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Combination of optimisation methods and material flow analysis for the improvement of the operational material use

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Combination of Optimisation Methods and Material Flow Analysis for the Improvement of Operational Material Use (KOMSA)

The concept and its implementation

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Agenda

- Background: Research project KOMSA – ideas and goals
- An example: The Two-Crude-Oil-Refinery
- Terminology: the standard optimisation model of OR
- Formulation by means of Material Flow Networks
- The framework of the KOMSA optimisation tool
- Solution with the prototype of our software tool
- Conclusions and Outlook

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What is KOMSA about?

Material Flow Analysis

- analysis of material flow systems
- assessment of (**real**) material flows
- improvement analysis

Operations Research

- mathematical = parametric representation of (**virtual**) system designs/ operation modes
- algorithms to find best feasible solution

⇒ synthesis: material flow based optimisation

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KOMSA (1) – Research Questions

- Objectives fit, methods either?
- How to map material flow based optimisation problems with material flow networks (MFNs)?
  - advantages? drawbacks?
  - application fields?
- How to optimise an existing MFN?
  Is that always possible?
- Which type of optimisation problem (OP) results?
- What are appropriate algorithms to solve them?

KOMSA (2) – Software Development

- enhance existing material flow modelling software Umberto® → module for algorithmic optimisation
  - formulation of material flow based OP: optimisation cockpit
  - implementation of appropriate algorithms
  - link to existing optimisation packages
- conserve experimental modelling approach of Umberto
  - flexibility in process specification
- user-friendly model formulation
  - adaptation of material flow network concept

KOMSA (3) – Application

- industrial partners: increase resource efficiency
  - Ciba speciality chemicals, Lampertheim
  - Hanomag Hardening Center, Hannover
- develop exemplary cases for optimisation module
  - test software
  - guidelines for future users
- description of potential application fields

What next…

- a small example for a material flow based OP
- framework of the KOMSA tool
- how to solve the material flow based OP using the tool
- some ideas on using material flow networks to formulate OPs

An example: the "Two crude oil" refinery

- fictitious refinery in Hamburg
- processes two different crude oils
  - from Venezuela 3000t/d
  - and from Saudi-Arabia 3000t/d
- and produces:
  - Gasoline
  - Jet fuel
  - Lubrificants

The company's objectives

- meet demand (constraints)

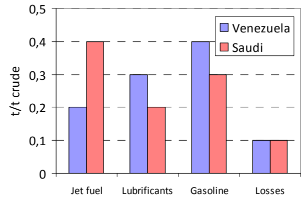
	Lower limit [t/d]	Actual output [t/d]
Gasoline	2.000	2.100
Jet fuel	1.500	1.800
Lubrificants	500	1.500

- minimise costs (objective)

	Saudi	Venezuela
Price [€/t]	19.25	14
Transport [€/t*1000km]	0. 1	0. 1
Distance [km]	7.500	10.000

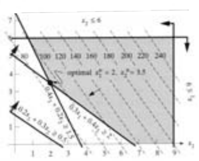
How to influence the company's costs?

- two crudes
  - different prices and transport distances
  - differ in chemical composition ⇒ product mix
- respective quantities of the crudes ⇒ **decision variable**



Standard Model of Operations Research

$$
\begin{aligned}
\min \quad & 20x_1 + 15x_2 \\
\text{s.t.} \quad & 0.3x_1 + 0.4x_2 \geq 2.0 \\
& 0.4x_1 + 0.2x_2 \geq 1.5 \\
& 0.2x_1 + 0.3x_2 \geq 0.5 \\
& x_1 \leq 9 \\
& x_2 \leq 6 \\
& x_1, x_2 \geq 0
\end{aligned}
$$



- objective function
- 2 decision variables
- (algebraic) constraints
  - inequalities
  - (equations)

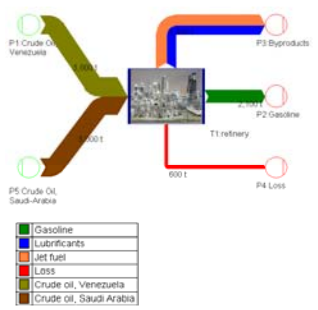
⇒ no start value (actual state of the system) necessary

⇒ decision variables → degrees of freedom → ranges!

⇒ constraints → "interaction"

example taken from: Rardin (2000) Optimization in Operations Research

"Two-Crude-Oil" as Material Flow Network



- Model variables $\vec{x} = (\vec{j}, \vec{p}, \vec{s})$
  - 6 material flows
  - 0 parameters and stocks
- Causality
  - topology of network
  - transition specifications
- Objective
  - cost accounting

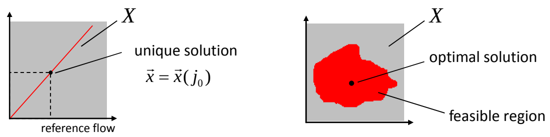
⇒ maps actual state

⇒ model variables → (calculated) values!

⇒ constraints?

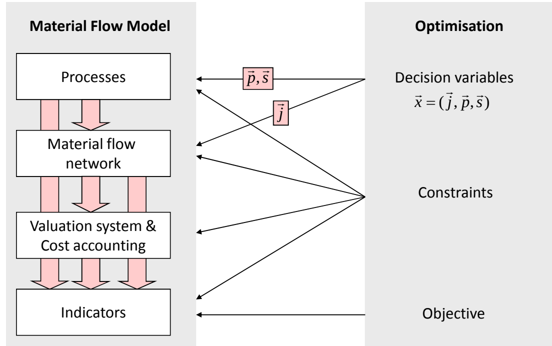
Different Modelling Paradigms

- $\vec{x} = (\vec{j}, \vec{p}, \vec{s})$ = vector with all model variables
- **usually, e.g. LCA**: given the functional we obtain a unique $\vec{x} = \vec{x}(j_0)$
- **Optimisation**: independent components of $\vec{x}$ span solution space, search for optimal $\vec{x}^*$

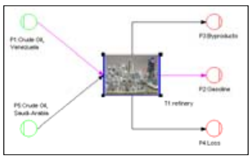


⇒ include degrees of freedom (choices) in the model!

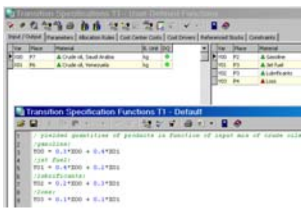
Matching of Concepts



The Role of Transitions

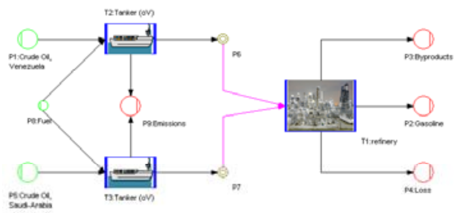


- 6 model variables, 6 decision variables?
- transition specification: equations reduce degrees of freedom!



⇒ Transitions **are effectively** constraints

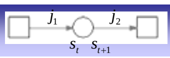
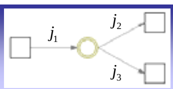
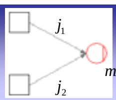
System Enlargement: Include Transport



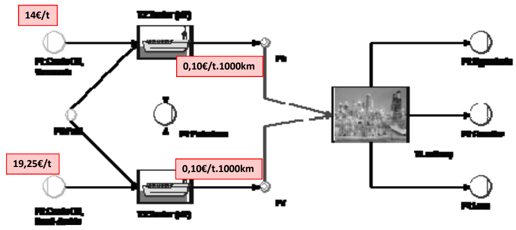
- include transport
- add many model variables (~20 material flows, 2 trans.-parameters)
- but: adds no degrees of freedom!

⇒ because: network structure adds constraints!

Places as Constraints... some Examples

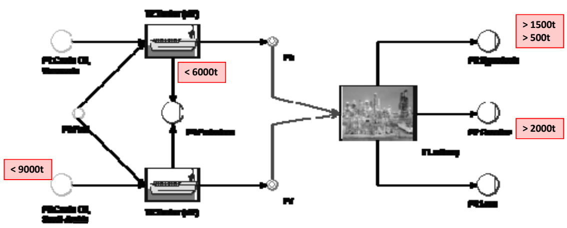
	$j_1 = j_2$	connection	1 DoF
	$s_{t+1} = s_t + j_1 - j_2$	store	3 DoF
	$j_1 = j_2 + j_3$	bifurcation	2 DoF
	$s_{t+1} = j_1 + j_2$	merging	2 DoF

Include Cost-Information



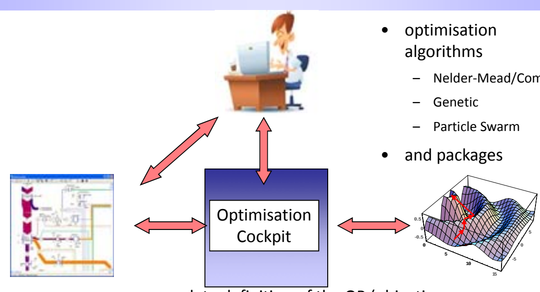
⇒ cost accounting: existing feature of Umberto®

Include additional Constraints



⇒ adding constraints: not yet part of Umberto®

Framework of the KOMSA tool



- optimisation algorithms
  - Nelder-Mead/Complex
  - Genetic
  - Particle Swarm
- and packages

- complete definition of the OP (objective, constraints,...)
- choose algorithms, set parameters,...
- controls optimisation procedure

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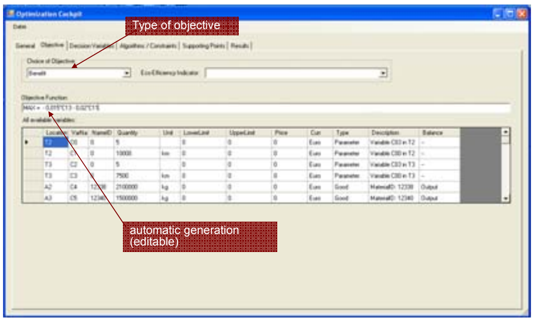
Generation of Objective Function



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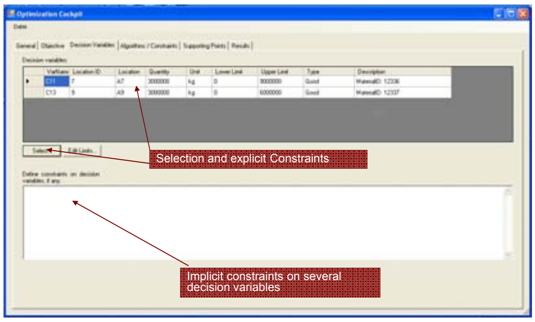
Selection of Decision Variables



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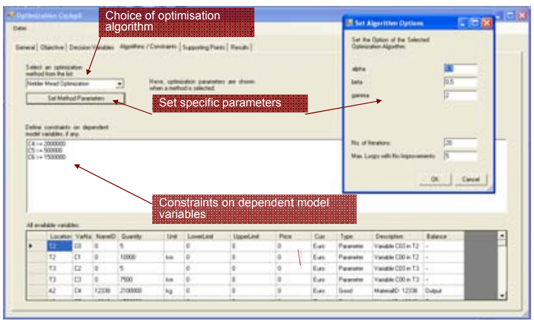
Algorithm and Constraints



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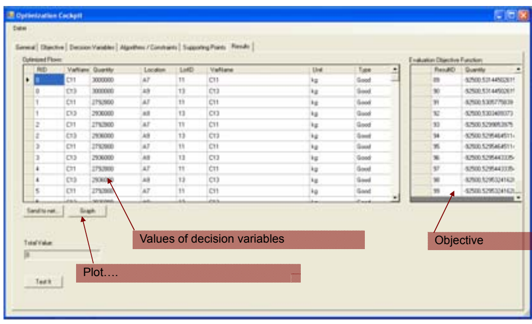
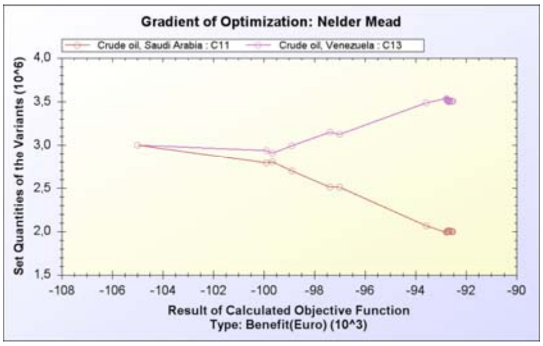
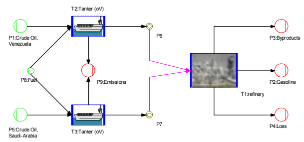
Results



Plot of the results…

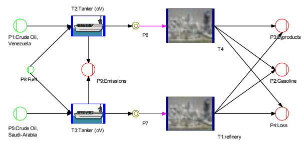


Different possible Representations



- Degree of freedom **within process**

- Degree of freedom **within network**



Conclusions

- Material flow models (Umberto)
  - are "natural" starting point for parameter optimisation
  - useful for structuring decision problems concerning material flow systems (strong causality, material flows)
  - Efficiency and effectiveness of algorithms ⇔ ease of model formulation
- Simulation-based optimisation approach operational as prototype

Outlook

- Further experiences ⟶ test cases!
- Algorithms: Interface to Matlab Optimisation Toolbox
- Role of transitions and places
  - substitutional inputs
  - flexible combined production
  - bifurcationsa
  - deduce: modelling principles for material flow based OPs.

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Thank you !