ORDER FROM DISORDER: HOW TIME-GAP HETEROGENEITY SUPPRESSES STOP-AND-GO WAVES IN TRAFFIC

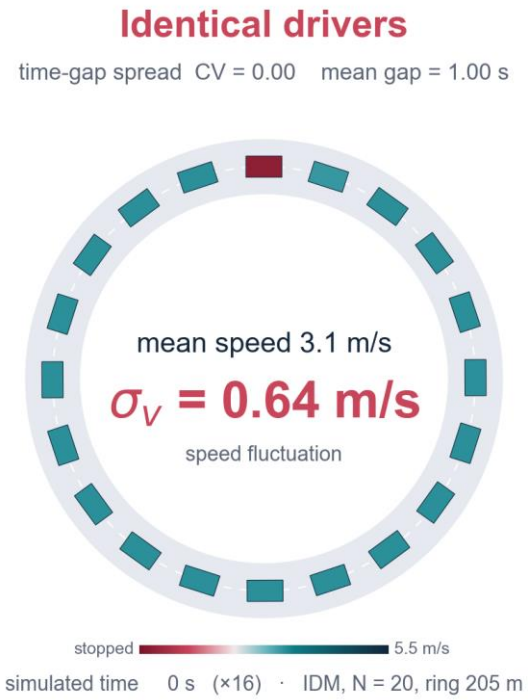
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SHOCKWAVE TRAFFIC JAMS
RECREATED FOR FIRST TIME
Footage courtesy of
University of Nagoya,
Nagoya, Japan

A traffic jam out of nothing



20 cars

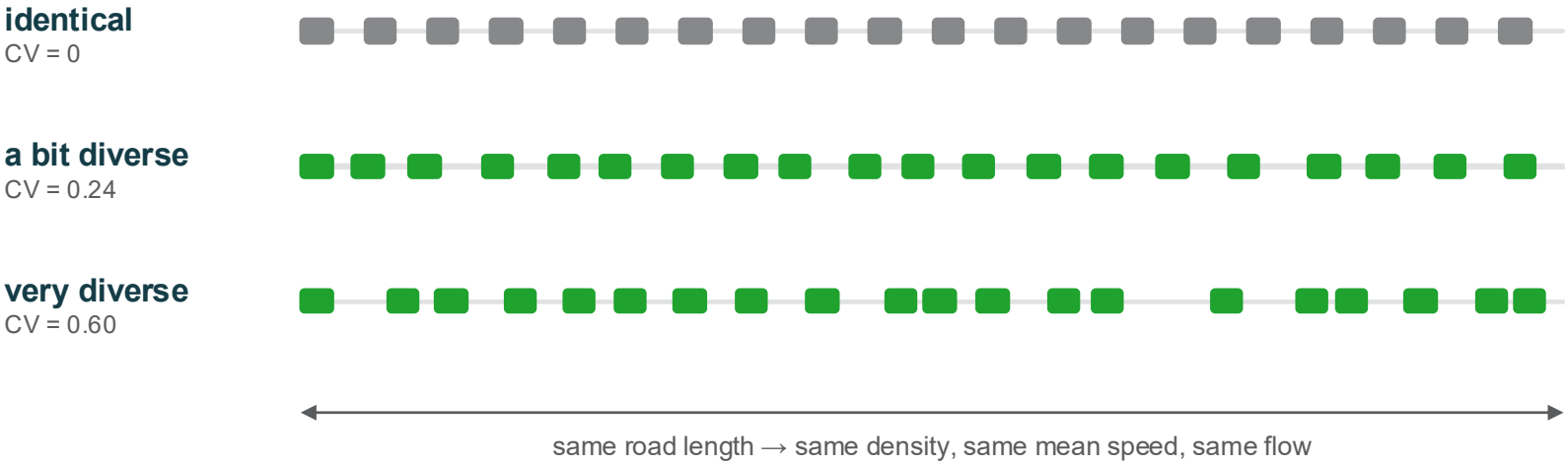
one ring road

no bottleneck, no accident

A tiny disturbance grows into a stop-and-go wave that never goes away: a phantom jam.

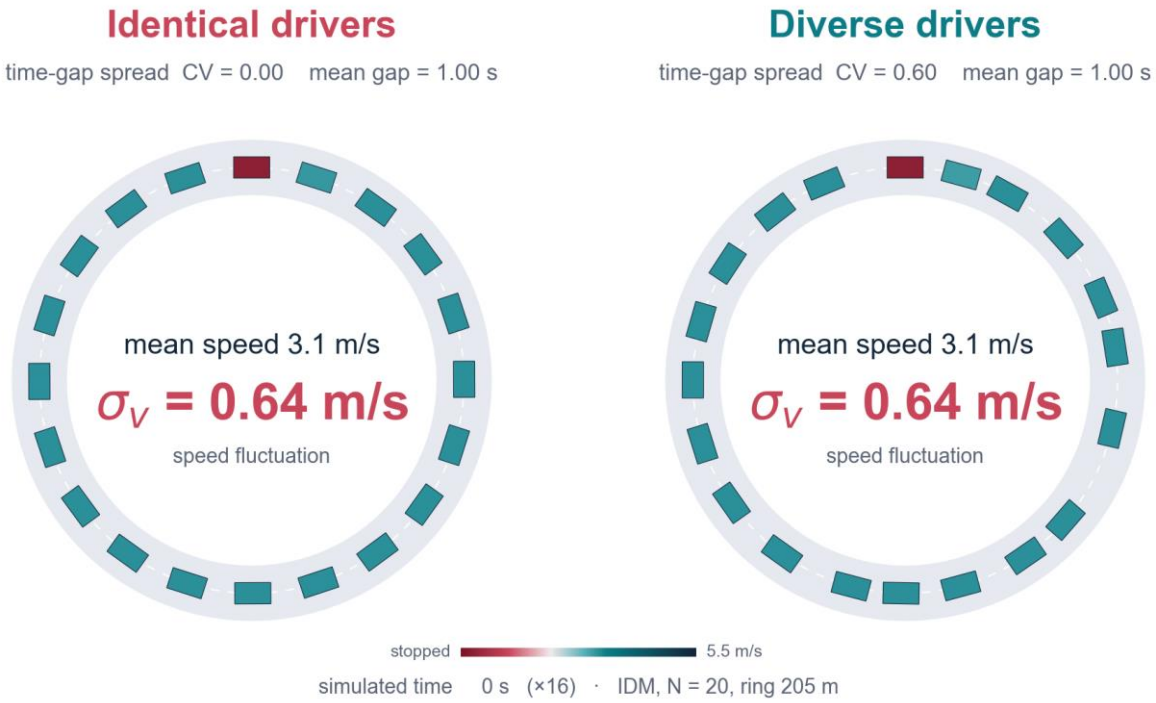
How would you get rid of it?

The unusual answer: make drivers heterogeneous

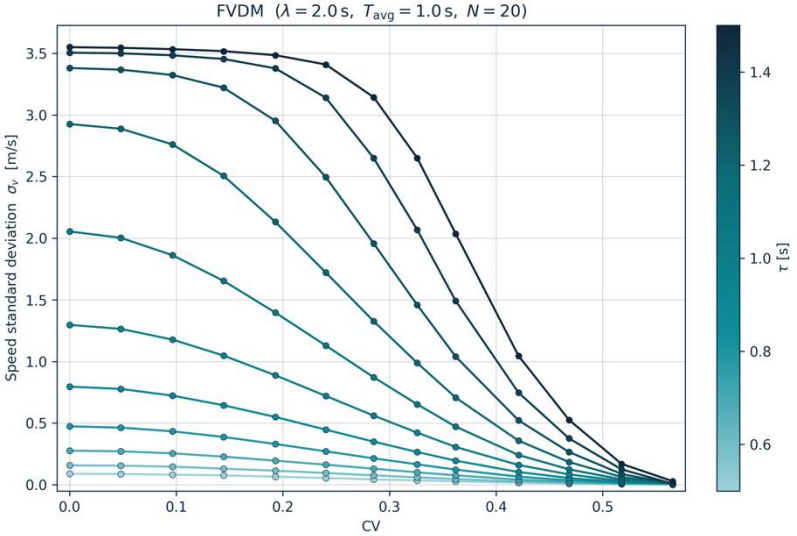


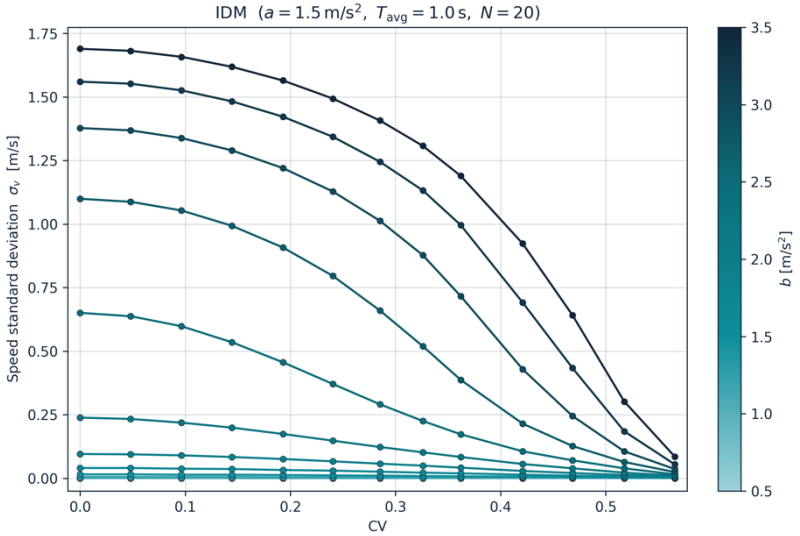
Each driver gets a desired time gap T_n drawn from a truncated normal on [0.2, 3.0] s. The mean is fixed at $\langle T \rangle$ = 1 s. **Only the spread changes: CV = σ_T / $\langle T \rangle$.**

Same mean gap. Different spread.



More disorder, smoother traffic





1 Wherever identical drivers produce waves, more spread lowers the speed fluctuation, monotonically, in both models.

2 Enough spread restores laminar flow, even in deeply unstable regimes, at the same mean gap.

Ring road, N = 20; every point is the time-averaged speed fluctuation σv in the saturated regime.

Why stability sees the area ΣT²

Follow a slow speed wave back through the platoon. Each driver shrinks or grows it a little.



1 **The gap damps the wave** damping T^2

Squared, because the damping acts a quarter cycle out of step with the pull of the gap: the two add like the sides of a right triangle.

2 **The driver's reaction amplifies it** amplifying α

$\Sigma\alpha$ is set by how the drivers accelerate and react (and by the mean gap), not by how the gaps are shared out.

3 **Around the ring, it all adds up** ΣT^2 vs. $\Sigma\alpha$

The wave meets every driver in turn, so each driver adds its own square to one common sum: the area.

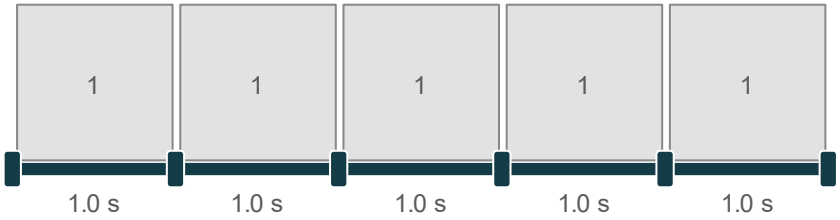
slow waves die out $\Leftrightarrow \quad \Sigma\, T_n^{\,2} \geq \Sigma\, \alpha_n$

$\Sigma\alpha$: fixed by the drivers. ΣT: fixed by the flow. **Only lever left: more ΣT^2 on the same ΣT.**

Criterion for mixed platoons: Ngoduy (2015); time-gap form and optimal buffering: Korbmacher & Tordeux, arXiv:2610.11557.

Same road, more area

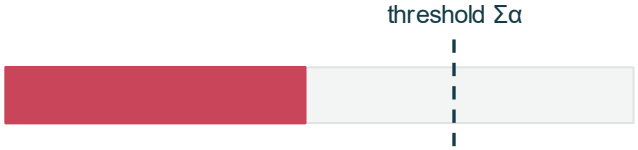
Same road **ΣT** (same flow). How do we get more area **ΣT²**?



road length ΣT = **5.0 s** (same flow)

spread CV **0.00**

area ΣT² **5.0**

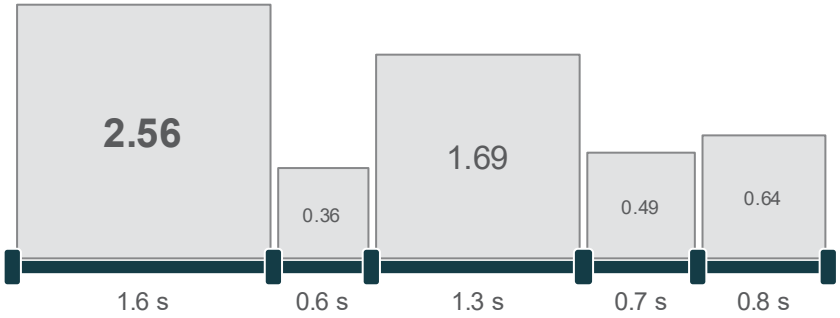


→ **stop-and-go waves**

ΣT² = N·⟨T⟩²·(1 + CV²): **on the same road, the area grows only with the spread CV.**

Same road, more area

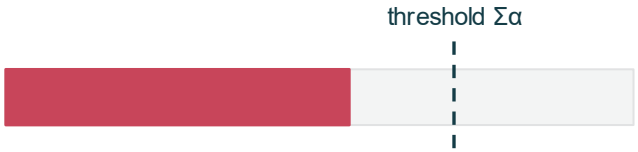
Same road **ΣT** (same flow). How do we get more area **ΣT²**?



road length ΣT = **5.0 s** (same flow)

spread CV **0.38**

area ΣT² **5.7**

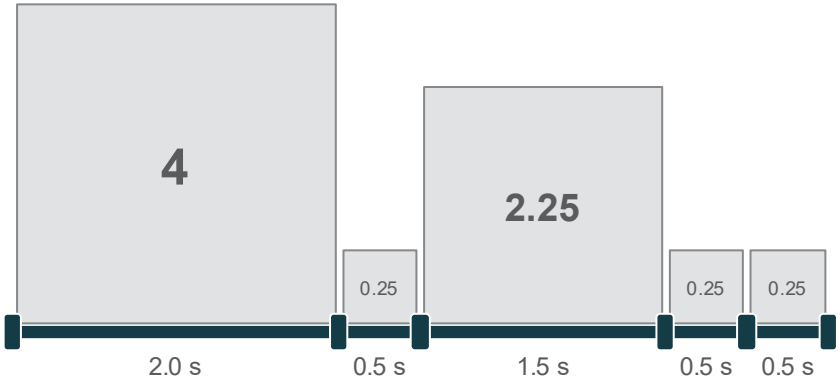


→ **stop-and-go waves**

ΣT² = N·⟨T⟩²·(1 + CV²): **on the same road, the area grows only with the spread CV.**

Same road, more area

Same road **ΣT** (same flow). How do we get more area **ΣT²**?



road length ΣT = **5.0 s** (same flow)

spread CV **0.63**

area ΣT² **7.0**

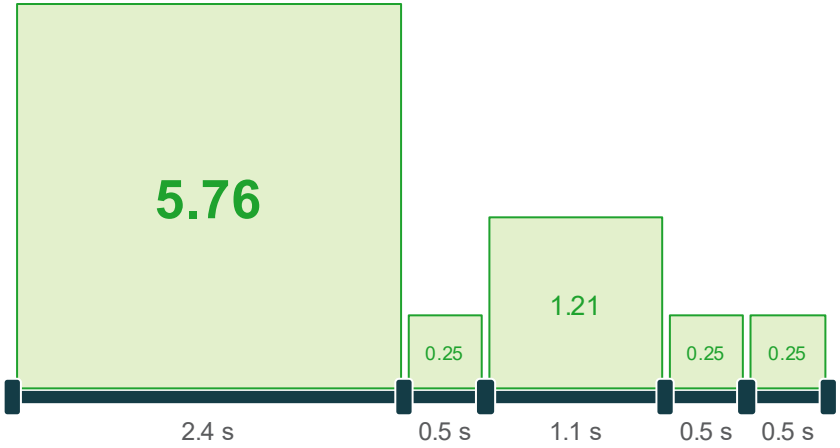


→ **stop-and-go waves**

ΣT² = N·⟨T⟩²·(1 + CV²): **on the same road, the area grows only with the spread CV.**

Same road, more area

Same road **ΣT** (same flow). How do we get more area **ΣT²**?



road length ΣT = **5.0 s** (same flow)

spread CV **0.74**

area ΣT² **7.7**

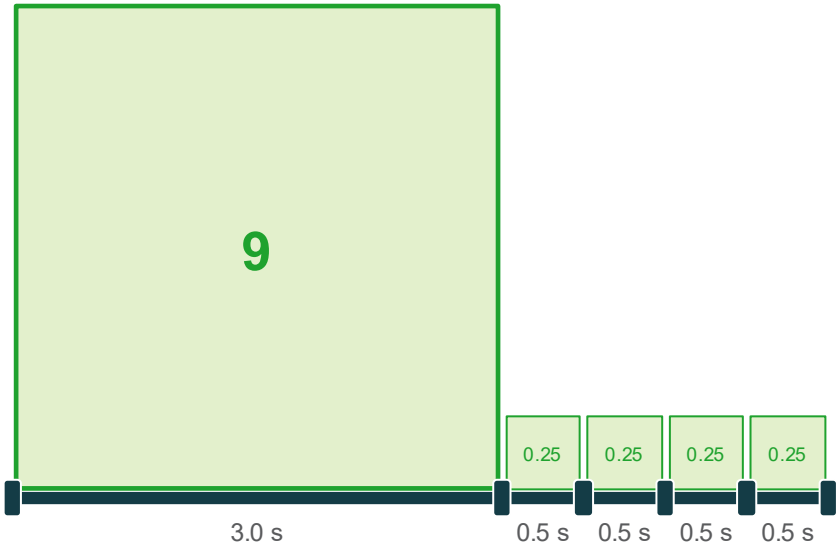


→ smooth, laminar flow

$\Sigma T^2 = N \cdot \langle T \rangle^2 \cdot (1 + CV^2)$: on the same road, the area grows only with the spread CV.

Same road, more area

Same road **ΣT** (same flow). How do we get more area **ΣT²**?



road length ΣT = **5.0 s** (same flow)

spread CV **1.00**

area ΣT² **10.0**



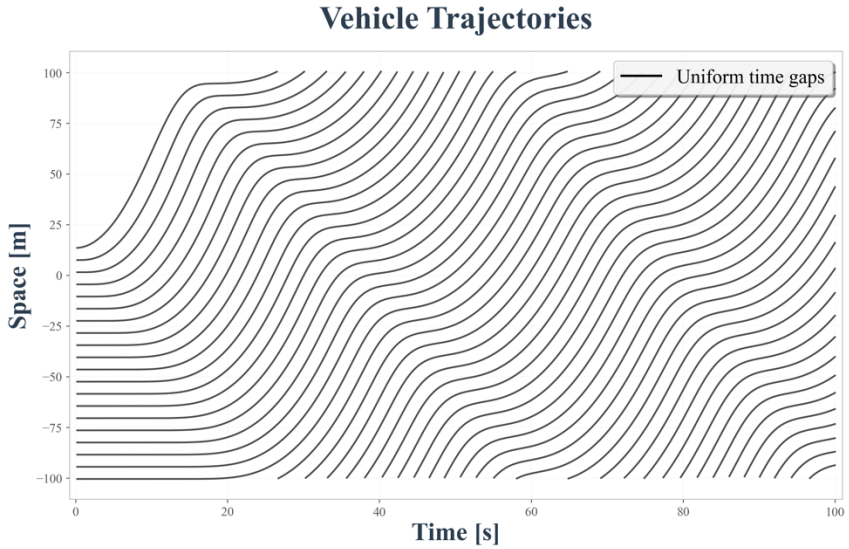
→ smooth, laminar flow

Maximum spread: all extra gap in one vehicle, the largest possible area.

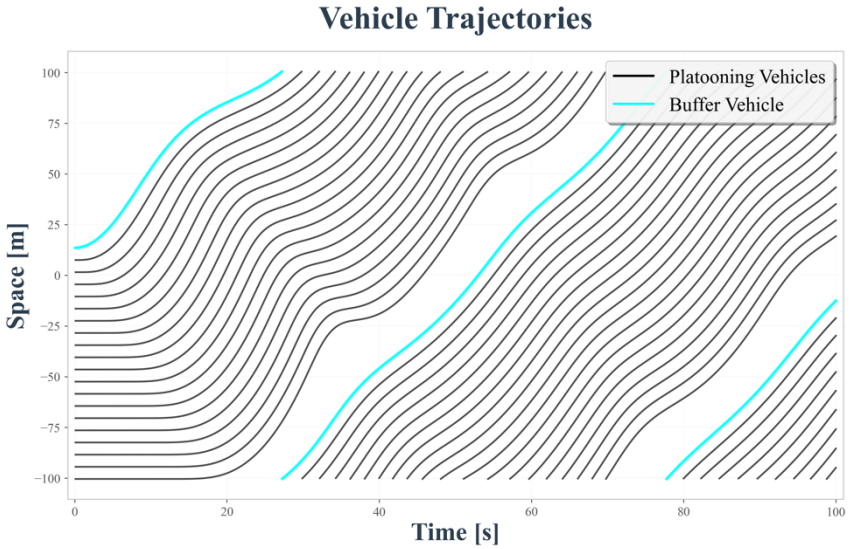
ΣT² = N·⟨T⟩²·(1 + CV²): **on the same road, the area grows only with the spread CV.**

Maximum spread: one buffer vehicle

uniform time gaps



one buffer + tight platoon (same mean gap)



Putting all the extra gap into one car maximises the variance, and it is **provably the flow-optimal stable allocation** under the linear criterion (Korbmacher & Tordeux, arXiv:2610.11557).

Take-home message

Heterogeneity is not noise to be averaged away.

It is a control parameter.

A free stabilising margin in today's mixed human traffic.
A design lever for automated and connected fleets.

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Code

Try it live

Literature

Theory
arXiv:2610.11557

Multi-agent RL
arXiv:2511.14378