a campaign to reduce speed in London to 20 mph.
- In Switzerland, ATE (Association of Transports and the Environment) pushed for a vote on a popular initiative held on 4 March 2001 (rejected by 79.7%)
- In France: Fontenay aux Roses, Nogent sur Marne, Sceaux, Clamart, Sèvres, Clichy la Garenne, Lorient, Neuilly-les-Dijon... but...
- In 2011, 54.9% of the population of Strasbourg rejected the project to turn the city center into a 30 km/h zone

Naked Street
- “A street or public space where vehicle movement and other activities are combined through informal social protocols, negotiation and design solutions rather than through formal regulations and controls.” (Living Streets, 2009).
- Many towns have experimented with this concept.
- But there is no consensus: Blind People, Deaf People, Cyclists
II - Safety as an area of complex system management

The actual design
• Road safety not the main challenge in public space layouts
• other considerations : accessibility, urban quality, sociability, etc...

Concerns sometimes contradictory:
• fewer cars in front of houses but greater accessibility
• lower speeds and rerouted lorry traffic
• shopkeepers want more parking spaces and better vehicle rotation
• associations want more cycling paths
• less nuisance and fewer traffic jams

But all constraints involving private transportation are politically difficult to promote.

In practice

A safety diagnosis is carried out, soon forgotten

• An action scene with the decision-making actors
• confrontation between possible solutions
• precise projects and more general technical notions
A process:

- certain projects disappear from the technical landscape
- relations become clearer
- coherence arises
- the Local Transport Plan scheme takes form

an “island strategy”:
- automobile traffic bypasses the central areas
- dense zones are connected by public transport
- the primary network is requalified with the tramway, reducing room for private travel modes
- high-performance cycling network is created...
A current practice

"island strategy" at different scale
Complexity

- Because of the adaptability of users, drivers, pedestrians – users of public spaces

The road system is a complex system and is therefore unpredictable.
- The relationship between the decision maker and the population using traffic spaces is a two-player game.
- the user will adapt his behavior in a way that is more effective for him, and not necessarily in a way that is better for collective safety

- improvements to visibility that reduce attention
- road resurfacing that increases speed
- creating cycling lanes used by powered two-wheelers
- misuse of on-board systems ...

All decisions are taken in a context of uncertainty. It is then necessary to measure the results of actions

But let us imagine that safety could become a priority objective...
This use of **objectives**, then technical **principles**, and then **tools** for integration, requires a real evaluation effort in return

- The *technical evaluation* measures the impact of a project’s implementation on safety
- The *conceptual evaluation* provides feedback used to apply a particular tool in several
- The *project evaluation* widens the viewpoint to the entire decision-making process

### III - The conditions for improvement

*Training in road safety*

Ezra Hauer (2007) describes two styles of thought on road safety
- The first is “pragmatic”, based on beliefs and the immediate interests of organizations.
- The second style defined by Ezra Hauer is “rational”

Four reasons explain the shift from the first style to the second:
- The first is that humanity has always evolved that way
- what remains to be done requires more serious knowledge
- legislation requires safety to be taken into account when planning
- many initiatives go in the right direction

But little demand for people with road safety training, which pleads in favor of the third condition, i.e. resorting to legal obligation
The conditions for improvement

*Availability of accident data.*

- In 2004 in France, the transmission of current judicial proceedings to IFSTTAR
- after text recognition, automatic requests are performed
- geolocation software is used to spatialise the information

**Geographic Information Systems**

- Data: geographical, economic, socioeconomic, demographic or financial, networks, notably transportation networks, business or recreational areas, built-up areas by function, etc...
- The link between these two sources of information lead to the measure of risk (group of inhabitants)
- This created a change of perspective in the foundation of local public policies on road safety

Example: the relative risk of depraved areas

![Map of study zones](image)

Estimation of the Adjusted Relative Risk: 1,363, interval [1,238; 1,502].
The conditions for improvement

Accident prototypical scenarios

• “A prototypical traffic accident scenario can be defined as a prototype of an accident process corresponding to a group of accidents with overall similarities in terms of the chain of events and causal relationships in the different phases leading to the collision”

• The construction of a real accident nosology in the form of prototypical scenarios

• It makes it possible to target actions to specific users, vehicles and environments

In conclusion

Who is responsible for safety, the urban layout designer or the user?

• avoiding all driver errors and, if an accident does occur minimal consequences.
  -> responsibility lies with the engineer (see “Vision Zero” in Sweden)
• calling for “civic behavior” or “good manners”
  -> responsibility lies with the user (see the “Naked Street”)

Coming back to the second diagram

• a good evaluation of the design processes and the layout tools
• well-documented and well-evaluated feedback

Effectiveness depends on:

• The location
• The quality of the layout
• The kinds of users present
• we need a good evaluation of the design processes and therefore to evaluate projects, rather than only evaluating layout tools independently of their location.
In conclusion

For a higher level of safety:
• the progress of knowledge and its dissemination,
• the development of technical tools for the design as well as for accident analysis and safety diagnosis,

But
• the lack of involvement of local politician and of the public, when they stress already made solution and “common sense” approach, not taking into account the complexity of the problem
平日時の交通と安全～交通安全の変遷と展望～

シンポジウム部会主催セッション
「これからの交通安全」
“Traffic Safety in the Future”
Session by IATSS Symposium Department

2012年9月20日（木）13:30～17:30
Thursday, 20 September 2012