COMPLEXITY METHODS FOR PREDICTIVE SYNCHROMODALITY (COMET-PS)

Frank Phillipson PDEng PhD
TNO – APPLIED SCIENCES

‘Organisation for Applied Scientific Research in the Netherlands’:

▷ Founded by law in 1932.
▷ To enable business and government to apply knowledge.
▷ Independent: not part of any government, university or company.
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:
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

Unimodal statistics

Global controlled multimodal under uncertainty

Complex synchromodal network optimization

2016

2021
THOUGHT-FRAMEWORK

- SELFISH
  - LOCAL
  - LIMITED
  - GLOBAL INFORMATION

- SOCIAL
  - LOCAL
  - GLOBAL INFORMATION
  - COOPERATIVE

INFRASTRUCTURE

- FIXED
- FLEXIBLE

EVENTS

- FIXED
  - EVENT 1
  - EVENT 3

- UNCERTAIN
  - DEMAND
  - TRAVELTIMES
  - EVENT 2
  - EVENT 4
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)

<table>
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<th>Parameter</th>
<th>Comp. Time</th>
<th>Solution</th>
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<td>$</td>
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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 $\sum_{P} \tau_G(P)x_P$ (or relative $\sum_{P} \tau_G \setminus F(P)x_P$)
3. Mean robustness: $\frac{1}{|\{e \in P_r\}|} \sum_{e \in P_r} \frac{F_e}{t_{e_2} - t_{e_1}}$ Where $\lambda = .01$
4. Customer satisfaction: $\left(\sum_{o \in P} s(o, t)w(o)\right)^2$
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 tolls 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 $\rightarrow$ flow (f).
- Create (Non-linear) problem to find minimal path tolls (NP-\(\beta\)).
- Solve NP-\(\beta\)-problem $\rightarrow$ path tolls
- Add path tolls to SO-problem SO-\(\beta\); 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 Synchronomodality: 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

CONTACT: FRANK.PHILLIPSON@TNO.NL

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