Results Presentation: 27th Techno-Ökonomie-Forum,
Vienna University of Technology

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Development of a hybrid adaptive optimization method for dynamic multi-criteria production smoothing

PhD student:

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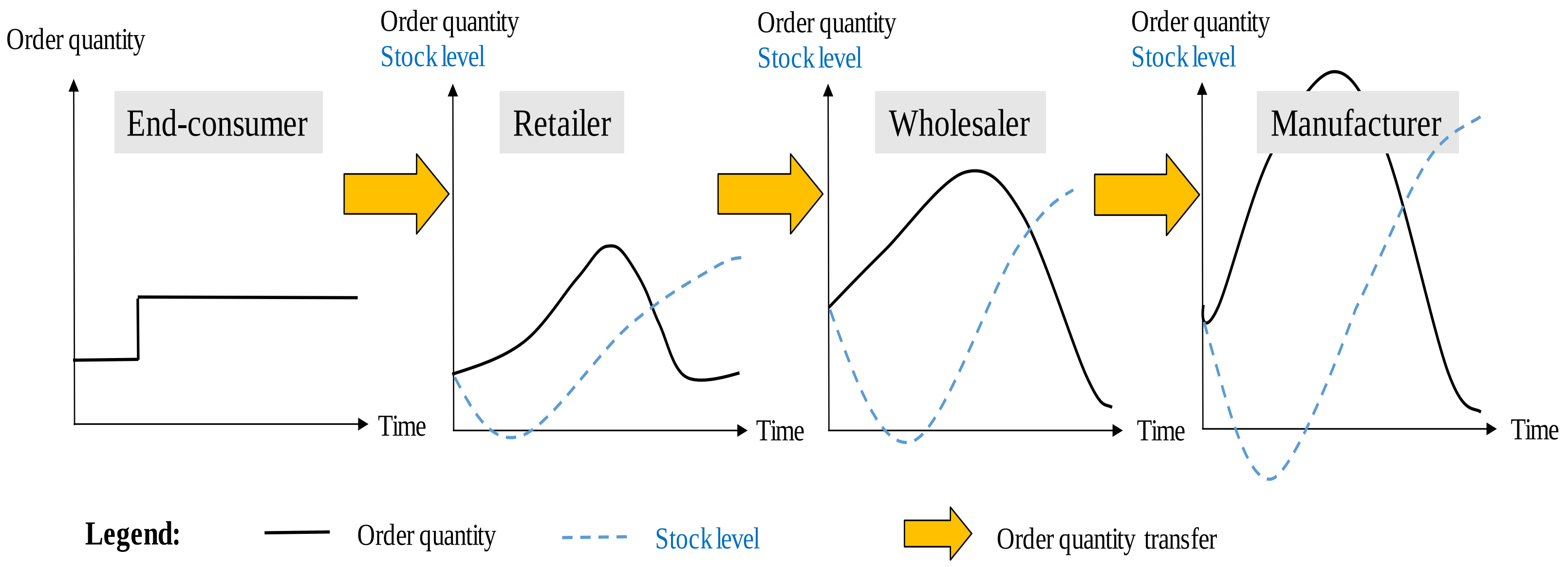
Concept Presentation: held at the 23th Techno-Ökonomie-Forum, University of Leoben

Agenda

- Introduction and Motivation
- Requirements Analysis
- Problem Description
- Model Formalization
- Optimization Results
- Conclusion and Outlook

Challenges of this Use-Case (I/II)

- Large variations in production output rate (**„Bullwhip Effect“**)
  - Products with strong Seasonal Effects
  - Large Promotion Volumes compared to Standard Volumes



The manufacturer continuously has to deal with large variations in the production output rate due to promotional and seasonal (sales) effects.

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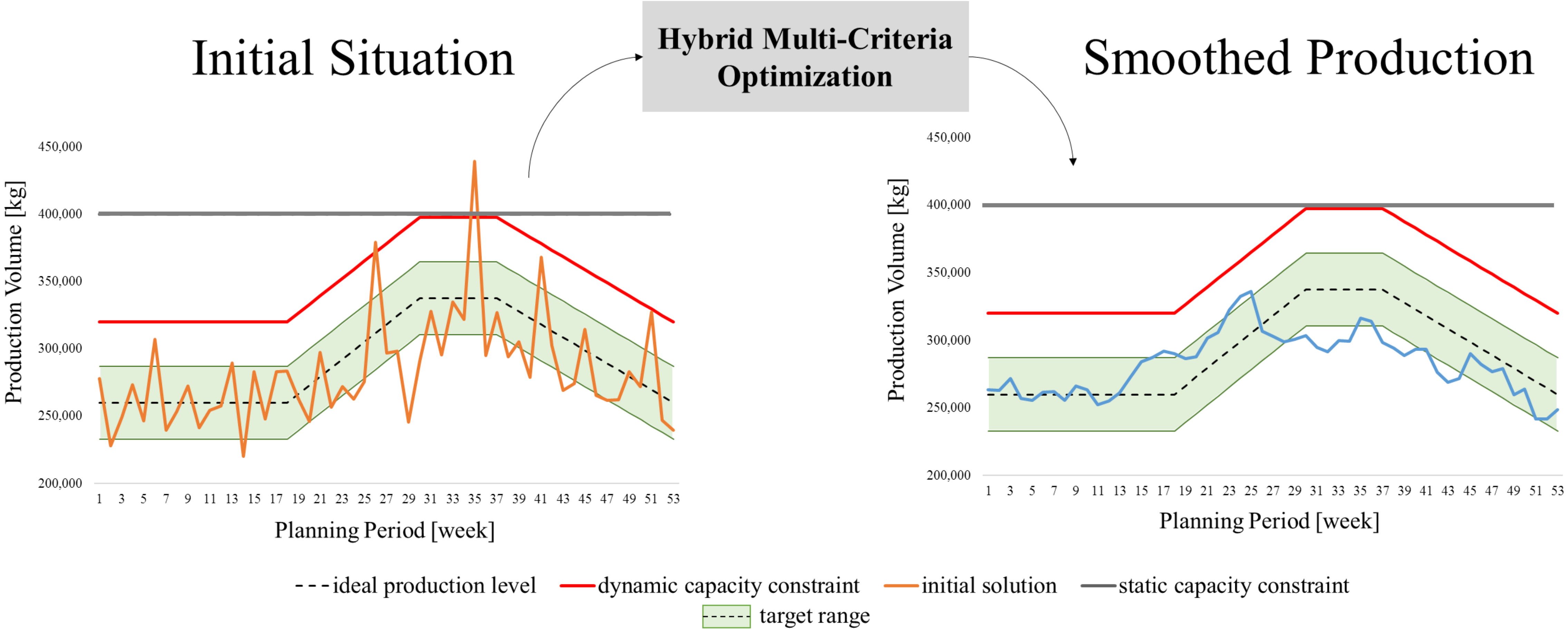
Challenges of this Use-Case (II/II)



Dynamic capacity and stock-level constraints next to article-specific constraints must be fulfilled and enable the food manufacturer to better adapt to the given demand variations

Research Method

- Design Science Research Methodology (DSRM) according to Hevner[0]
  - Comprises 7 guidelines
  - Design as an Artifact, Problem Relevance, Design Evaluation, Research Contributions, Resarch Rigor, Design as a Search Process, Communication of Research

- Operations Research Modeling Approach (ORMA)
  - Applied for the ‚Research Rigor' guideline
  - Consists of 6 phases
  - Problem Definition, Formulation of a mathematical model, Computer based development of an algorithm, validation, preparing the model for continuous application, implementation

The Operations Research problem at hand is solved by a combination of the DSRM and ORMA

State-Of-The Art

- Modern heuristic and metaheuristic optimization methods are rigid and do not learn from the past → **lacking adaptability**

- Currently available methods (e.g. metaheuristics) only work with one dimension, without logically dividing it further into **sub-planning levels** to be **considered / optimized separately** → FMCG industry requires a consideration of e.g. **curant quantities and promotion quantities** as well as different specific requirements

- **Rigid production capacities** → **Consideration of rolling flexible capacity limits and dynamic target and minimum inventory values** represent research gaps in modern ERP/APS planning systems

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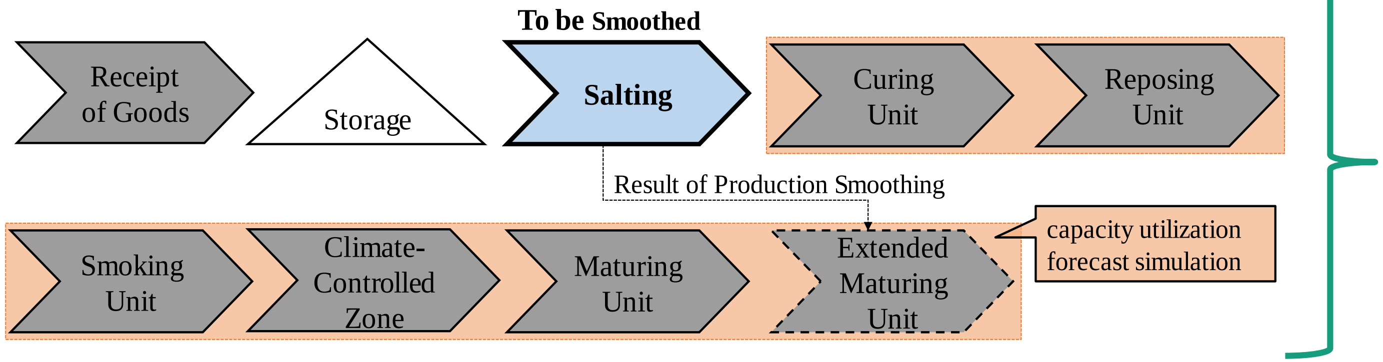
Requirements Analysis

- Case-Study: European Industrial Food Producer
- Problem Definition: Goldratt's Theory of Constraints[1]
- Primary Goal: Smoother production flow and optimization of labour intensive key production equipment
  - Reduced production volume peaks
  - Optimized capacity utilization
  - Optimized stock-levels



Production Smoothing **requires** a process variable in

- Lead Time
- Throughput

Legend:

Key Production Equipment Unit

Process steps covered by Simulation

The smoothed bottle-neck production step (Salting) has to be evaluated next to the whole production system by an integrated dynamic simulation module.

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Multi-Objective Multi-Product Multi-Period (MOMPMP) problem

- MOMPMP are described my m product types and n periods and its underlying multi-criteria planning objectives
- Single-Product Multi-Period (SPMP) problems are already np-complete[2]
- Focus on capacitated dynamic lot-size optimization for a smoothed production

- **Shortcomings** of existing (state-of-the-art) approaches:
  - Missing consideration of dynamic capacity and target stock-levels[3] enabling the consideration of seasonal effects and resource (labour, capacity, …) adjustments
  - Missing utilization of sub-dimensions within a certain planning level (e.g. production quantities)
  - Lack of methodical adaption based on an explorative data analysis (on rolling horizon level)
  - Pure algorithmic optimization approaches often lack the use of an Integrated Simulation

The given problem requires the development of a holistic problem-specific simheuristic optimization approach for an approximate solution

Research Questions

1. How can an efficiently implemented dynamic multi-criteria production smoothing method be designed to address the major shortcomings of available optimization methods for MOMPMP?
   a) How does the objective function differ from other optimization problems?
   b) How does a dynamic method differ from a statically implemented method?
   c) Sequential (multi-phase) sequence or synchronous optimization?
   d) In which way can the runtime efficiency of the presented methodology be evaluated and validated in theory and practice?
   e) Which conceptual differences of the methodology (in design) exist between a one-time consideration compared to a rolling application
2. Which requirements must be met for the successful application of the methodology for multi-criteria production smoothing in the meat processing industry developed in this dissertation?
3. Which properties and characteristics must be fulfilled for the industrial application in order for the method to be carried out sensibly?

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Hybrid Optimization Model Formalization: Overview

- Methodological basis: Mathematical model including lexicographically ranked multiple part-goals within one scalarized objective function, utilization of heuristic lot splitting concepts[4]

- Planning scope: Optimized long-term (78 weeks) production plan covering all (~ 25) production articles of the new plant facilities.

- The presented hybrid optimization methodology focusing on Production Smoothing features

Phase 1
- Rule-based heuristic optimization ← Knowledge-Based lexicographic Optimization

Phase 2
- Simheuristic optimization ← Simulated Annealing versus Genetic Algorithm Metaheuristic Optimization applying Simulation

Phase 3
- Statistical data analysis

Model Formalization: Objective function (simplified)

Weights (adjustable) — According to decisions makers preference

$$\boldsymbol{Minimize}\ f(x) = \omega_1 \sum_{\substack{i=1\\ j=1}}^{\substack{j=m\\ i=n}} f_1(k\_prod_{ij}) + \omega_2 \sum_{\substack{i=1\\ j=1}}^{\substack{j=m\\ i=n}} f_2(k\_stock_{ij}) + \omega_3 \sum_{\substack{i=1\\ c=1}}^{\substack{c=o\\ i=n}} f_3(k\_capacity_{ic}) + \omega_4 \sum_{i=1}^{i=n} f_4(k\_plant_i)$$

Product type gradient

Stock-level gradient

Capacity-level gradient

Plant-level gradient

The objective function *f* applied within the Simulated Annealing scalarizes the problem by using a weighted and scaled fitness function value. The scaling is executed using the part-goals of the best heuristic solution.

Dynamic and Static Constraints within the optimization model

- Dynamic capacity constraint:

$$\sum_{j=1}^{m} q_{ij} \leq q_{max_i}, \forall i, q_{ij} \epsilon A_i, q_{max_i} \epsilon B_i$$

- Static capacity constraints:

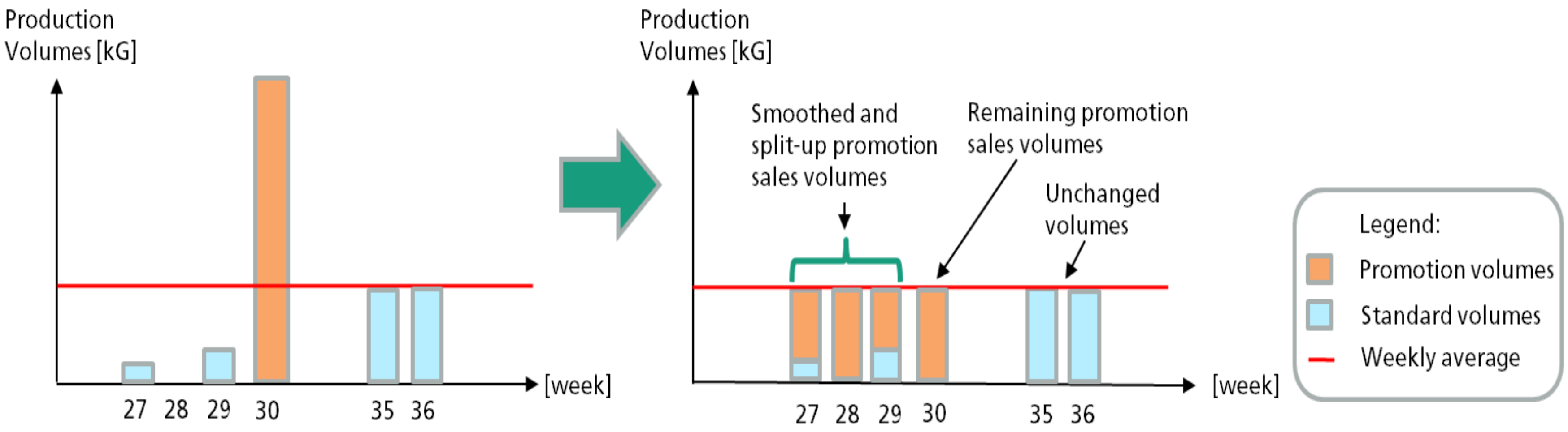
$$\sum_{c=1}^{o} q_{ic} \leq max\_cul_{ic}, \qquad \forall i \in \{1, \dots, n\}$$

- Consideration of article specific offsets for shifting:

$$k_{ijl} \leq k_{max}, \forall i \in \{1, \dots, n\}, \forall j \in \{1, \dots, m\}.$$

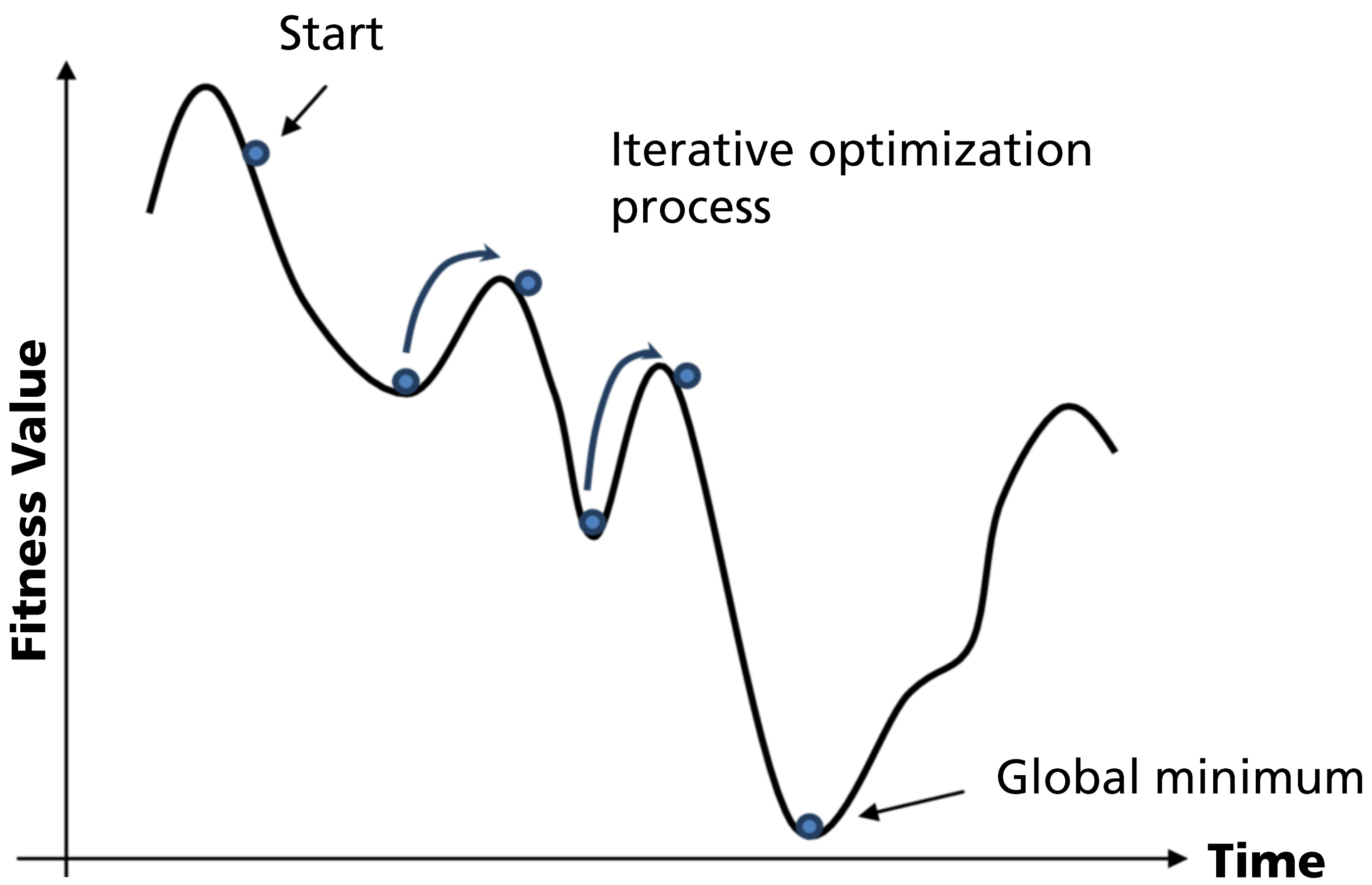
Phase 1: Production Smoothing Heuristic

- Primary Target: Minimization of production volume peaks / Lot-size optimization step
  - The gaps in periods closest to the current period are filled up first, until the current «*average production load*» *(APL)* per period for the specific article is achieved
  - The remaining quantities are shared between all offset-periods, resulting in a higher APL
  - This heuristic is applied for both dimensions – promotion and standard volumes – separately



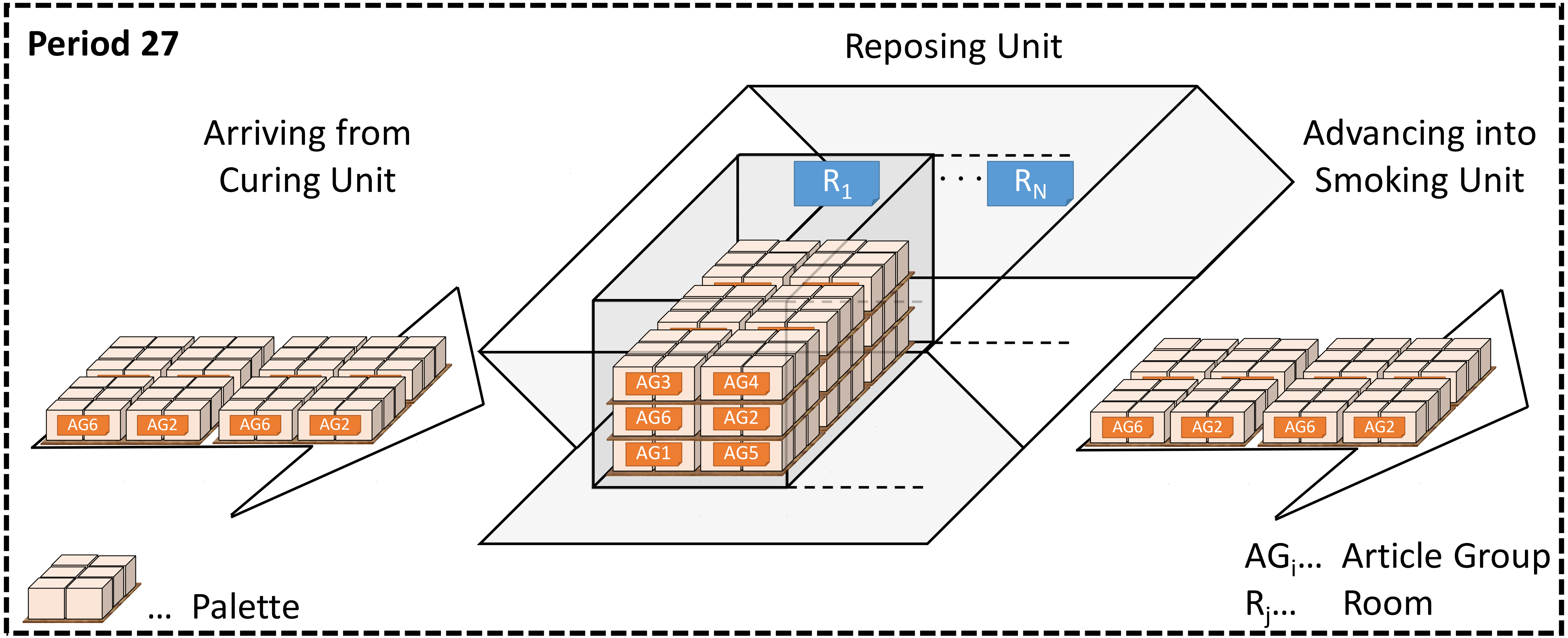
Rule-based heuristic optimization leads to a significant search space reduction and emulates the planners' production rules.

Phase 2: Simulated Annealing (SA) versus Genetic Algorithm (GA)



In larger optimization runs a **Genetic Algorithm** has proven superior to Simulated Annealing!

Simulation Optimization



An integrated dynamic simulation model on palette unit-level is required in order to provide a realistic and accurate dynamic capacity utilization forecast of the core downstream processes (f_3).

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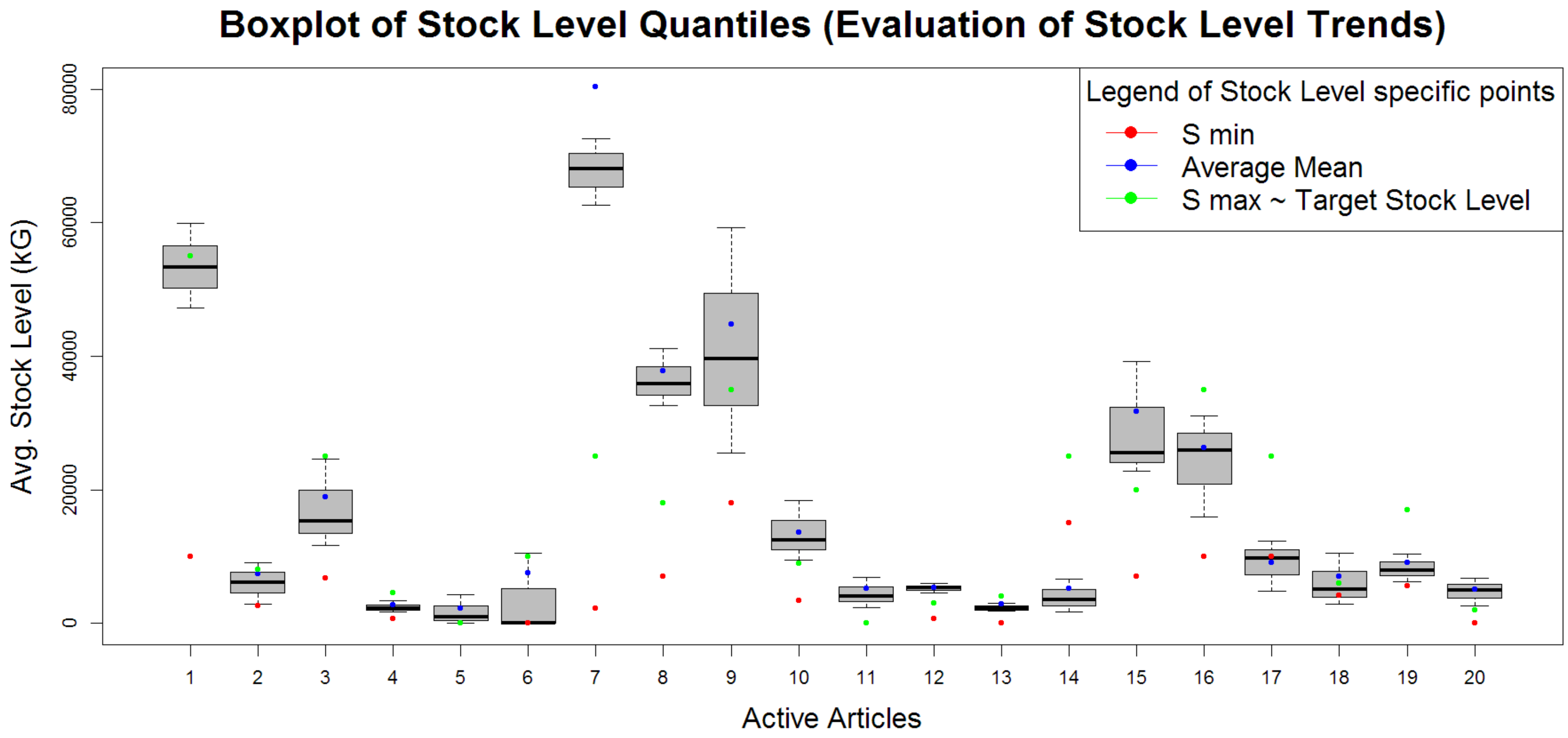
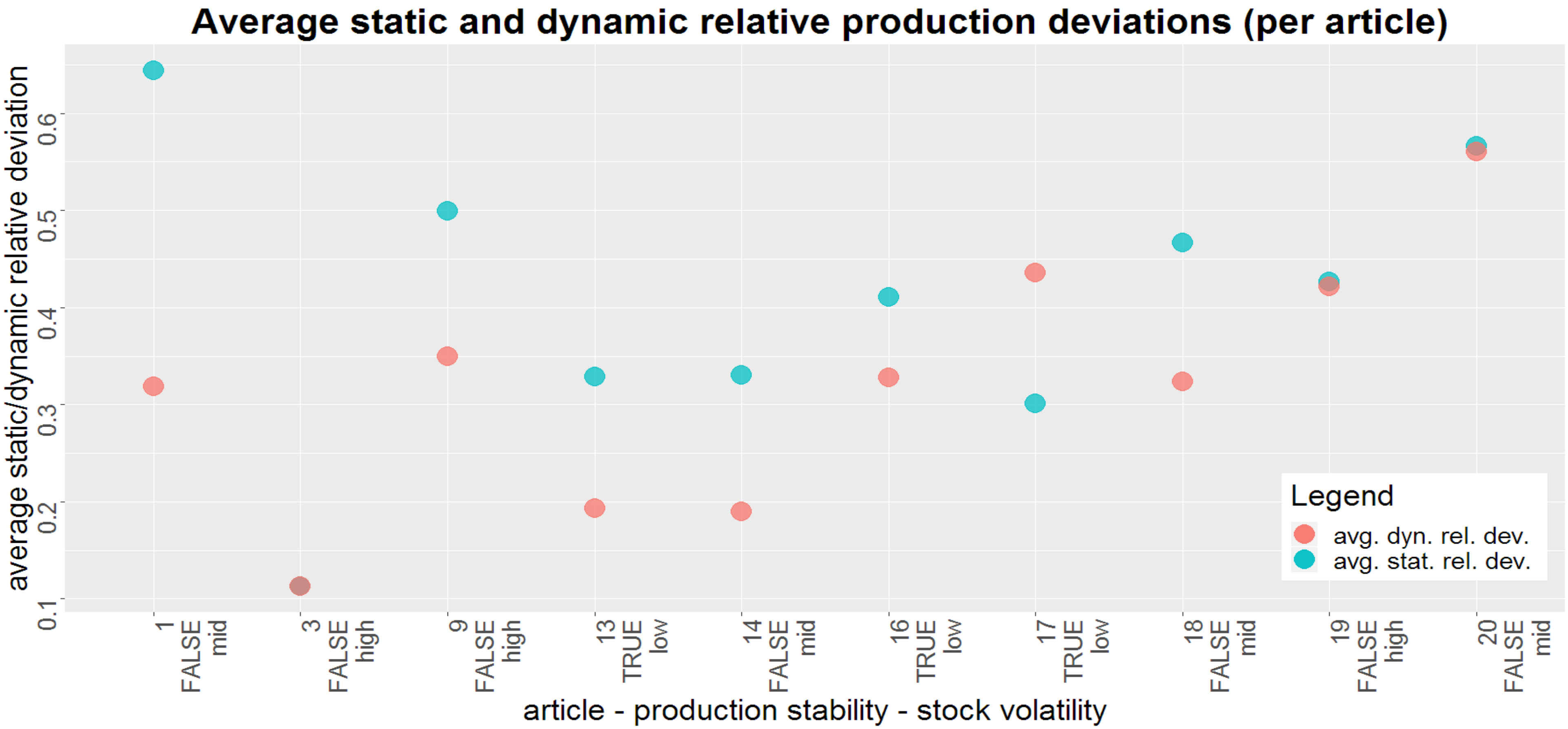
Phase 3: Statistical data analysis: Input factors (I/II)



Phase 3: Statistical data analysis: Input factors (II/II)



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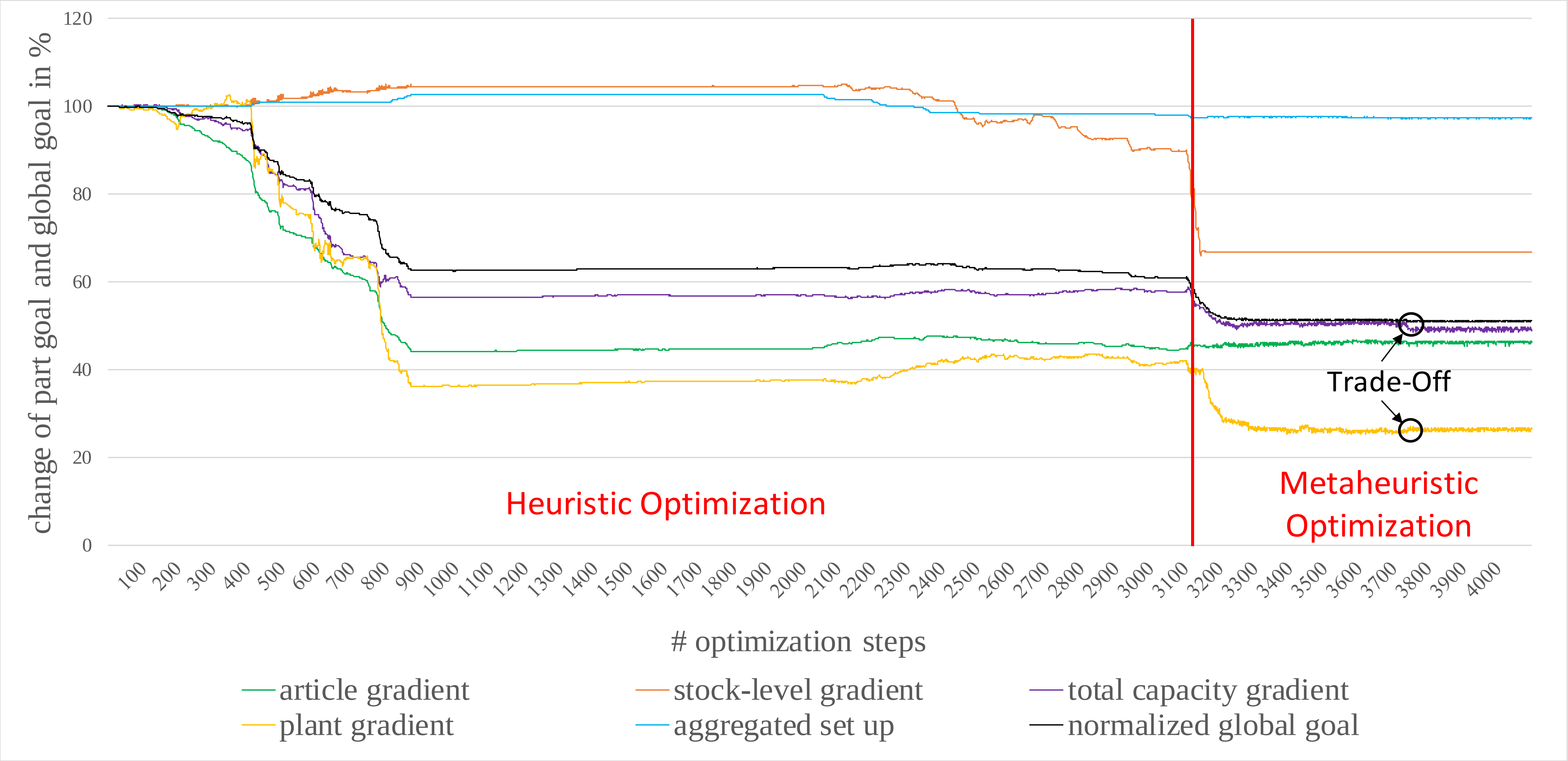
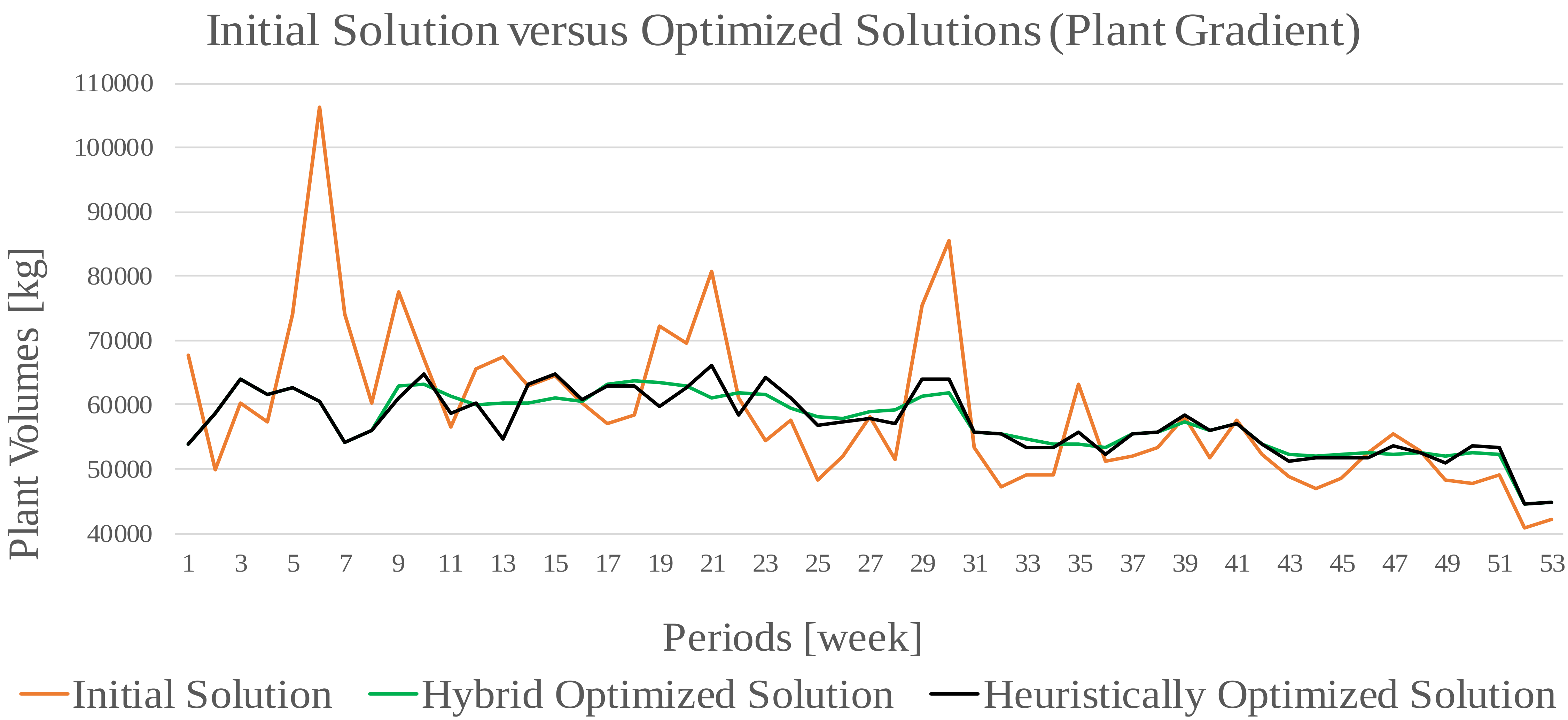
Results of the combined heuristic and metaheuristic optimization



Confrontation: Initial solution versus Optimization



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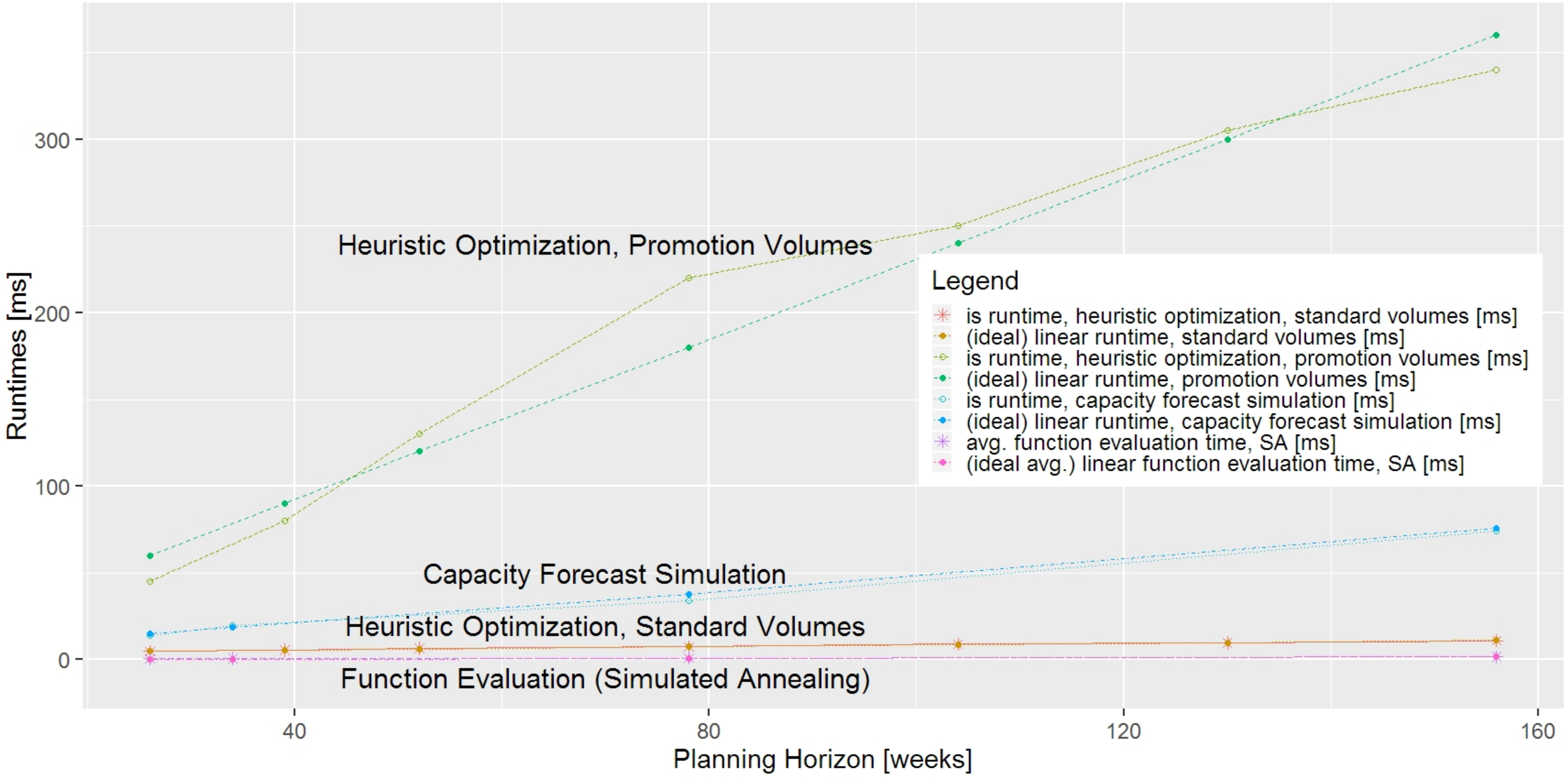
Evaluation: Runtime complexity



Statistical data analysis: Outcome

Article	Smin	Smax	ABC	Production forecast	ABC recommendation	Inventory risk evaluation	Recommendation (inventory levels)	Recommendation (production stability)	Overall recommendation
1	10050	55000	A	447566	A	OK	K	K	K
2	2680	8000	A	67453	A	OK	K	K	K
3	6700	25000	A	341840	A	OK	K	R10	R10
4	700	4500	B	51425	B	OK	K	K	K
5	0	0	B	24617	B	high inventory level, high risk	L20	K	L20
6	0	10000	A	331457	A	OK	K	K	K
7	2200	25000	A	440377	A	high inventory level, high risk	L20	K	L20
8	7000	18000	A	103656	A	high inventory level, high risk	L20	K	L20
9	18000	35000	A	340918	A	OK	K	R10	R10
10	3350	9000	A	75455	A	high inventory level, mid risk	L10	K	L10
11	0	0	A	21363	C	high inventory level, high risk	L20	K	L20
12	700	3000	C	21304	C	high inventory level, mid risk	L10	K	L10
13	0	4000	A	41586	B	OK	K	L10	L10
14	15000	25000	A	130838	A	low inventory level, high risk	R20	K	R20
15	7000	20000	A	47114	B	high inventory level, mid risk	L10	K	L10
16	10050	35000	A	329122	A	OK	K	L10	L10
17	10050	25000	A	176292	A	low inventory level, high risk	R20	L10	R10
18	4200	6000	A	151732	A	OK	K	K	K
19	5600	17000	A	269876	A	OK	K	R10	R10
20	0	2000	A	28800	B	high inventory level, high risk	L20	K	L20

Legend: [K = Keep inventory levels] [L10/L20 = Lower inventory levels by 10%/20%] [R10/R20 = Raise inventory levels by 10%/20%]

The primary outcome is an overall rolling recommendation for the adaptation of the stock-levels and ABC values complemented with a risk assessment of inventory stock based on threshold levels.

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Conclusion

- Production smoothing potential of approximately 40 – 50% compared to the initial manually compiled solution
  - Lowered investments for production equipment (scope: double digit millions)
  - Improved resource and energy efficiency due to improved capacity utilization
  - Significantly reduced labor costs due to balanced operation times
  - Low additional **evaluated costs** for extended maturing (process extension for defined quantities)
- Practical considerations
  - High proven runtime efficiency being beneficial for rolling horizon optimization
  - Master data optimization of mid-term inventory levels
- Outlook
  - Additional smoothing of downstream packaging processes (not considered now)
  - More detailed/refined simulation (e.g. including transport simulation handling,…)

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Relevant and most recent publications

- F. Kamhuber, T. Sobottka, B. Heinzl and W. Sihn, "An Efficient Multi-Objective Hybrid Simheuristic Approach for Advanced Rolling Horizon Production Planning" 2019 Winter Simulation Conference (WSC), National Harbor, MD, USA, 2019, pp. 2108-2118, doi: 10.1109/WSC40007.2019.9004902. IEEE

- F. Kamhuber, T. Sobottka, B. Heinzl, J. Henjes and W. Sihn, „An Efficient Hybrid Multi-Criteria Optimization Approach regarding Rolling Production Smoothing of a European Food Manufacturer" 2020 Computers & Industrial Engineering, Available online **27 June 2020**, https://doi.org/10.1016/j.cie.2020.106620, In Press.

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- (1) R. Lenort, R. Klepek, and A. Samolejová, "Heuristic algorithm for planning and scheduling of forged pieces heat treatment," Metalurgija, ISSN 0543-5846, 2012
- (2) M. Karimi-Nasab and I. Konstantaras, „A random search heuristic for a multi-objective production planning," Computers & Industrial Engineering, Vol. 62, No. 2, pp. 479 – 490, 2012
- (3) C. Morawetz, „Vorgehensweise zur Entwicklung eines Entscheidungsunterstützungssystems zur kostenoptimalen mittelfristigen Kapazitätsanpassung," Dissertation, TU Wien, 2015
- (4) C. Low, C.-M. Hsu, and K.-I. Huang, „Benefits of lot splitting in a job shop scheduling," The International Journal of Advanced Manufacturing Technology, Vol. 24, No. 9-10, pp. 773-780, 2004