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Technical Paper Series - Intoxication

Blood Alcohol Concentration is an insufficient ground truth for real-time impairment detection

Background

Adapting Driver Monitoring Systems (DMS) to mitigate the risk of intoxicated driving requires reconsideration of what Blood Alcohol Concentration (BAC) truly represents.

For decades, BAC has been central to public health enforcement: a simple threshold around which laws, penalties, and deterrence campaigns have been built. Despite widespread acceptance and high efficacy as a roadside testing approach, BAC was never designed to capture the moment-to-moment realities of impairment. DMS technology can now build upon these longstanding roadside approaches and complement with real-time assessments. Further, while there is undisputed evidence for the overall causal relationship between BAC and crash risk, the biphasic nature of alcohol's effects, with its underlying psychopharmacological variability over time, makes BAC an insufficient truth for real-time detection of impairment. Developing effective real-time safety technology against drunk driving therefore requires understanding when and why this widely recognised measure may underestimate risk.

When alcohol is consumed, it takes time for it to be absorbed into the bloodstream. Once circulating, most of it is metabolised and broken down by the liver, with a much smaller proportion being expelled through breath, sweat, and urine. As a result, BAC follows a curved trajectory over time, rising during absorption; then falling as the body clears it. But impairment does not track this curve in a simple way. To understand why and when BAC and impairment diverge on this curve, it helps to look into the overlapping processes of pharmacokinetics and pharmacodynamics.

- **Pharmacokinetics** is how alcohol moves through the body. The coordinated processes of absorption, distribution, metabolism, and elimination determine how much of the consumed alcohol is present in blood or breath at a given time. BAC, therefore, provides a snapshot of this concentration, either directly in the blood or indirectly approximated from breath.
- **Pharmacodynamics** is how alcohol affects the brain and body. This process results in the subjective experience of intoxication and objectively observable impairment. Crucially, the mechanisms by which alcohol leads to subjective experience and objective impairment is a complex orchestration of neurochemical disruption that often outlasts the raw concentration of alcohol reflected by a BAC measure[1]. This dynamic functional effect is the focus of real-time impairment detection.

Understanding the BAC curve

For a simplified representation, the BAC curve can be categorised into four distinct parts:

01

Ascending limb (BAC rising)

- **Kinetics:** During this phase, there is still alcohol in the stomach that is being steadily absorbed and making its way into the bloodstream. The amount and type of food that is present in the stomach affects how fast the alcohol is absorbed.
- **Dynamics:** Once in the blood, alcohol reaches the brain and starts changing neurochemical balance which leads to behavioural disinhibition, and the person feeling stimulated and "buzzed". The stimulation occurs due to alcohol's immediate effects on the reward pathways in the brain that release feel-good neurochemicals like dopamine. Impairment may be less obvious as it is still building up and masked by the rewarding effect.
- **Key point:** The behavioural effect of alcohol does not start until what is consumed makes its way to the blood. As a result, during this phase, both the BAC measure and impairment will be less than the maximum expected for the amount consumed, since a portion of it is still in the process of being absorbed from the stomach.

02

Peak (BAC plateau)

- **Kinetics:** The absorption rate has outpaced the elimination process and BAC has reached its maximum level until it starts to decline through metabolic activity and elimination.
- **Dynamics:** The increased availability of alcohol in the bloodstream continues to shift neurochemical balance. This leads to the initial buzz and euphoria to be dampened by impairment as reaction time slows and motor coordination starts to deteriorate.
- **Key point:** This peak point is what most experimental studies on alcohol effects are based on. Findings from such studies have contributed to policies on maximum permissible BAC limits, as well as general guidelines on maximum number of drinks per hour in order to remain within a legal BAC level.

03 Descending limb (BAC falling)

- **Kinetics:** As the body continues to process and expel the alcohol, BAC starts to decline.
- **Dynamics:** Although BAC is declining, it takes longer for the brain to regain neurochemical balance. The more alcohol consumed, the longer this process takes. During this readaption phase, the rewarding effect of alcohol wears off, people feel more sedated, cognitive and motor activities relevant to driving often show greater impairment than at the same BAC level during the ascending limb, and even peak BAC[2].
- **Key point:** In this case, BAC underestimates the actual impairment. This is particularly concerning because studies show that people are more likely and willing to drive during this phase than either ascending or peak BAC stages[3]. This tendency stems from the mistaken belief that a reduced subjective feeling of stimulation signals that they are sobering up. The alignment between when people are more likely to operate a vehicle after drinking and BAC is likely to underestimate their risk makes real-time impairment detection a critical safety requirement.

04 Hangover (BAC near zero)

- **Kinetics:** Alcohol has mostly left the body. BAC as indicated through breath and blood tests read very low to zero. However, depending on the amount of alcohol consumed, alcohol metabolites can be detected in the blood for up to 24 hours following a drinking session and serve as biomarkers of recent alcohol intake.
- **Dynamics:** When a larger volume of alcohol is consumed there is a longer lasting metabolic strain on the body and a compensatory rebound activity of neurochemicals in the brain. This happens because of lingering byproducts of alcohol, inflammation in the body, poor sleep, and the brain's rebound activity. As a result, impairment can persist long after BAC has returned to zero.
- **Key point:** While the safety risk of hangover state is generally understood, it has not been systematically addressed as it is not reflected by BAC. A study of apprehended drivers, all of whom tested negative for alcohol and drugs but were stopped because of suspected impairment such as erratic driving or accident involvement, found that alcohol metabolites were significantly more common and at higher concentrations among those functionally assessed as impaired[4]. This demonstrates a real-world safety risk where impairment caused by alcohol cannot be reflected through BAC.

Harnessing new possibilities afforded by technology

The main rationale for adapting DMS technology to detect alcohol-related impairment is that alcohol remains a leading cause of road fatalities and injuries despite extensive preventive measures.

Rather than replacing existing strategies, this technology complements them by addressing the gaps in real-time assessment that highly effective roadside tests cannot. One such gap lies in the disconnect between BAC progression and the way impairment actually unfolds over time. By directly assessing functional impairment in real time, DMS can bridge this gap. However, if feature development continues to rely solely on BAC as the ground truth, the effectiveness of such technology will remain systematically constrained. To advance beyond this limitation, both the training and performance assessment of DMS solutions should account for the variability of impairment across the BAC curve rather than just discrete concentration levels in order to capture the temporal dynamics of impairment. Incorporating this temporal perspective would allow DMS to better reflect how impairment evolves across the ascending and descending phases of intoxication, ensuring that detection sensitivity, intervention strategies and evaluation criteria align more closely with real-world driver performance and associated risk.

In developing solutions for detecting and mitigating the risk of alcohol-related impairment, Seeing Machines has been partnering with experts at various universities to conduct experiments that specifically explore this temporal disconnect between BAC and functional impairment of the driver.

Further information about our position and supporting research can be found in our submission to NHTSA's Advance Notice of Proposed Rule Making (ANPRM)[5].

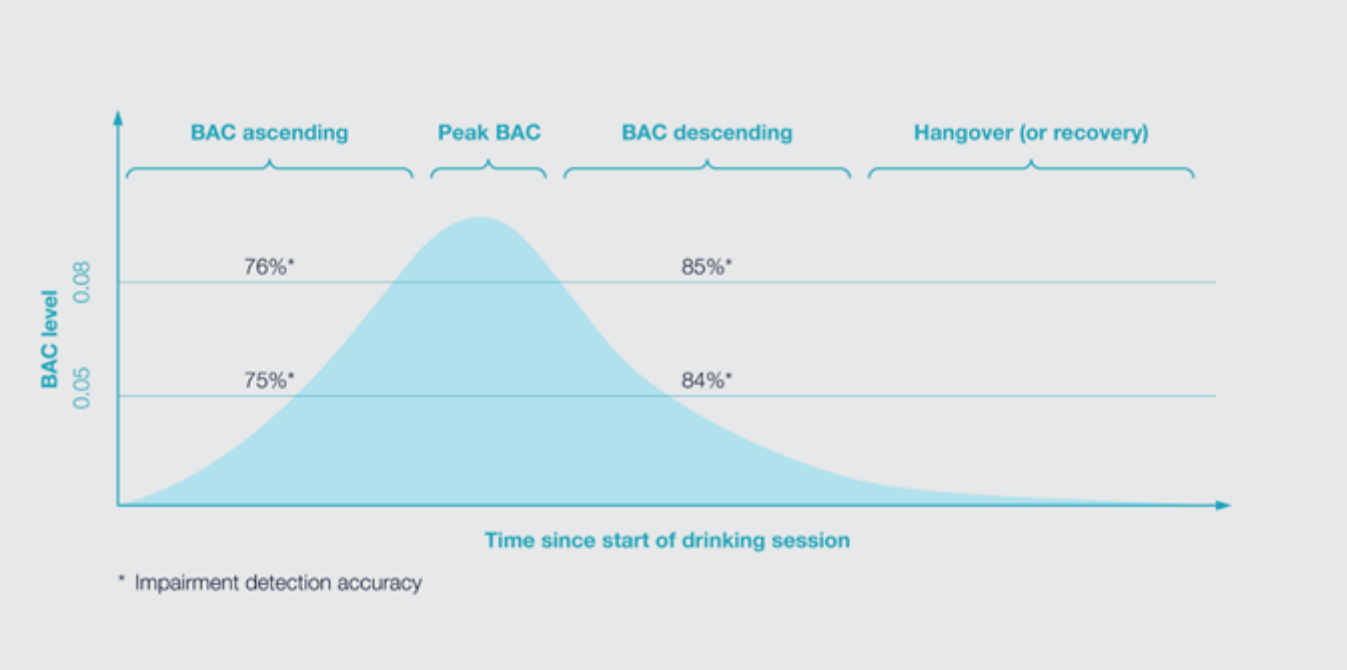

Figure 1: Real-time impairment is more prominent during the descending phase compared to the ascending phase with comparable BAC range. This figure was reproduced from conference presentations[6,7].

References

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