Self-organization leads to supraoptimal performance in public transportation systems

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Prediction vs. Adaptation

- Prediction useful for "*stationary*" problem spaces.
- Adaptation useful for "*non-stationary*" problem spaces.

- Of which type are urban problem spaces???

Self-organization as a Method to Build Adaptive Systems

When building a self-organizing system, elements are designed to *dynamically* and *autonomously* solve a problem or perform a function at the system level.

- Useful when solution is not reducible (complex interactions), not known beforehand, or changes constantly.
  - Non-stationary problem domains.
- As problem changes, elements adjust their behavior, adapting to the new situation and finding new solutions.

A Methodology (Gershenson, 2007)

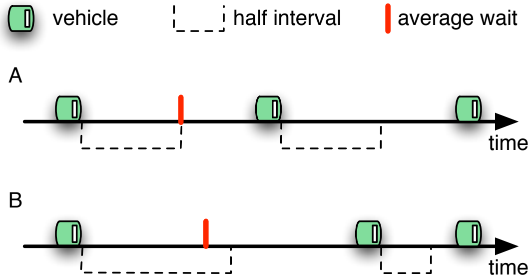
- An *agent* is a description of an entity that *acts* on its environment
- An observer can describe the *goals* of an agent
- The "fulfillment" of goals can be measured with a variable $\sigma \in [0, 1]$, representing *satisfaction*
- Agents *interact*, affecting each other (and their goals and satisfactions) positively, negatively, or neutrally
- *If we minimize "friction" (negative interactions) and maximize "synergy" (positive interactions), global "satisfaction"* σ_{sys} *will increase*
- Use *mediators* to promote and constrain behaviors that reduce friction and maximize synergy.
- Focus on interactions, not only on elements.

Public Transportation Systems

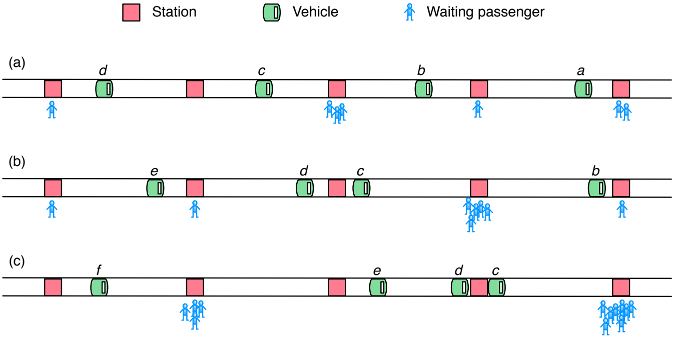
- Urban mobility has a high impact on society.
- More than half of people living in cities, 2/3 by 2050.
- 100 million daily passengers in 100 busiest metro systems.
- Do we know how to regulate public transportation systems?
- NO!

Headways: the theory

Passenger waiting times at stations are minimized with equal headways.

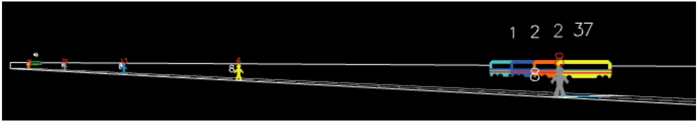


Equal Headway Instability



- Gershenson, C. & Pineda, L. A. (2009). Why does public transport not arrive on time? The pervasiveness of equal headway instability. *PLoS ONE* (10): e7292. doi:10.1371/journal.pone.0007292.

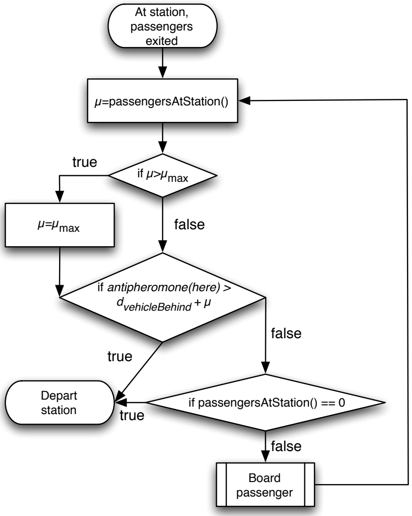
Simulation



http://tinyurl.com/antipheromones

- *DF*, default method: no restrictions. Equal headways always unstable.
- *MX*, adaptive maximum method: t_{min} and t_{max}, latter one adapted depending on global passenger demand. Equal headways maintained.
- *SO*, self-organizing method: antipheromones to regulate headways locally. Adaptive headways.

SO algorithm



Results: homogeneous scenario

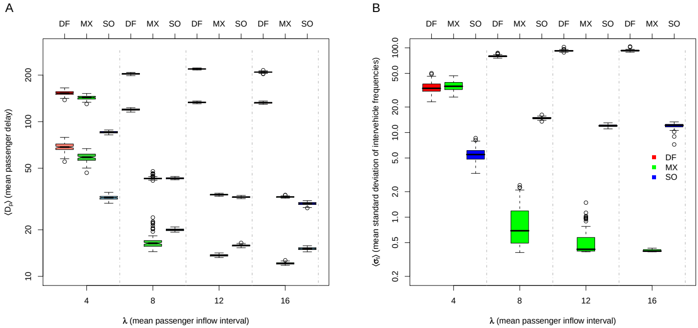


Figure: **Results for homogeneous scenario.** A. Passenger delays for methods: "default" (*DF*), "max" (*MX*), and "self-organizing" (*SO*), for different passenger demands (lower λ means higher demand). Lower boxes at each column show waiting times at stations. Higher boxes show total waiting times. B. Headway standard deviations. Lower σ_f implies more regular headways.

Results: heterogeneous scenario

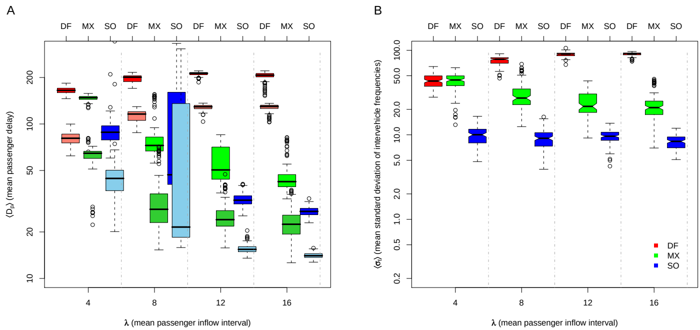


Figure: **Results for heterogeneous scenario.** A. Passenger delays for methods: "default" (*DF*), "max" (*MX*), and "self-organizing" (*SO*), for different passenger inflow intervals λ. Lower boxes, slightly shifted to the right, at each column show waiting times at stations. Higher boxes show total waiting times. B. Headway standard deviations. Lower σ_f implies more regular headways.

Discussion

- Current theory focuses on waiting times at stations.
- 'Slower-is-faster' effect leads to supraoptimal performance.
- Solution is not predefined, adapts locally to the current situation.
- Adaptation matches timescale of system change.

Social factor...

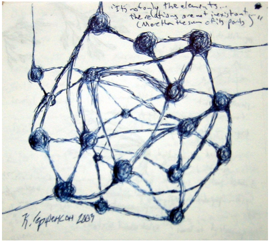
- Equal headway instability not only a technical, but also social problem.
- In many systems, the single source of delays which lead to instability depends on passenger behavior.
- Promote behaviors that reduce delays and thus instability.
- Provide timely information to passengers.

Future Work

- Metro
- Metrobus
- Pumabus
- More realistic simulations
- Crowd dynamics

Conclusions

- Equal headway instability is a general phenomenon.
- Self-organization can lead to supraoptimal performance.
  - ‘slower-is-faster’ effect.
  - antipheromones provide local information.
  - adaptation at appropriate timescale.
- There is a great potential impact in daily life.



Complexity Digest

http://comdig.unam.mx