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Alternative distance functions for change minimization in manufacturing network optimization (presentation of results)

Tuomas Ojavuo

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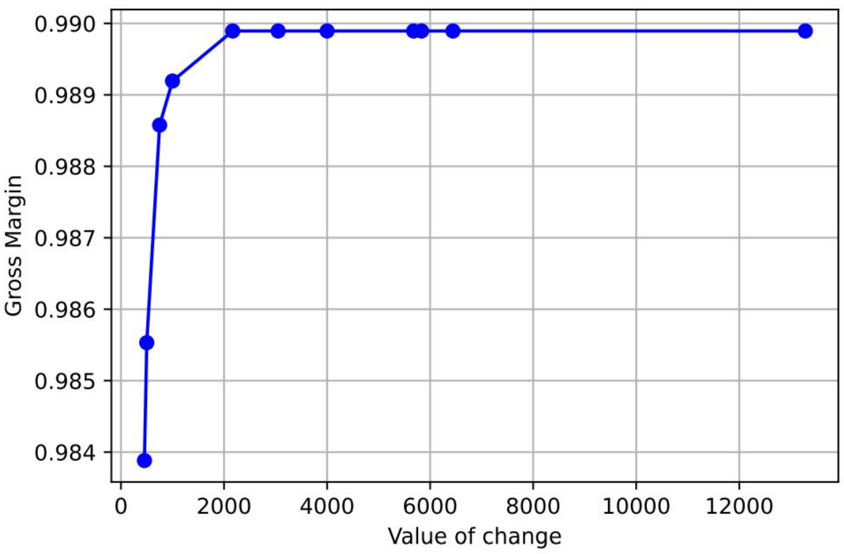
Advisor: *DI Tuomas Suominen*
Supervisor: *Prof. Fabricio Oliveira*

Systeemianalyysin laboratorio

Background

Bi-objective model for optimizing a renewable fuel production network

- First objective: maximize gross margin
- Second objective: minimize deviation from the reference plan
- Uses the ε-constraint multi-objective method



Reference: *Vuola: Bi-objective model for scenario optimization of a manufacturing network (2022)*

Initial distance function

- Change minimization objective uses the L_1 norm for measuring the change in material flow across all arcs
- L_1 norm does not adequately represent the real-life phenomena

$$\mathbf{x} = \begin{pmatrix} 2 \\ 2 \\ 3 \\ 2 \\ 0 \\ 10 \end{pmatrix}, \mathbf{y} = \begin{pmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 0 \\ 20 \end{pmatrix} \Longrightarrow$$

$$\begin{aligned} ||\mathbf{x} - \mathbf{y}||_1 &= \sum_{i=1}^{6} |x_i - y_i| \\ &= |2-1| + |2-4| + |10-20| \\ &= 13 \end{aligned}$$

Chosen approach

Incorporating the number of changes to the existing change minimization function

- advantage: directly implementable to the existing model
- challenge: setting weights for the two functions

Approach: a linear combination of the volume change and the change count objectives, with possible constant terms.

Normalization

- Volume change and change count are generally not of the same magnitude
- To use their sum as an objective function while representing their tradeoffs as accurately as possible, both are normalized:

$$f_i^{normalized} = \frac{f_i - z_i^*}{z_i^{nad} - z_i^*} = \frac{1}{z_i^{nad} - z_i^*} f_i - \frac{z_i^*}{z_i^{nad} - z_i^*}$$

- Their sum can then be used as an objective:

$$f_2' = f_2^{normalized} + f_3^{normalized} = \frac{f_2 - z_2^*}{z_2^{nad} - z_2^*} + \frac{f_3 - z_3^*}{z_3^{nad} - z_3^*}$$

Modeling binary variables

Two alternative methods were tested for coupling the binary variables to the continuous variables:

- big-M constraints of the form

$$\mu_{ijt}^{k} \leq M_{ijt}^{k} \alpha_{ijt}^{k}$$

- constraints of the form

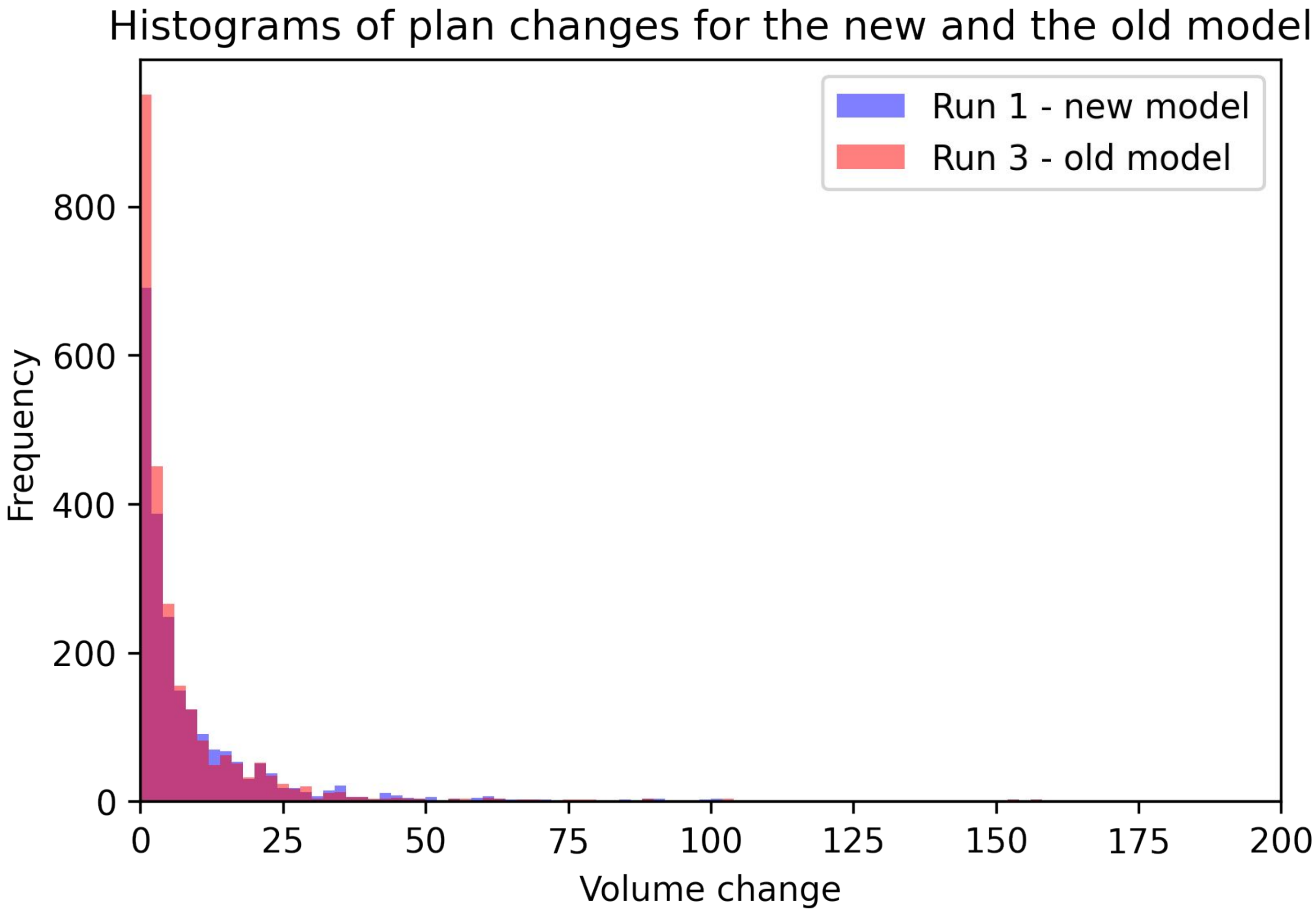
$$\mu_{ijt}^{k} \leq \mu_{ijt}^{k} \alpha_{ijt}^{k}$$

Results

- The number of changes can be significantly reduced
- Both binary variable modeling techniques produced successful results

	Middle solution 1				Middle solution 2			
Optimization run	Scaled GM	GM, % improved	Volume change	Change count	Scaled GM	GM, % improved	Volume change	Change count
Run 1	0.99884761	-0.08%	17209.1937	1706	1.00356319	0.36%	21668.6062	2193
Run 2	0.99941125	-0.02%	17034.8300	1705	0.99901583	-0.09%	21171.0694	2186
Run 3 (control)	0.99960872	0%	15808.5636	2070	0.99995954	0%	20443.6037	2479

Results



Histograms of plan changes for the new and the old model
Run 1 - new model
Run 3 - old model
Frequency
0
200
400
600
800
0
25
50
75
100
125
150
175
200
Volume change

Results

- In some sense, the new model offers better results for the business case
- However, the computational effort is significantly higher:

Optimization run	Time taken to complete optimization
Run 1	40 minutes and 18.55 seconds
Run 2	39 minutes and 29.09 seconds
Run 3 (control)	9 minutes and 25.85 seconds

Visualization

- The original implementation uses the Pareto front graph as illustration for the DM
- In the new implementation, the normalized score f'_2 could be used to draw the graph
- However, also showing the objective values in a table would be beneficial, as the normalized score is only a number in [0, 2] and thus not very informative

Literature and references

- Vuola: Bi-objective model for scenario optimization of a manufacturing network (2022)
- Fang, S. C., Qi, L.: Manufacturing network flows: A generalized network flow model for manufacturing process modeling (2003)
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- Ehrgott, M., Ruzika, S.: Improved ε-Constraint Method for Multiobjective Programming (2008)
- Theodoridis, S., Koutroumbas, K.: Pattern recognition (2006)