ETH zürich

Railway traffic control room, and room for control
How to get the best out of your transport network?

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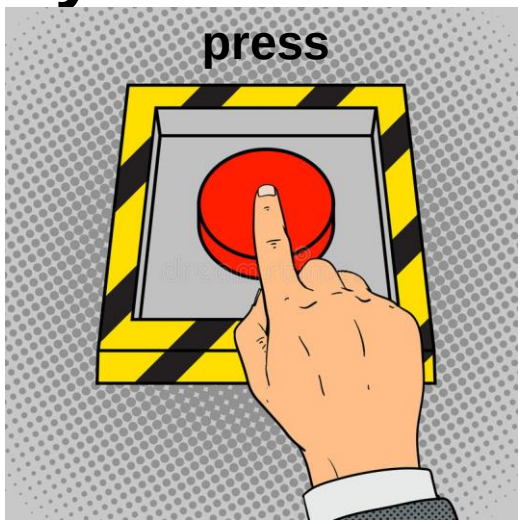
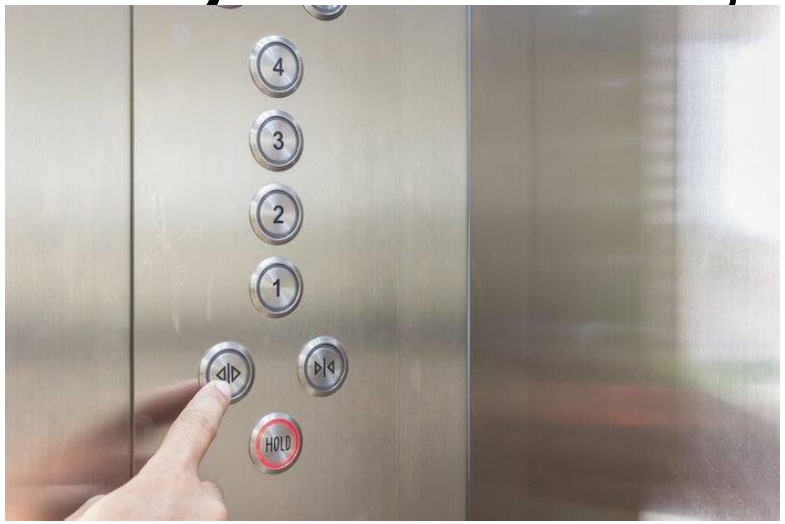
Not so much room for control (also no control room)

Maeklong market, Thailand
https://www.youtube.com/watch?v=Dsi_ItK-j30
https://slate.com/human-interest/2016/04/vendors-and-shoppers-must-periodically-make-way-for-trains-at-the-unusual-maeklong-railway-market-in-thailand.html

Room for control? What if control does nothing?
If you can choose only one outcome, what is that for a control?





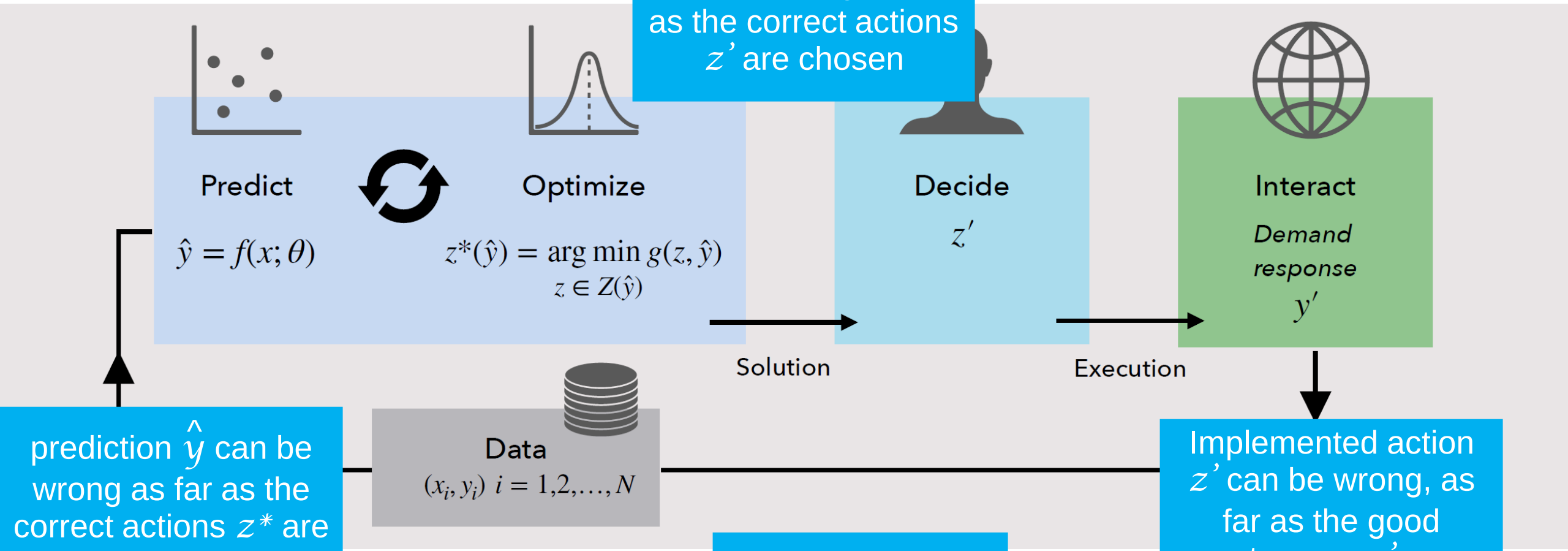
https://www.rd.com/list/buttons-that-do-nothing/
http://www.realclear.com/comics/dilbert/2016/04/25/

Goal of control (rooms)

- To reach the best possible state of a system, by changing some aspects of it

A formal definition of our s

Suggested action z^* can be wrong as far as the correct actions z' are chosen



prediction $\hat{y}$ can be wrong as far as the correct actions z^* are identified

Implemented action z' can be wrong, as far as the good outcomes y' are anyway resulting

We can learn from our mistakes!

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Not now; in the future

Best possible for whom?

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Which aspects can I change (steer/control), which aspects do I want to change (steer/control)?

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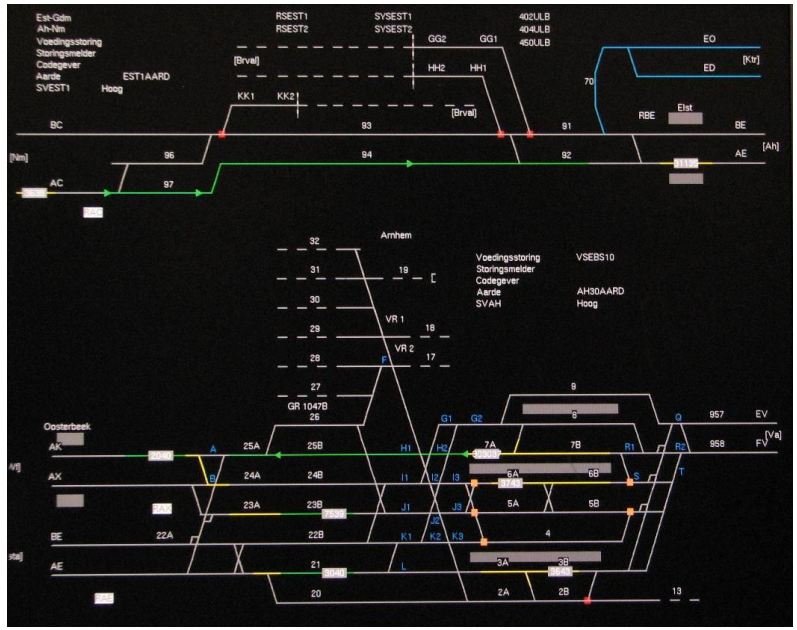
Predictions are needed

- Explicitly, or implicitly

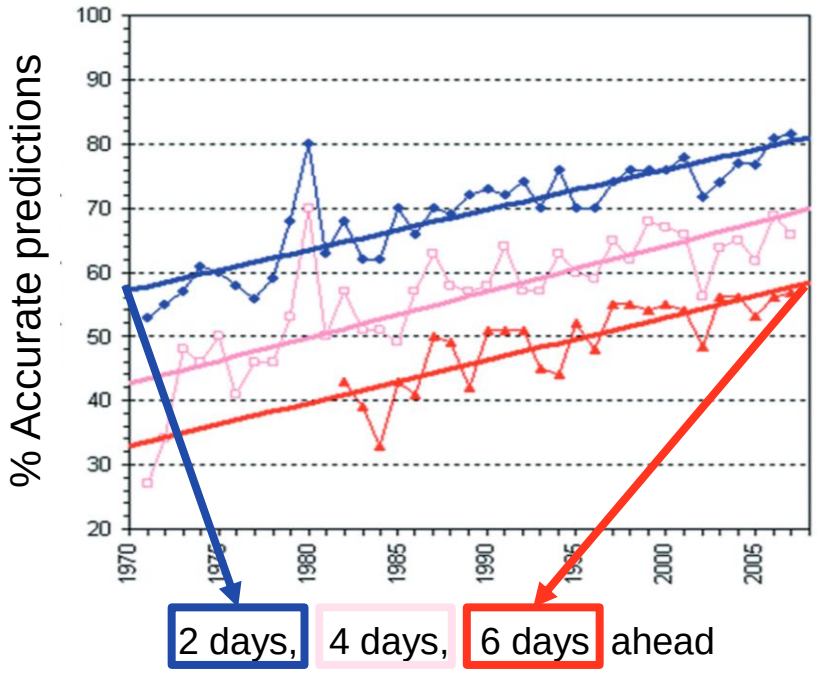


Predictions are wrong

- We like predictions when they are **understandable / explainable**
  (we can forgive them because we understand why they were wrong)
  → simple(r), or at least traceable

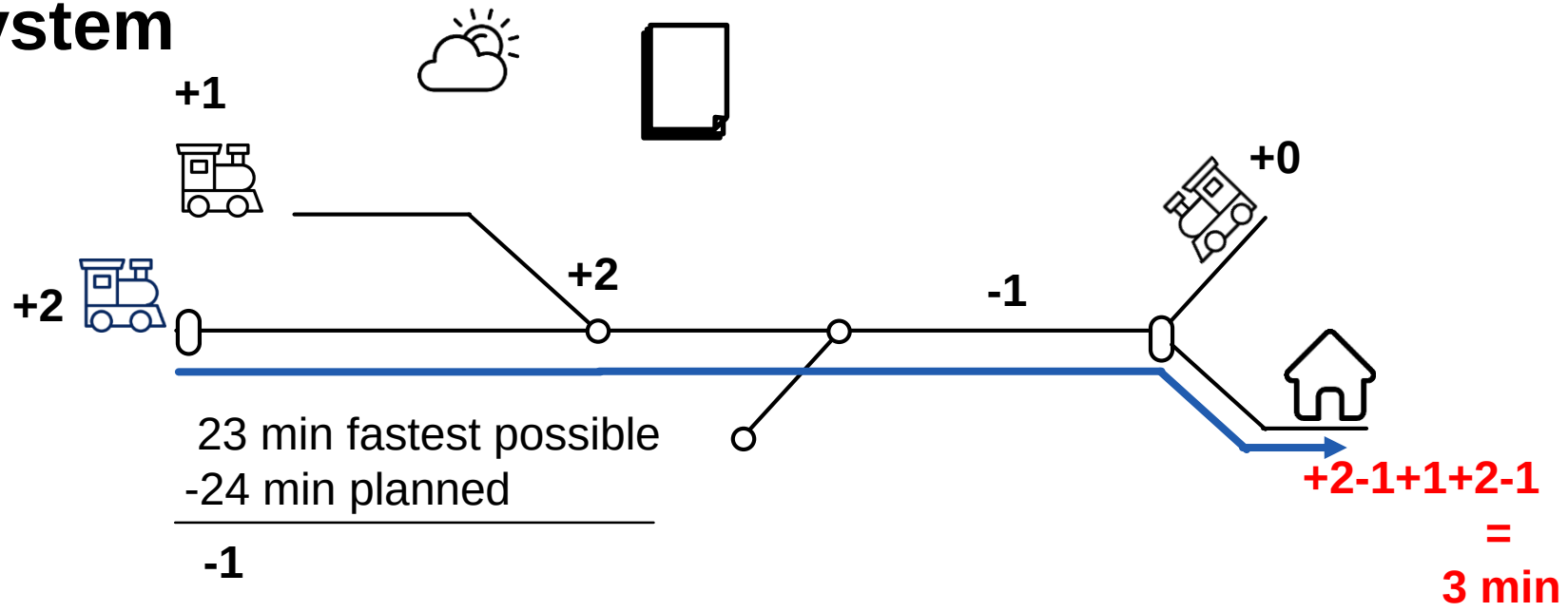
- We like predictions when they **know that they are wrong**
  (we know we are asking too much for them to be correct)
  → Include uncertainty

Current state of the art in prediction

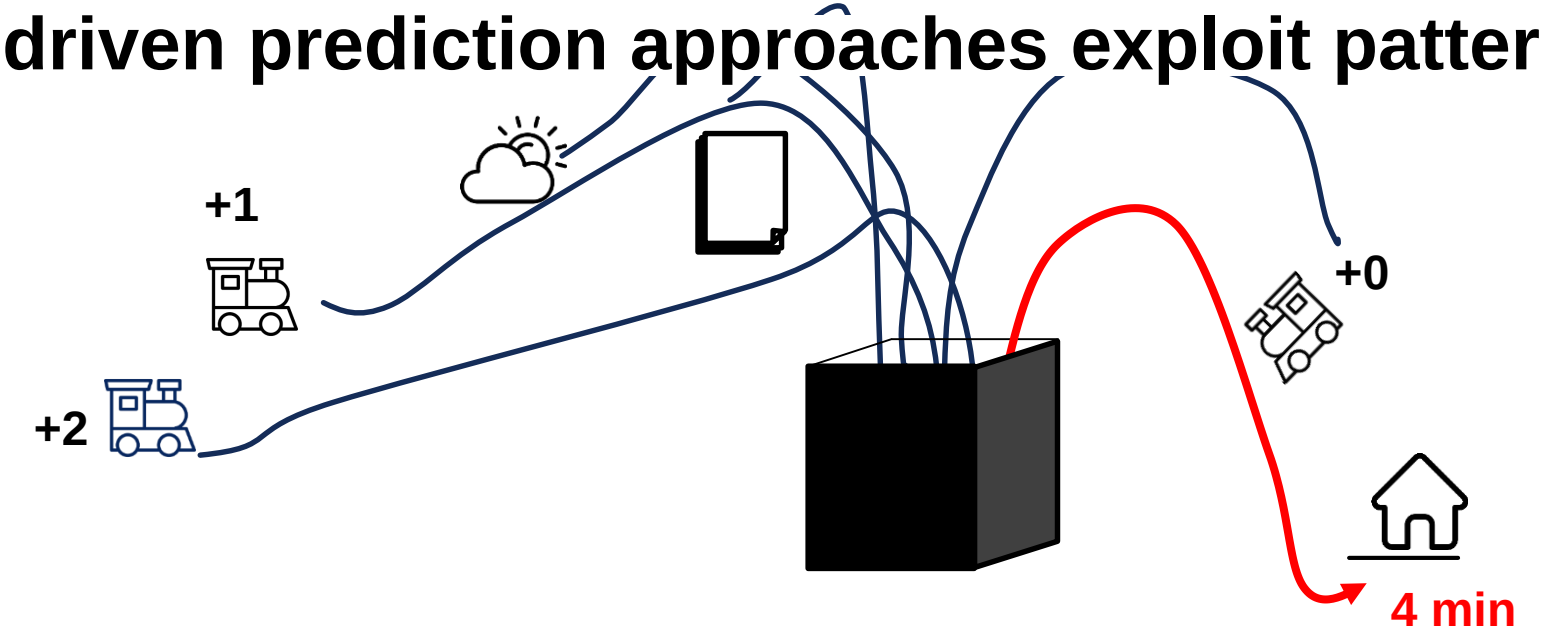


Accuracy of weather forecast 6 days in 2010,
better than 2 days in 1970 [Deutscher Wetterdienst]

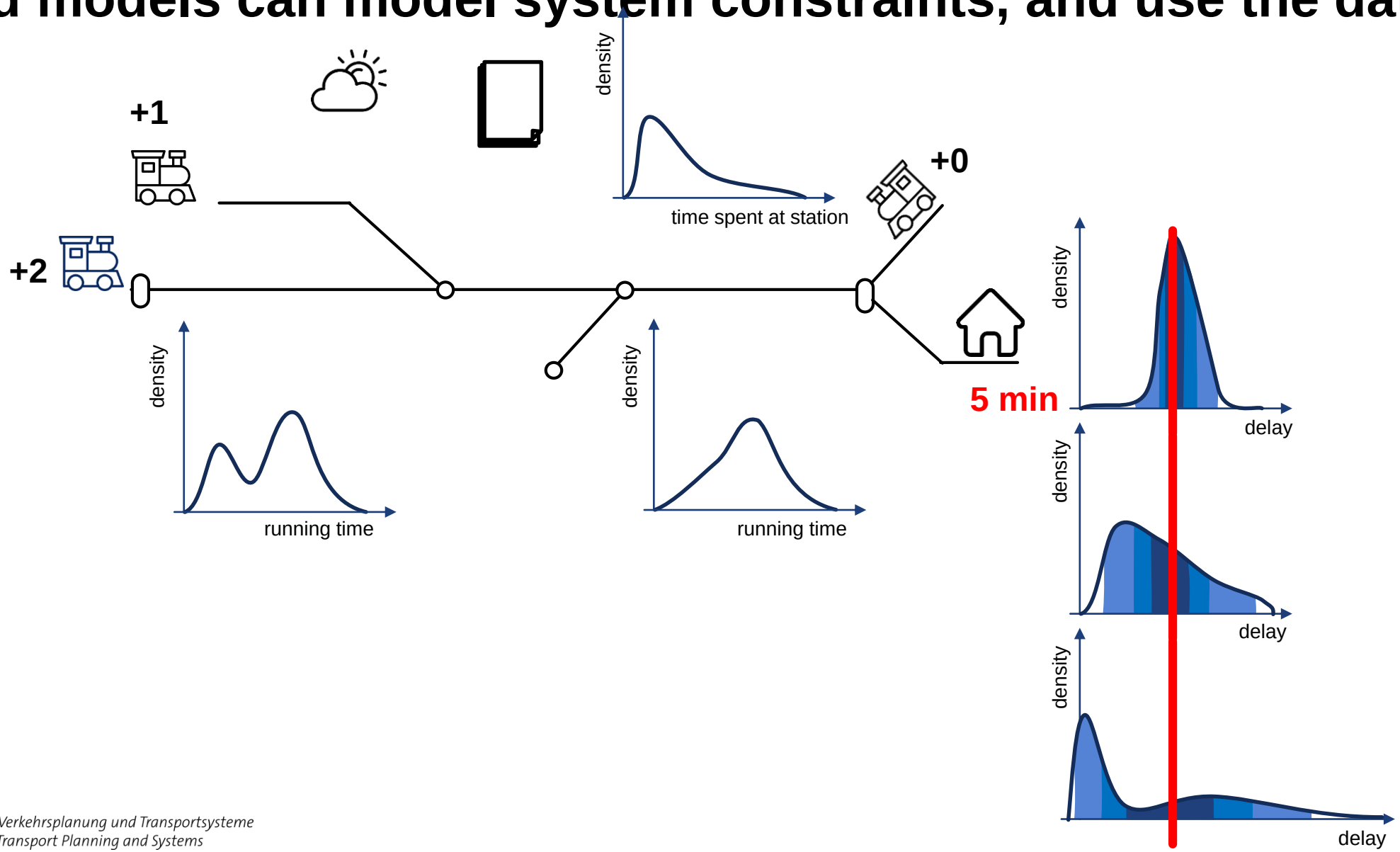
Model-based prediction approaches represent the constraints of the system



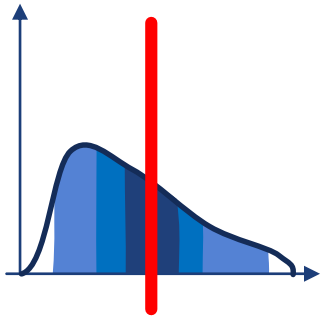
Data-driven prediction approaches exploit patterns in the data

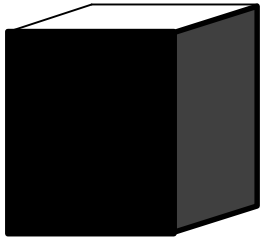


Hybrid models can model system constraints, and use the data



Our Bayesian network approach is precise, insightful, and describes its own uncertainty





+2-1+1+2-1
=
3 min

Bayesian networks
1 min prediction error
max error ~ 5 min

Data-driven
4 min prediction error

with additional predictors:
1.4 min prediction error
max error ~ 12 min

Model-based
1.5 min prediction error
max error ~ 8 min

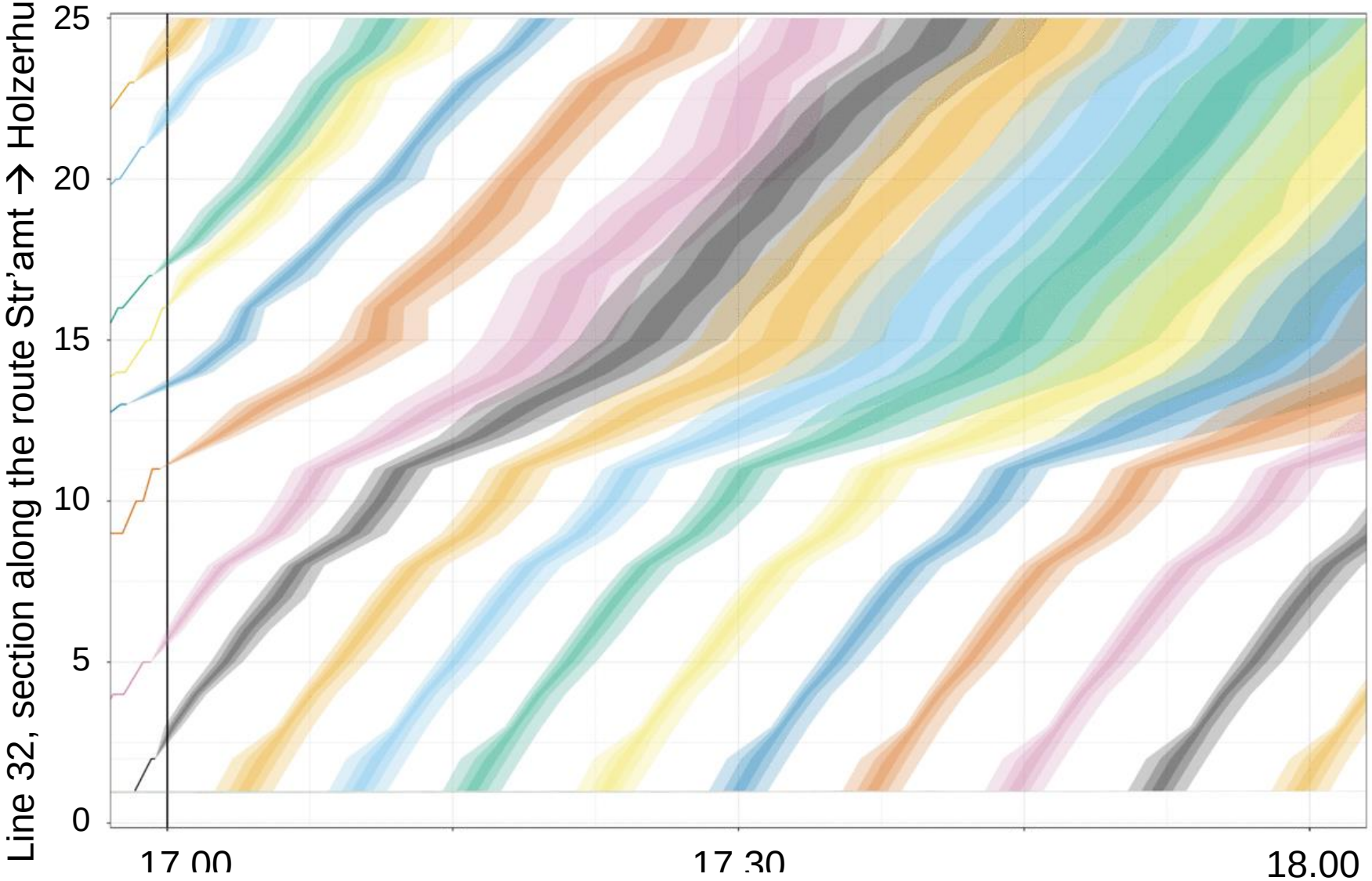
Corman F., Kecman P. (2018) Stochastic prediction of train delays in real-time using Bayesian networks. Transportation Research Part C 95, 599-615

Current state of the art in prediction

- Explainable and complex enough: Linear relations are too simple for much processes in this world. But can help understanding a lot of things
- Include uncertainty in output, and in input/training; Exploiting variation as a source of information of the hidden dynamics of your system
- Artificial intelligence / machine learning is able to determine relations in the data, we are not aware of

- Decrease of marginal effects; the wrong predictions now are rare phenomena; next big issue are badly estimated correlations and truly unpredictable things (at least, in deterministic sense)

What do I know about my future?



Büchel B., Corman F. (2020) Meaningful Modeling Of Section Bus Running Times By Time Varying Mixture Distributions Of Fixed Components. Transportation Research Record 2674 (8), 626-637

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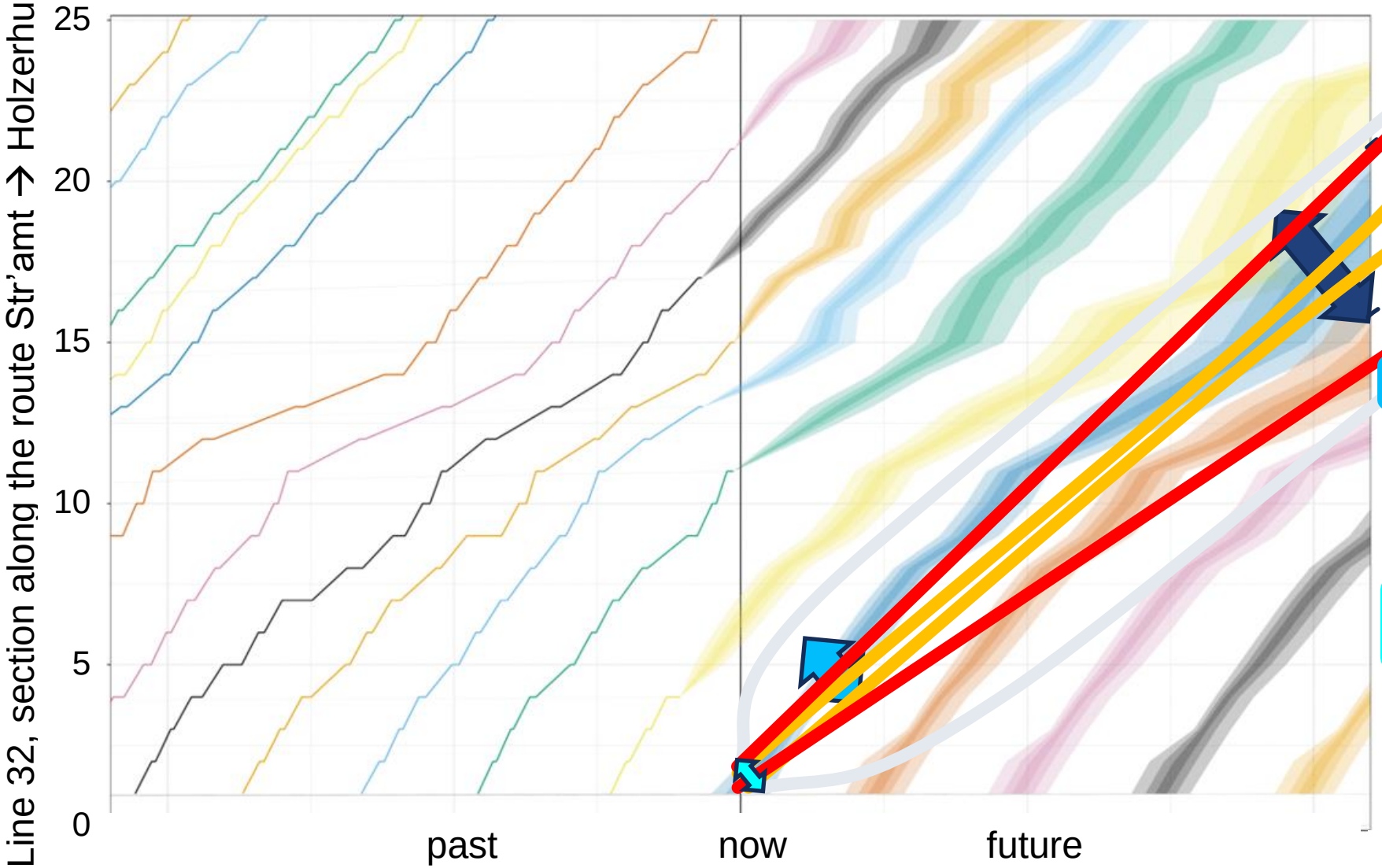

Close events have less prediction variance than far future events

Convergence to an offline variance, and a residual variance, just before it happens

Transition between offline and residual variance can happen well ahead, later, at the last moment

Exponential decay model: $v(T) = v_{long} - v_{short}\, e^{-\frac{t_{1/2}}{\ln(2)} \cdot T}$

Bucher B., Corman F. (2020) Meaningful Modeling Of Section Bus Running Times By Time Varying Mixture Distributions Of Fixed Components. Transportation Research Record 2674 (8), 626-637

Prediction, and Room for Control

- Shortly ahead of actual event, very good prediction quality.
  But there is nothing left to change/ control

- Very ahead of time, very large room for control.
  But typically very bad prediction quality

- Where do we need resources to hedge against truly unpredictable things?
- Where do we need better information and know more of the system?

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Not now; in the future

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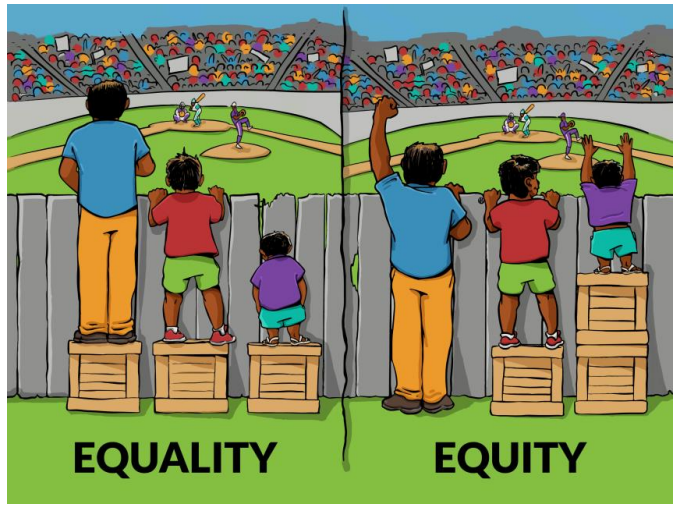
The Goal.

“What then is time? Provided that no one asks me, I know.
If I want to explain it to an inquirer, I do not know” (St Augustine)

Conflicting objectives



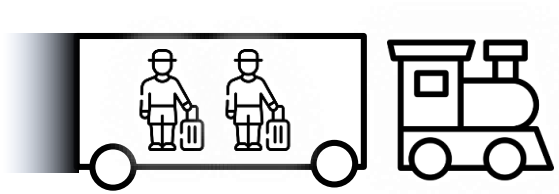
A lot of competition in railway system for limited resources:

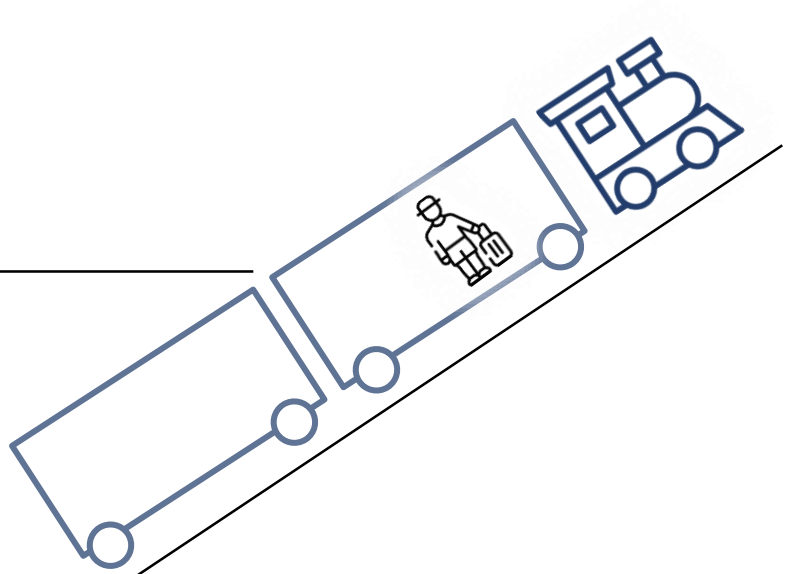
- **within service class**
  (economic competition in the market, non-discriminatory treatment)
- **across service class**
  (integration/ harmonization of regional and long distance traffic, freight traffic)
- **across service usage**
  (maintenance integration into train schedules)

Easy to agree goal

- Passengers (or in general, customers)

Single objective versus multi objective: trains versus passengers





How to (partially) solve dilemmas in multi objective

- Dominance

- Weighted sum
- Max
- Normalized
- Data Envelopment Analysis
- TOPSIS, ….
- Iterative interactive embedding of decision-maker in the process

Needed research on multiple objective for passenger oriented control

- Difference between **passenger delays** and **train delays**:
  more parameters required (capacity, peaks, max,…) to be evaluated together
- Reframe decisions based on simpler rules, thresholds for practical acceptability; nervousness of solutions
- **Connection management**: requires precise input and estimation of downstream effects, to avoid surprising or counteracting effects.
- Understand **sensitivity** of the results to the possible sources of error: passenger demand; second best decisions; robustness
- Understand to which extent **information** to passengers is needed to guide them (i.e. how different is from what was planned; and from what seems a "*logical reaction to the average traveler*")

Interactions in a complex system

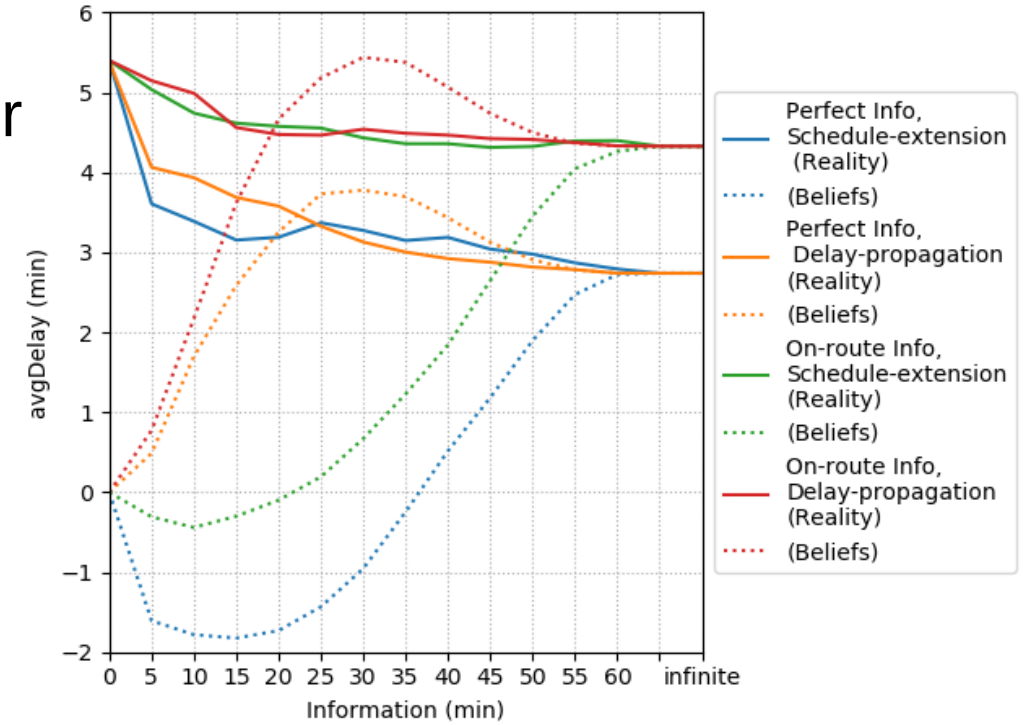
- Amount of people
  ←→ Dwell time

- Impact of circulations, rolling stock rostering
  ←→ Delays

- Amount of people that can benefit from a transfer
  ←→decision about keeping/ breaking transfer connection
  ←→ dispatching/disposition of traffic
  ←→ information dissemination
  ←→ amount of people that can benefit from a transfer

What happens when not everybody has the right information?

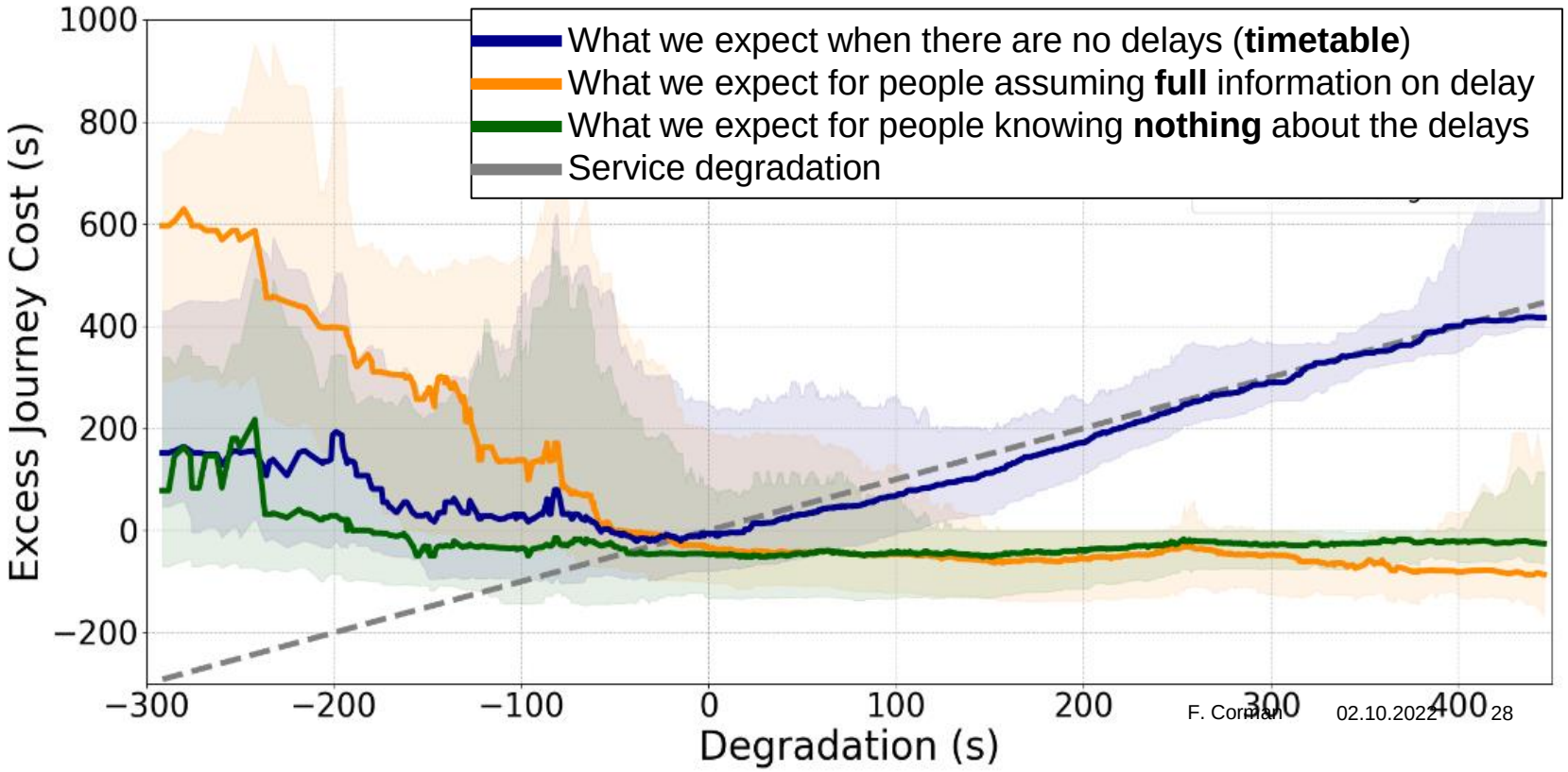
- Influence of past & present (often known)
  future reality (unknown)
  implicit future forecast (Incorrect) of the operator
  implicit future forecast (Incorrect) of the traveler towards the
  actions taken in result by operator and traveler
- Assuming shortest path assignment,
  and perfect information might NOT
  have a single equilibrium point
  (flipping behavior)



Leng N., Corman F. (2021) Communicating delays and adjusted disposition timetables: modelling and evaluating the impact of incomplete information to passengers. Expert Systems with Applications.

Understand complex effects in reality

- GPS Tracking data (~3000 trips), processed by AI methods
- For small delays, best response remains the same
- Inertia: replanning takes place after some delay
- “Good delays” are ignored



Marra A.D. (2021) Phd Thesis

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Best possible for whom?

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Which aspects can I change (steer/control), which aspects do I want to change (steer/control)?

Introduce room in your control (include space in your plan)

- If there is nothing to change, there is nothing to decide!
- Typically railway has a lot of control at any level, from planning all the way to the real-time. This results in a lot of rigidity of the system.
- Most of those boundaries are **artificial**, to simplify control.

- Give freedom downstream in planning!
- Example: promise what is required (e.g. start/end station, start/end time interval), but not more (route followed, precise minute of departure, platform..)
- Give freedom downstream in planning, **only if you can handle it in some smart way**

Here I could talk about all research of the world on improved solution to complex problems

- To make sure that you can handle the flexibility you considered, when you need to!

- Operations Research, MILP, non linear optimization, RL, heuristics, ADP, data-driven optimization, …

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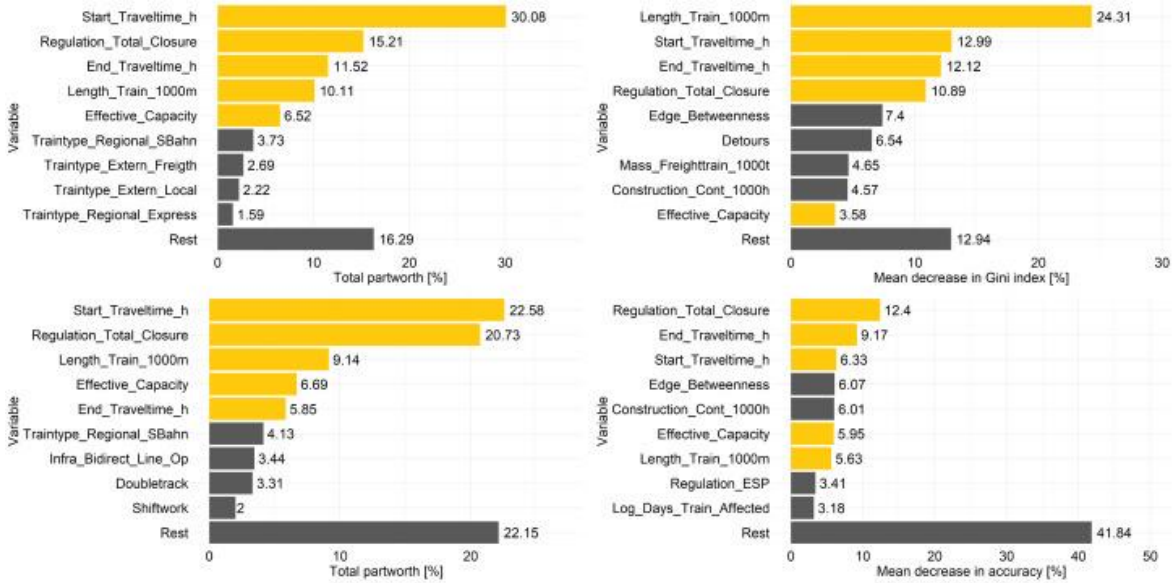
A decision is useless if not take into account!

- Consider human factors when designing the control
- Separate fast simple control (possibly completely automated) from human control (control rooms, dashboard, complex tradeoffs)

- Understand what people did, and why. Otherwise they will not trust what you suggest them
- Management of the transitions – learning curve
- Control as an enabler for decision maker; not as a replacement for decision makers

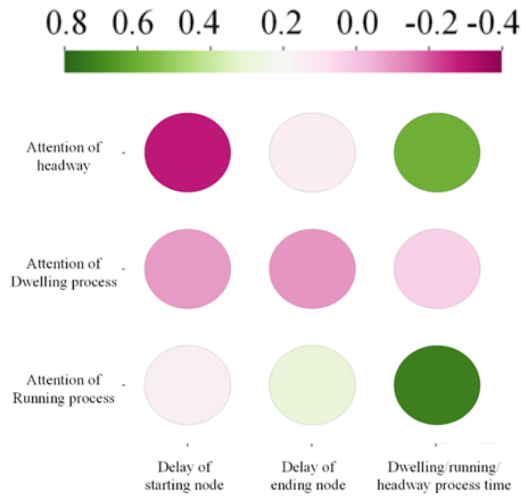
Modelling of current decisions

- Graph Attention Networks (GAT) discern the different importance of characteristics into actual decisions and or actual performance of traffic
- Discrete choice models to replicate decisions of possession planners



(a) $VI_{MNL,k}$ (top) and $VI_{MIXL,k}$ (bottom) (b) $VI_{MDG,k}$ (top) and $VI_{MDA,k}$ (bottom)

Spearman correlation between attention scores and train delays



Huang P. (2022) ongoing research
Schmid, B., Becker, F., Molloy, J., Axhausen, K. W., Lüdering, J., Hagen, J., & Blome, A. (2022). Modeling train route decisions during track works. Journal of Rail Transport Planning & Management, 22, 100320.

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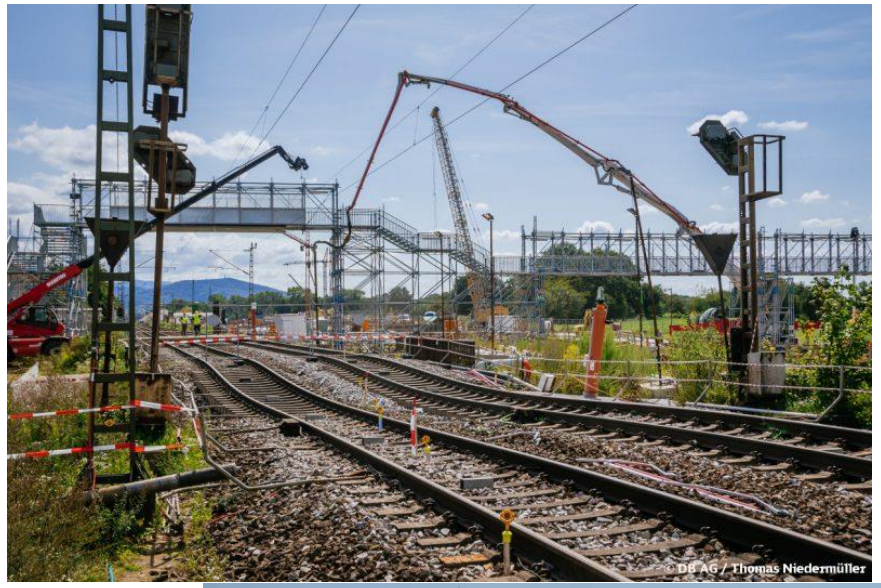
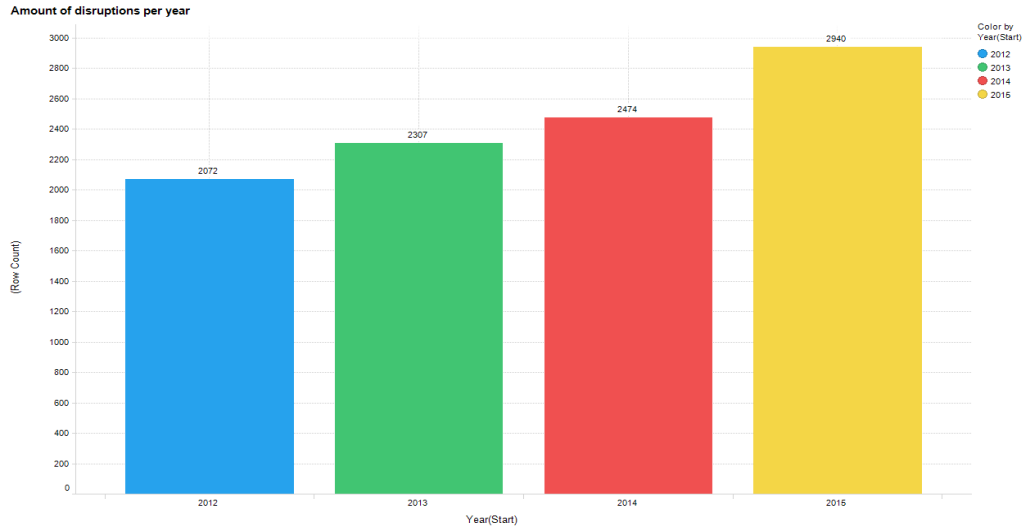
Disruptions can only increase! Interconnectedness can only increase! Need for decision support can only increase!



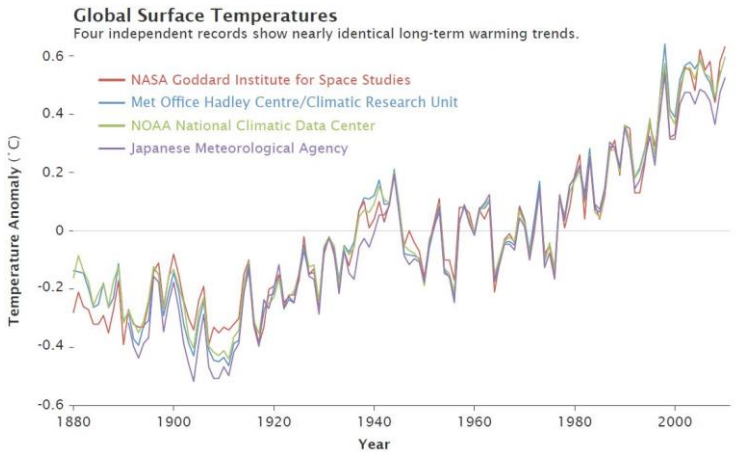
Rastatt Tunnel disruption, august- October 2017-DB AG



2012 2013 2014 2015

Amount of events classified as disruption, Dutch Network [Corman]

https://www.euronews.com/2022/08/10/germany-drought-river-rhine-water-levels-could-fall-to-critical-low



Summarizing, controlling (railway)…

- …requires to understand the most likely future. Data, and models, are useful. A lot of research is ongoing or available
- …requires understanding what is a good decision, what is a worse one. It seems easier than it is
- … requires to compute the action to suggest, especially when those are for complex situations or comprising multiple adjustment at the same time. Many ongoing challenges for academia
- … requires to expand the scope of the problem when no useful actions can be found (room for control). Often, changes of paradigm for industry
- … requires the decision maker to understand and accept the suggestion. Not always the priority of academics, often considered too little in industry

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How to get the best out of your transport network?

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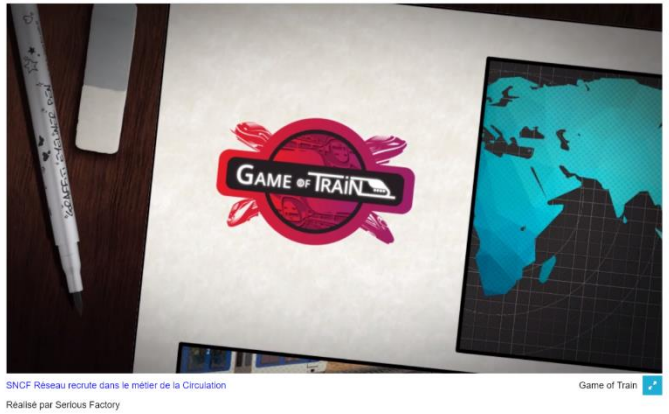
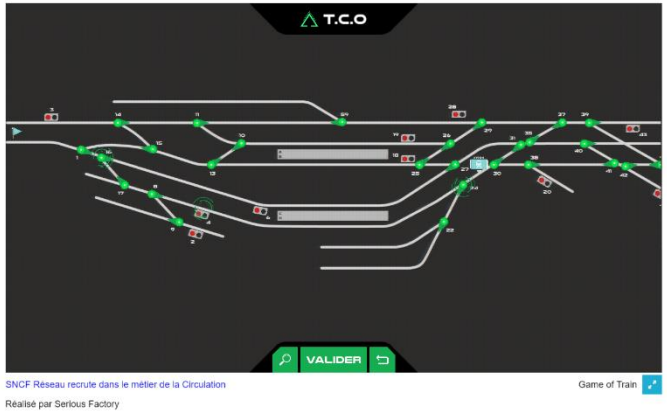
Control is fun!

Game of trains, http://gameoftrain.sncf-reseau.fr





Railway Laboratory