COMPLEXITY METHODS FOR PREDICTIVE SYNCHROMODALITY (COMET-PS)

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TNO innovation for life

TU Delft

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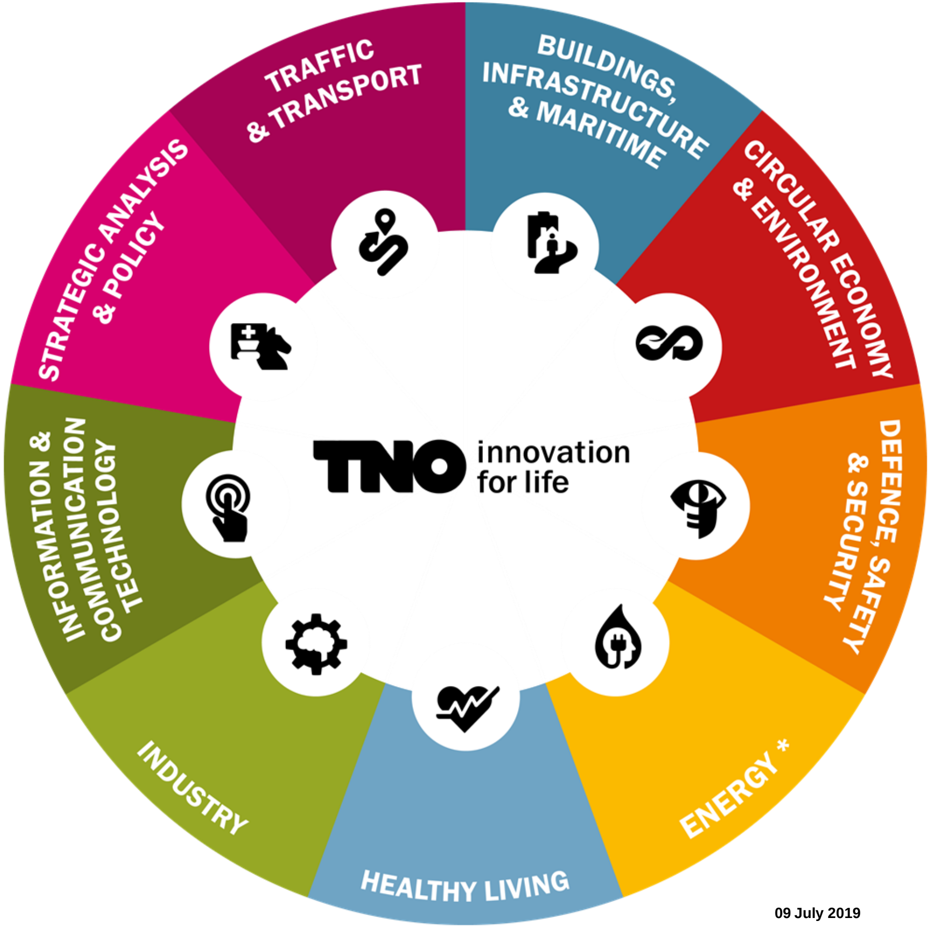


COMPLEXITY METHODS FOR PREDICTIVE SYNCHROMODALITY

Goal: Enable a streamlined logistic system with improved transport efficiency, higher loading rate of vehicles, less emissions and costs, making use of complex synchromodal network optimization.

Funded by: NWO, TKI DINALOG, TNO, CTT

Partners:

Knowledge partners

Co-financers (in cash or in kind)

Supporters

WHAT DID WE PROMISE?

- A prototype of a synchromodal planning system
  - well documented and supported by several (scientific) papers.

- Evaluated on real cases that have different freight characteristics like:
  - Bulk and container transport.
  - Net centric versus freight centric.
  - High and low level of uncertainty.

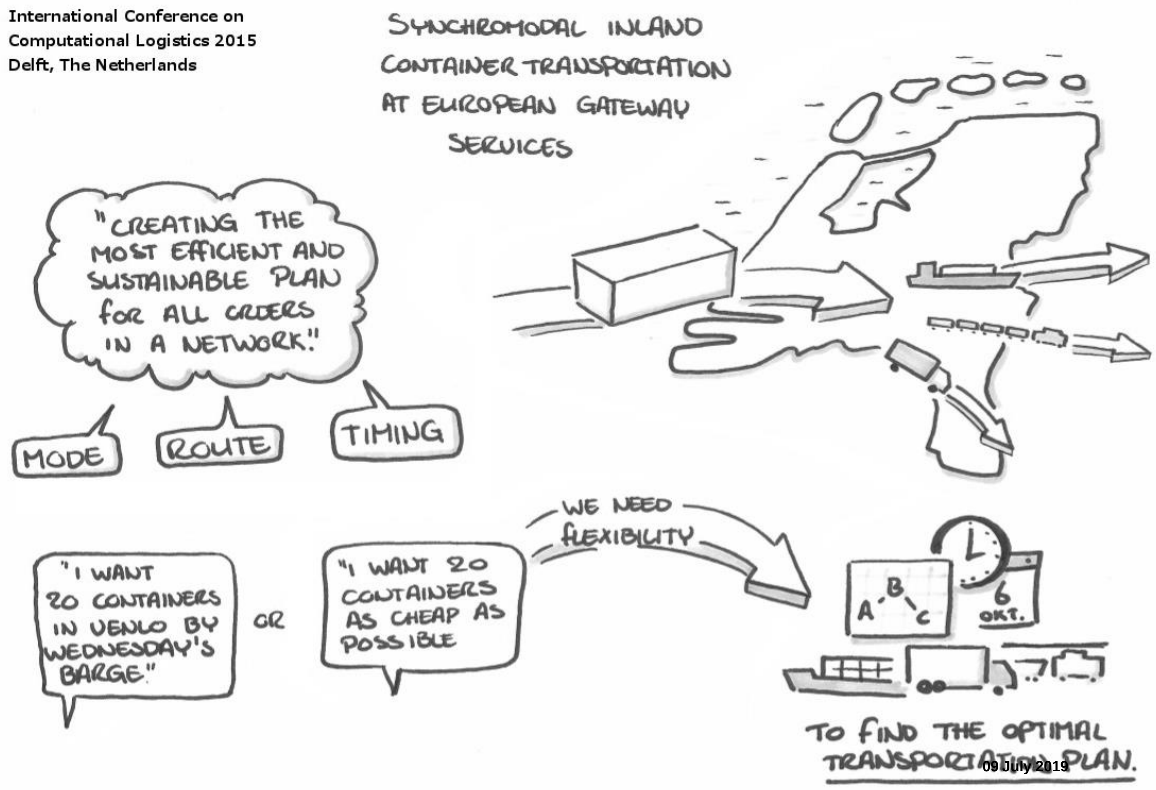
- Predictive Synchromodality: incorporating models, methods and tools based on *predictive data analysis and stochastic decision making in (distributed) control environments.*

SYNCHROMODAL TRANSPORT

From inter-modal to synchro-modal means:

1. Clients will only tell the logistics service provider when and where their cargo needs to arrive, entrusting the logistics service provider to determine how it gets there;

2. Planners will use data that is (more) real-time, and routes will become subject to change in real time when beneficial.



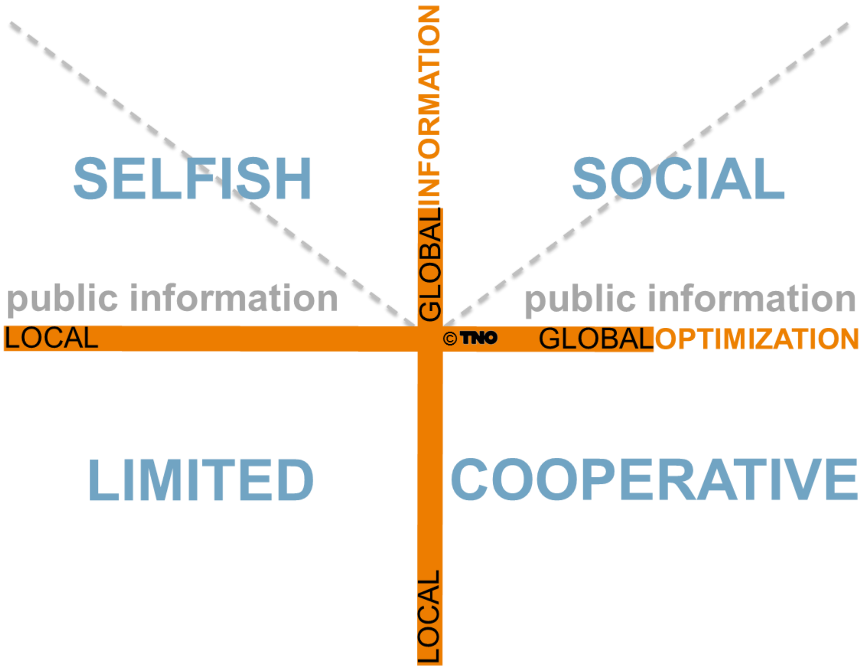
SYNCHROMODAL PLANNING

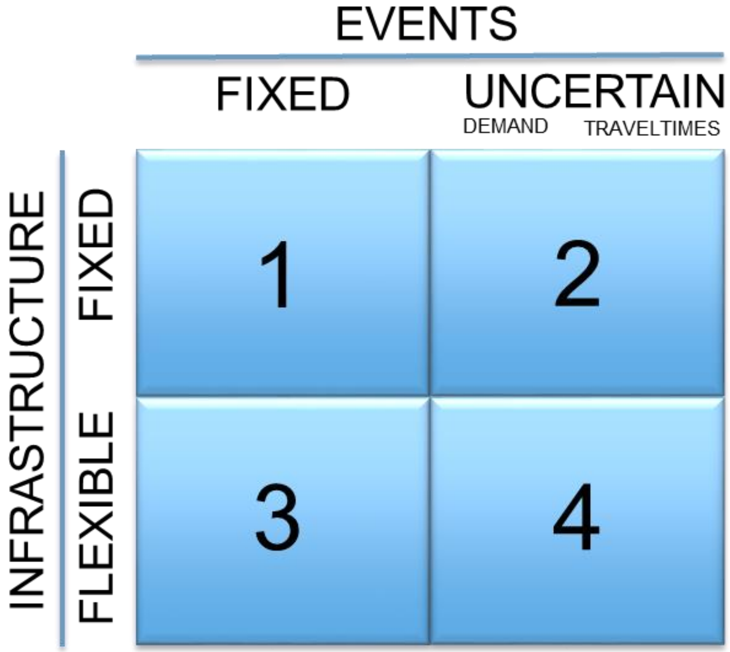
- Planning is based on data that is (more) real-time, and routes will become subject to change in real time when beneficial.

- This could mean:
  - A lot of re-planning – need for fast planning methods
  - Robust planning
    - Stochastic;
    - Worst case / robust optimization;
    - Define robustness and use as objective;
  - Decentralised planning / Distributed control
  - Self-organisation
  - Use of predictions / *predictive data analysis*

THE ROAD TO PREDICTIVE SYNCHROMODALITY

THOUGHT-FRAMEWORK





THREE PAPERS FROM COMET-PS ACCEPTED

- *Reduction of Variables for Solving Logistic Flow Problems.*

  K. Kalicharan, F. Phillipson, A. Sangers, M. De Juncker

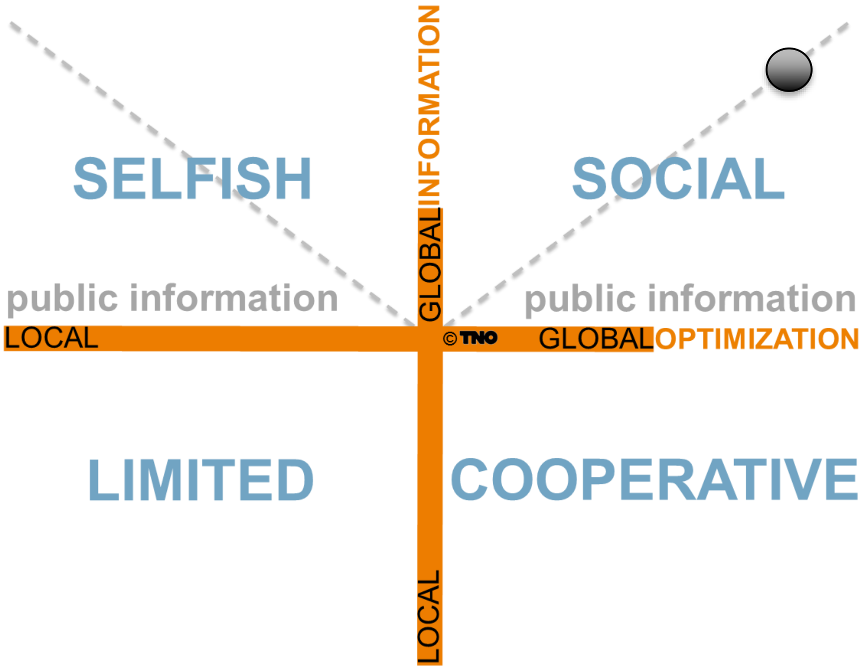
- *Decision making in a Dynamic Transportation Network: a Multi-Objective Approach*

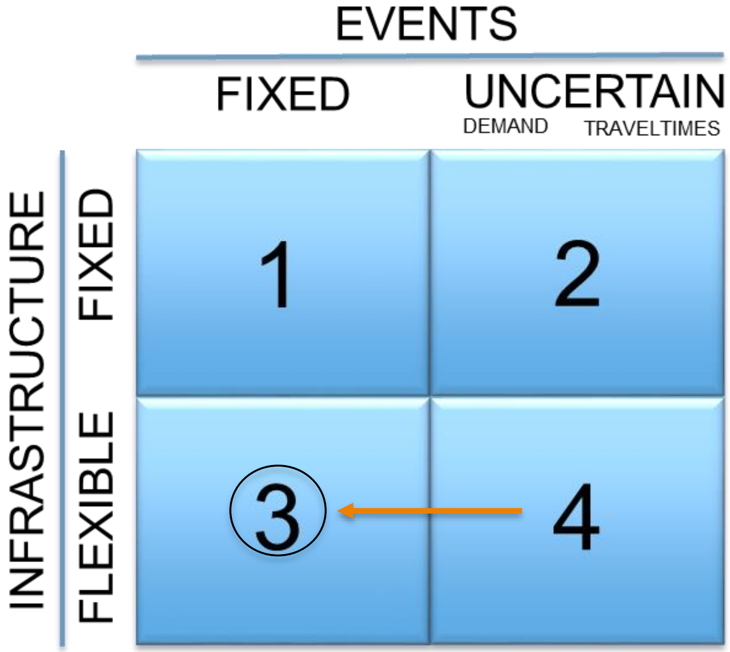
  M.R. Ortega del Vecchyo, F. Phillipson and A. Sangers

- *User Equilibrium in a Transportation Space-Time Network*

  L.A.M. Bruijns, F. Phillipson and A. Sangers

PAPER 1: *REDUCTION OF VARIABLES FOR SOLVING LOGISTIC FLOW PROBLEMS.*

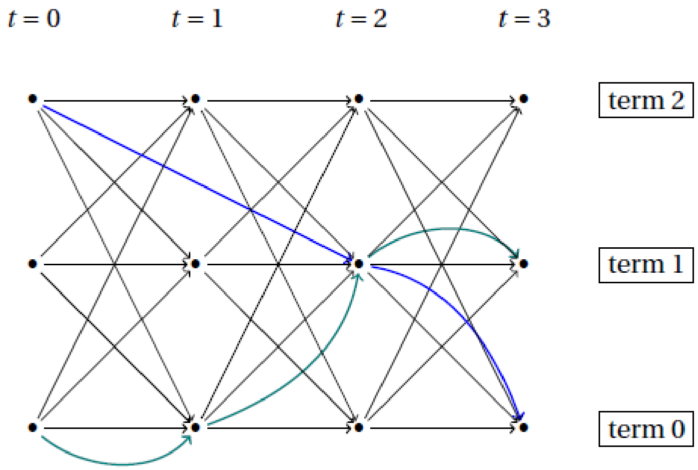




A lot of re-planning – need for fast planning methods

1 IMPROVED EFFICIENCY OF SOLUTIONS FOR DETERMINISTIC PLANNING PROBLEMS

- *Reduction of Variables for Solving Logistic Flow Problems.*
  K. Kalicharan, F. Phillipson, A. Sangers, M. De Juncker



- Min-cost multi-commodity flow problem on a space-time network, which can be solved with an ILP solver. The model can be expanded to also allow 'infinite resources' and simultaneous soft due dates and hard deadlines.

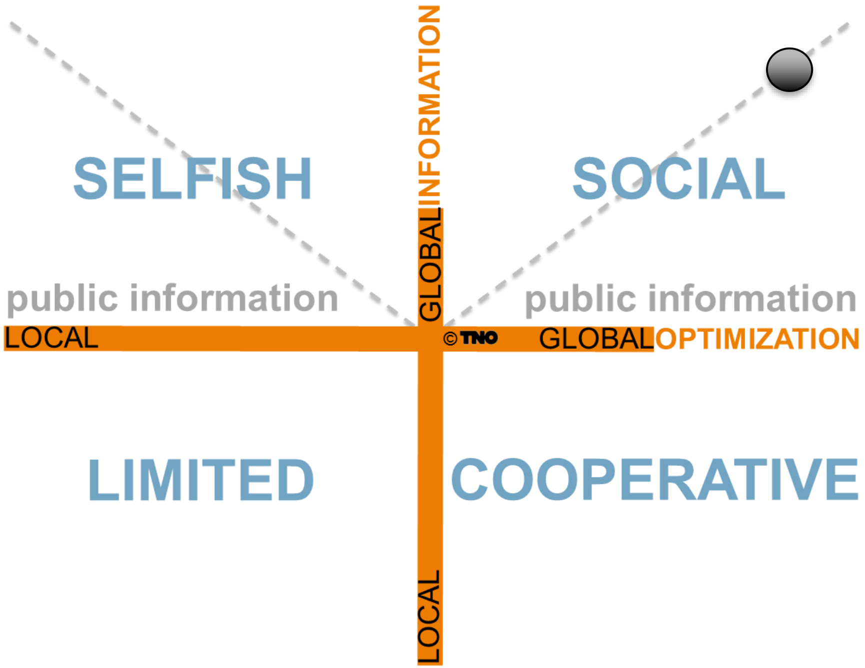
- Improving the mathematical model with cutting planes, model reductions and solution techniques, resulting in drastically decreased solving time.

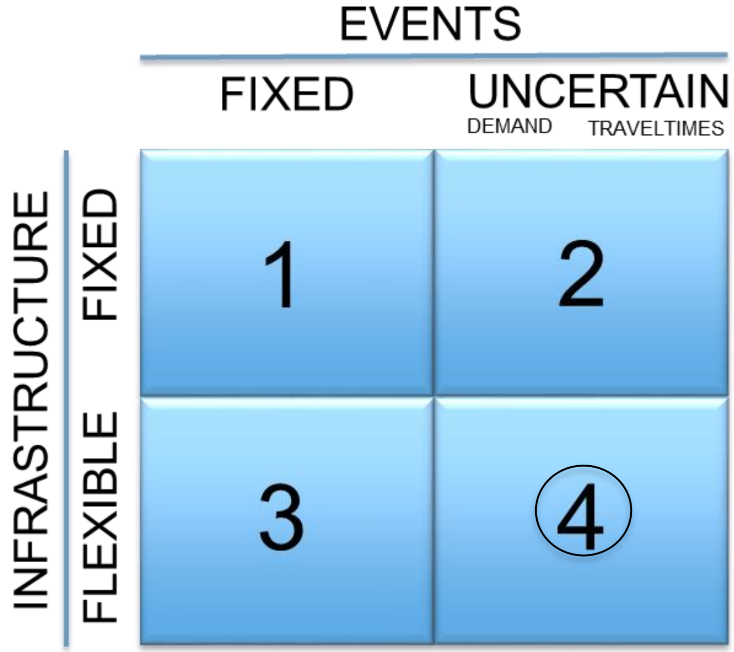
VARIABLE REDUCTIONS

- Commodity reductions:
  - Same sink/source reduction (A)
  - Disjoint time frame bookings reduction (B)
- Same vehicle type reduction (C)
- Arc reductions:
  - Source/sink location reduction (D)
  - Obsolete mode link reduction (E)
- Location reductions:
  - Minimal path reduction (F)
  - Direct connection reduction (G)

Reduction	Active	Parameter	Comp. Time	Solution
A	No	K=25	7.12s	2600 (opt.)
A	Yes	K=25 → 20	5.86s	2600 (opt.)
A	No	K=50	67.45s	3760 (opt.)
A	Yes	K=50 → 39	61.16s	3760 (opt.)
B	No		61.16s	3760 (opt.)
B	Yes		43.35s	3760 (opt.)
C	No	$\|W\|$=6	1667.61s	3760 (opt.)
C	Yes	$\|W\|$=5	628.58s	3760 (opt.)
C	Yes	$\|W\|$=4	183.51s	3760 (opt.)
C	Yes	$\|W\|$=3	61.16s	3760 (opt.)
D	No		117.61s	3760 (opt.)
D	Yes	Sink Incoming	61.16s	3760 (opt.)
D	Yes	Sink In/Out	64.58s	3760 (opt.)
D	Yes	Complete	58.50s	3760 (opt.)
F	No		129.98s	3760 (opt.)
F	Yes		61.16s	3760 (opt.)
G	No		> 300.00s	-
G	Yes		61.16s	3760 (opt.)

PAPER 2: *DECISION MAKING IN A DYNAMIC TRANSPORTATION NETWORK: A MULTI-OBJECTIVE APPROACH*





Robust planning: define robustness and use as objective

MULTI-OBJECTIVE OPTIMIZATION OF MCMCF

- *Decision making in a Dynamic Transportation Network: a Multi-Objective Approach*
  M.R. Ortega del Vecchyo, F. Phillipson and A. Sangers

- (mathematical) Definition of alternative objectives (within the MinCostMCF-framework):
  - Robustness: the capacity of a plan to overcome delays in travel times and handling times on terminals and still be carried on as planned.
  - Flexibility: the capacity of a plan to adapt to delays in travel times and handling times on terminals when these force the plan not to be able to be carried on anymore.
  - Customer satisfaction

(1) Cost: $\sum_k \sum_{P \in P(k)} C(P)X(P)$ (and trucks $\sum_k \sum_{P \in T \subseteq P(k)} X(P)$)

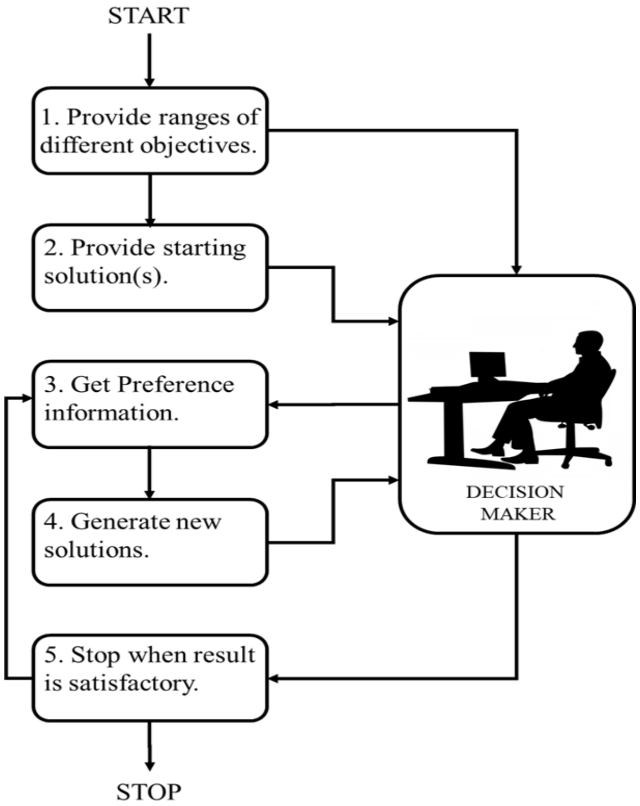
(2) Linear anti-flexibility: simple $\sum_P \iota_G(P) x_P$ (or relative $\sum_P \iota_{G \setminus F}(P) x_P$)

(3) Mean robustness: $\frac{-\lambda}{|\{e \in Pr\}|} \sum_{e \in Pr} \frac{F_e}{t_2^e - t_1^e}$ Where $\lambda = .01$

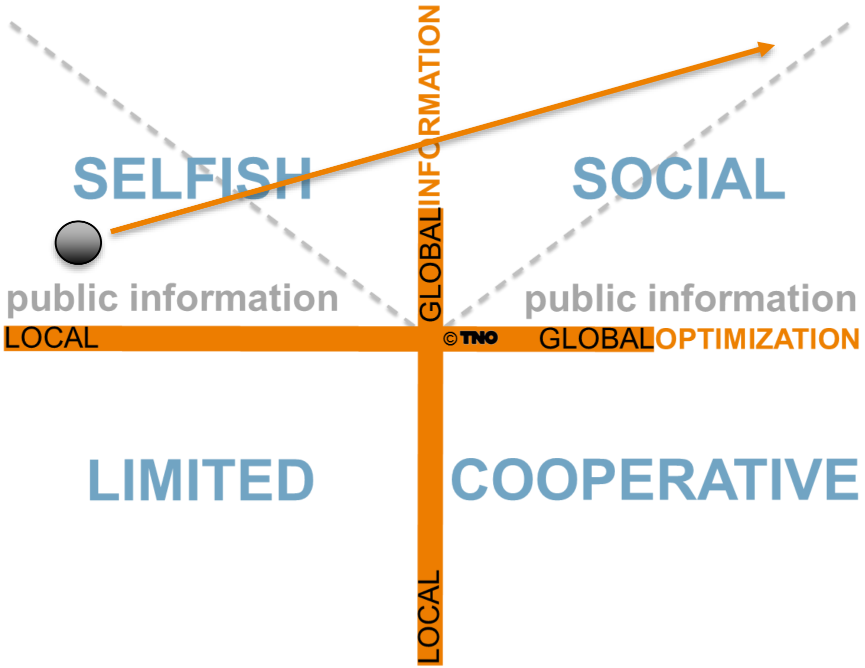
(4) Customer satisfaction: $(\sum_{o \in P} s(o,t)w(o))^2$

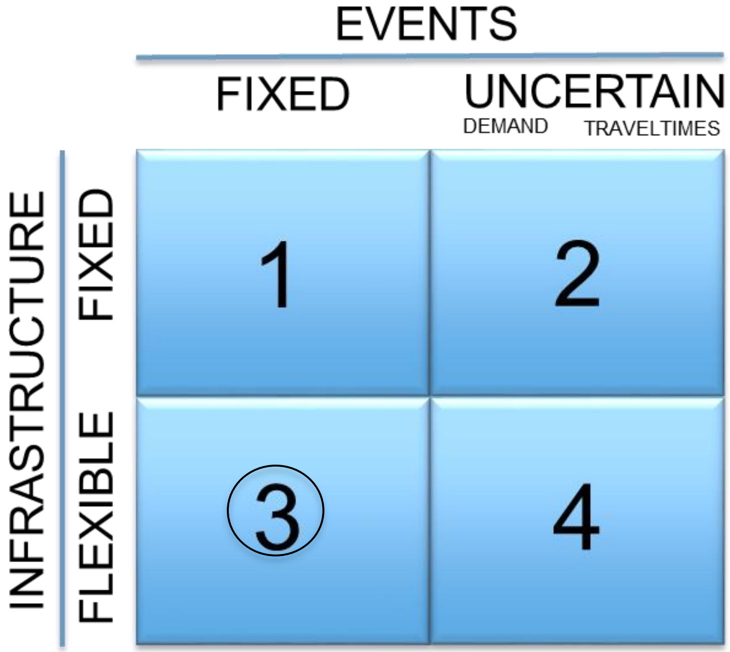
MULTI-OBJECTIVE OPTIMIZATION OF MCMCF

- Generating Pareto optimal solutions:
  - An allocation is *not* Pareto optimal if there is an alternative allocation where improvements can be made to at least one participant's well-being without reducing any other participant's well-being.
  - The Pareto frontier is the set of choices that are Pareto efficient. By restricting attention to the set of choices that are Pareto-efficient, a designer can make trade-offs within this set, rather than considering the full range of every parameter.



PAPER 3: *USER EQUILIBRIUM IN A TRANSPORTATION SPACE-TIME NETWORK*





Decentralised planning

3 FAIRLY DISTRIBUTE COSTS OF CONTAINER TRANSPORT OVER ORDERS

- *User Equilibrium in a Transportation Space-Time Network*
  L.A.M. Bruijns, F. Phillipson and A. Sangers

- Min-cost multi-commodity flow problem on a space-time network with an LSP that controls the container flows
  - Global (system) optimization and satisfy the customers simultaneously
  - Add <u>tolls</u> to orders and paths

- Looking at solutions that are System Optimal, and User Equilibrium in its tolled version.

3 FAIRLY DISTRIBUTE COSTS OF CONTAINER TRANSPORT OVER ORDERS

- Create System Optimal (SO) problem-formulation.
- Solve SO-problem → flow (f).
- Create (Non-linear) problem to find minimal path tolls (NP-β).
- Solve NP-β–problem → path tolls
- Add path tolls to SO-problem SO-β; now optimum of SO-problem = UE in that network.

- *Not really an approach to use in a Selfish environment but rather a way to distribute the 'cost of the social optimal solution' fairly.*

SUMMARY - CONCLUSIONS

- Complexity Methods for Predictive Synchromodality: incorporating models, methods and tools based on *predictive data analysis and stochastic decision making in (distributed) control environments.*

- Planning is based on data that is (more) real-time, and routes will become subject to change in real time when beneficial.

- TNO works on:
  - Fast (re-) planning methods
  - Robust planning
  - Analysis of Selfish-models

THANK YOU FOR YOUR ATTENTION

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Take a look:
TNO.NL/EN/TNO-INSIGHTS