Vehicle platoons with ring coupling

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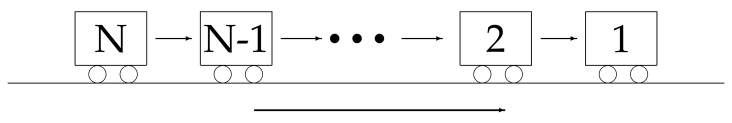
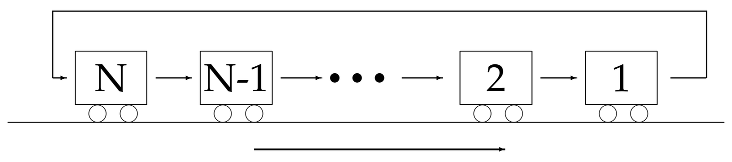
IAP V/22 Work package 3

Interconnection topology

- A classical control structure: the leading vehicle drives freely - the other vehicles follow (supervisory-type control)



- Our proposal: the behavior of the platoon is a result of cooperation between the vehicles (self-organization)



System dynamics

Each vehicle is described by:

$$\ddot{x} + p\dot{x} = u,$$

- x: position of the vehicle,
- u: input,
- p: drag coefficient per unit mass.

The coupling between consecutive vehicles is described by:

$$u_i = K(x_{i-1} - x_i - L_i), \quad i \in \mathcal{N} \triangleq \{1, \ldots, N\},$$

- $K > 0$: the uniform coupling strength,
- L_i: chosen set points, where $L_1 \leq 0$, $L_i \geq 0$, $i \in \mathcal{N} \setminus \{1\}$.

Existence of solutions

Equilibrium solutions of the system:

$$x_i(t) = \alpha t + \beta_i, \ \forall i \in \mathcal{N},$$

with

$$\alpha = \frac{-K}{Np} \sum_{j=1}^{N} L_j \text{ and } \beta_i - \beta_{i-1} = \left(\frac{1}{N} \sum_{j=1}^{N} L_j \right) - L_i, \ i \in \mathcal{N},$$

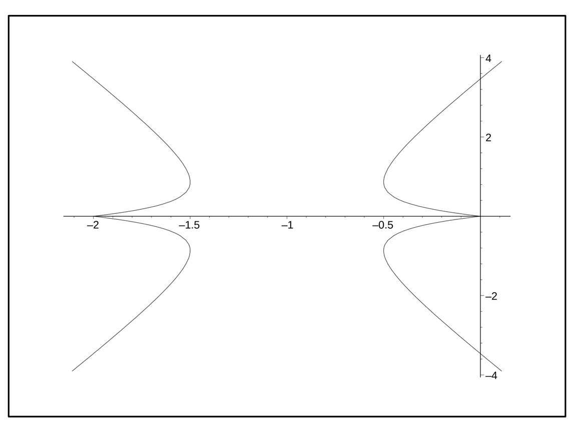
Stability result

Theorem 1 *If and only if*

$$K < \frac{p^2}{2\cos^2(\pi/N)},$$

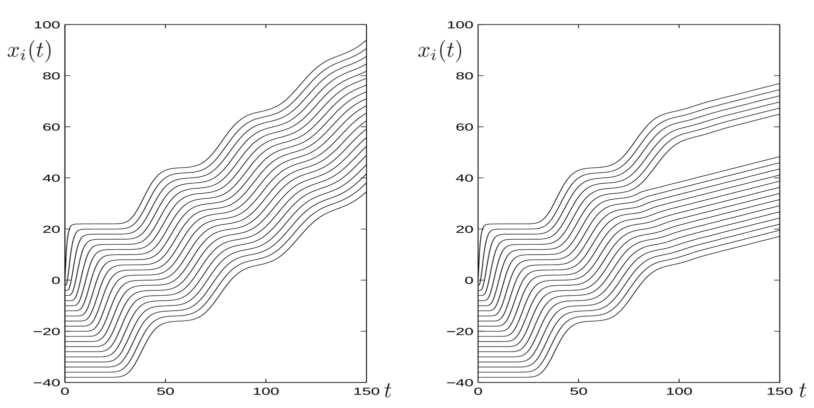
the above solution is **asymptotically stable***.*

Example: Location of the eigenvalues for varying K ($N = 3$,$p = 2$):



Robustness

Evolution of the position for a platoon of 39 vehicles. Left: no malfunctions. Right: at $t = 80$ s, the 12th vehicle starts malfunctioning and cannot drive faster than 0.3 m/s.



String stability

- Common problem in platoons: the slinky effect.
- Solution: Construct a controller that renders the platoon **string stable**:

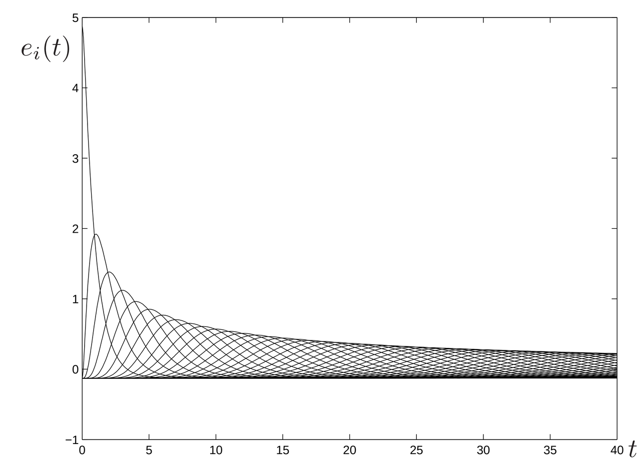
Definition 1 *Let e_i be the distance error between the i-th and $(i-1)$-th vehicle. The platoon is called string stable if*

$$\|e_i(t)\|_\infty < \|e_{i-1}(t)\|_\infty, \quad \forall i > 1,$$

where $\|e_i(t)\|_\infty$ denotes $\sup_{t\geq 0} |e_i(t)|$.

String stability: simulation

- Assume the platoon is driving according to an equilibrium solution to set points L_i
- Control: replace L_1 by $\tilde{L}_1$. Keep the other set points constant. This defines the corresponding initial condition.
- Slowing down manoeuvre corresponding to $L_1 - \tilde{L}_1 = -5$:



Adding integral control

The control is given by

$$u_1(t) = K(x_N(t) - x_1(t) - L_1) + q \int_0^t (x_N(\tau) - x_1(\tau) - L_1)\,\mathrm{d}\tau, \ \forall t \in \mathbb{R}^+,$$
$$u_i = K(x_{i-1} - x_i - L_i), \quad i \in \mathcal{N} \setminus \{1\},$$

Equilibrium solutions of the system:

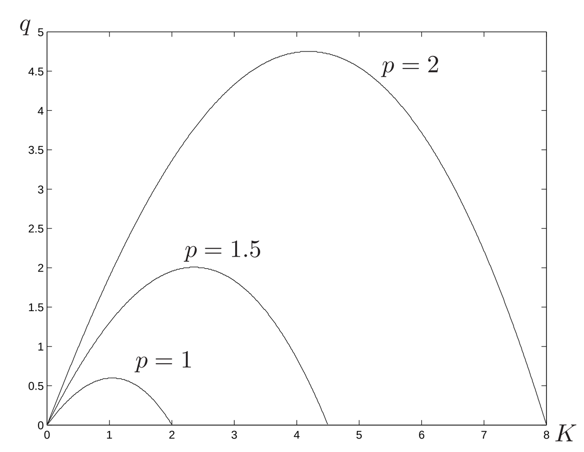
$$x_0(t) = -\frac{\alpha p}{q},$$
$$x_i(t) = \alpha t + \beta_i, \ \forall i \in \mathcal{N},$$

with

$$\begin{cases} \alpha = \dfrac{-K}{(N-1)p} \displaystyle\sum_{j=1}^{N} L_j, \\ \beta_N - \beta_1 = L_1, \\ \beta_i - \beta_{i-1} = \left(\dfrac{1}{N-1} \displaystyle\sum_{j=1}^{N} L_j\right) - L_i, \ i = 2, \ldots, N. \end{cases}$$

Stability

Stability regions for a 3-vehicle platoon at different values of the drag coefficient.



Stability region for a 7-vehicle platoon with drag coefficient $p = 2$.