ESTEP SPRING DISSEMINATION EVENT

5-6 JUNE 2025 KRAKOW (POLAND)

Enhanced Steel Production Efficiency Through Fuzzy Logic Aided Genetic Algorithms

Marco Vannucci[1]*, Valentina Colla*[1]*, Orlando Toscanelli*[1]*, Erwin Sirovnik*[2]
[1] ICT-COISP – Scuola Superiore Sant'Anna, Pisa, Italy
[2] Thyssenkrupp Rasselstein GmbH, Andernach, Germany

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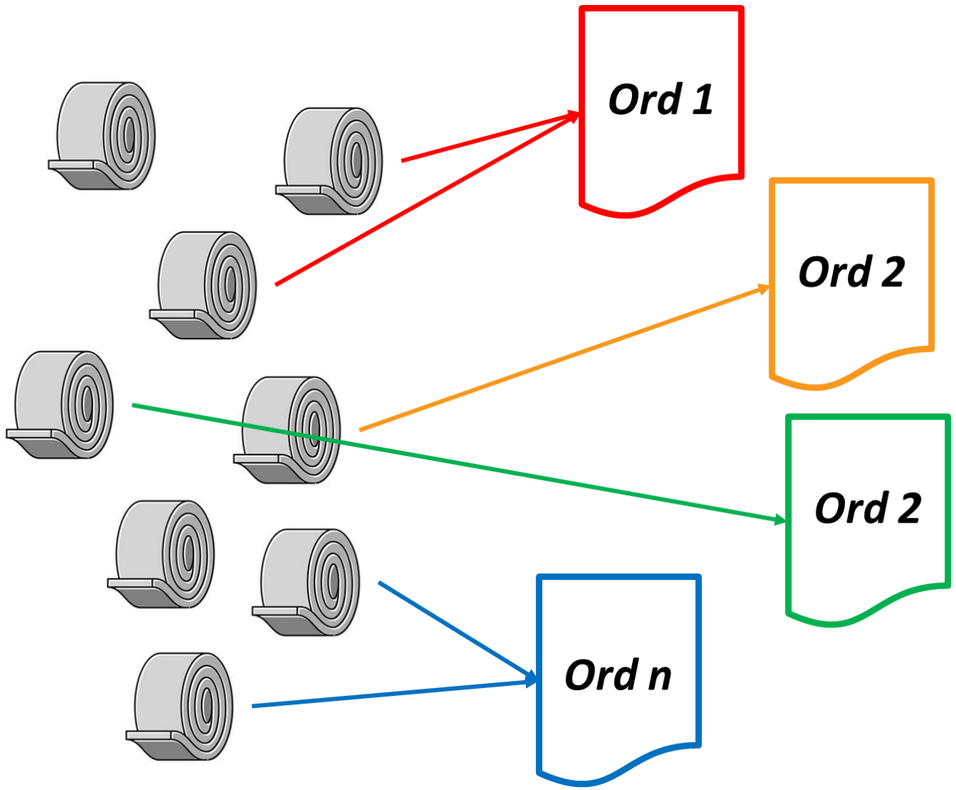
Outline

- The problem of **coil-order alloation** (COA)
  - A real world case study from TKS Rasselstein within the DynReact project
- COA solution by using **Genetic Algorithms** (GA)
- Embedding human reasoning via **fuzzy logic**
- Results, comparison and discussion
- The future

Introduction: coil order allocation



Main issues

- Orders require coils with specific characteristics (grade, dimension, provenience, mill, …)
- Orders have a due date
- Coils in stock may nedd some adjustments to be associate to an order

What do we look for

- Efficient method to allocate available coils in order to
  - Respect constraints
  - Respect due dates
  - Limit adjustments and reduce work, waste, energy,…
- Complex task due to all constraints and dynamic stock

The DynReAct_PDP case study – *TKS Rasselstein*

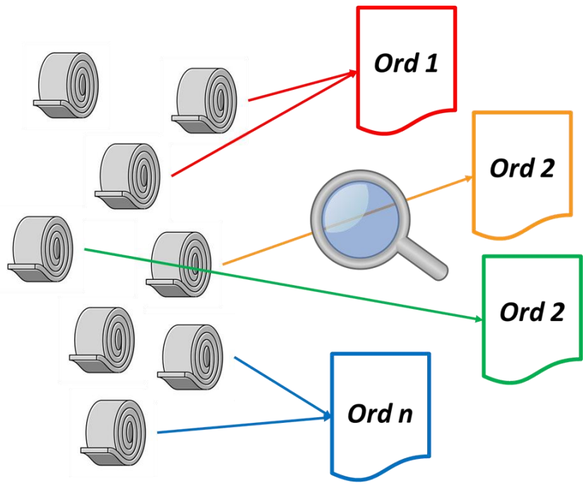
- TKS Rasselstein (Andernach, Germany) is the **world's largest tinplate production site**, with an annual capacity of **1.5 million tonnes**
- Specializes in **high-quality tinplate and chrome-coated steel coils for packaging** (food cans, steel boxes, twist-off caps, closures, etc.)
- Supplies **over 400 customers** in more than 80 countries worldwide

- High daily production volume creates **complex operational challenges**, especially in **coil allocation** to customer orders.
- Some coils are rejected during production due to quality issues (e.g., surface defects), requiring **manual allocation by experienced personnel**.

The DynReAct_PDP case study - *Challenges*

Manual or automatic COA requires navigating a **complex decision-making process** that involves balancing **multiple constraints** and **objectives**

*This task is critical to ensure order fulfillment while minimizing waste and **optimizing production efficiency**.*



Constraints

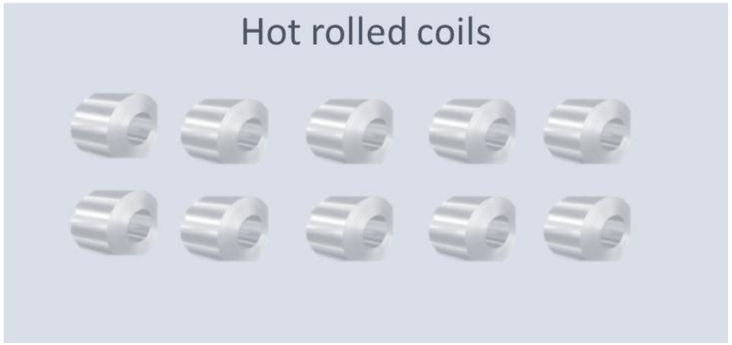
- Steel grade
- Dimensions
- Coil weight
- Hot-Rolling Mill
- Provenance

Objectives

- Minimize **discrepancy** between **requested and allocated material** (optimize resource use)
- Meet order delivery **deadlines** (prioritize urgent orders)

Case study – Available data

Orders and Coils backlog provided by RAS (with a looong tutorial for data ingestion)



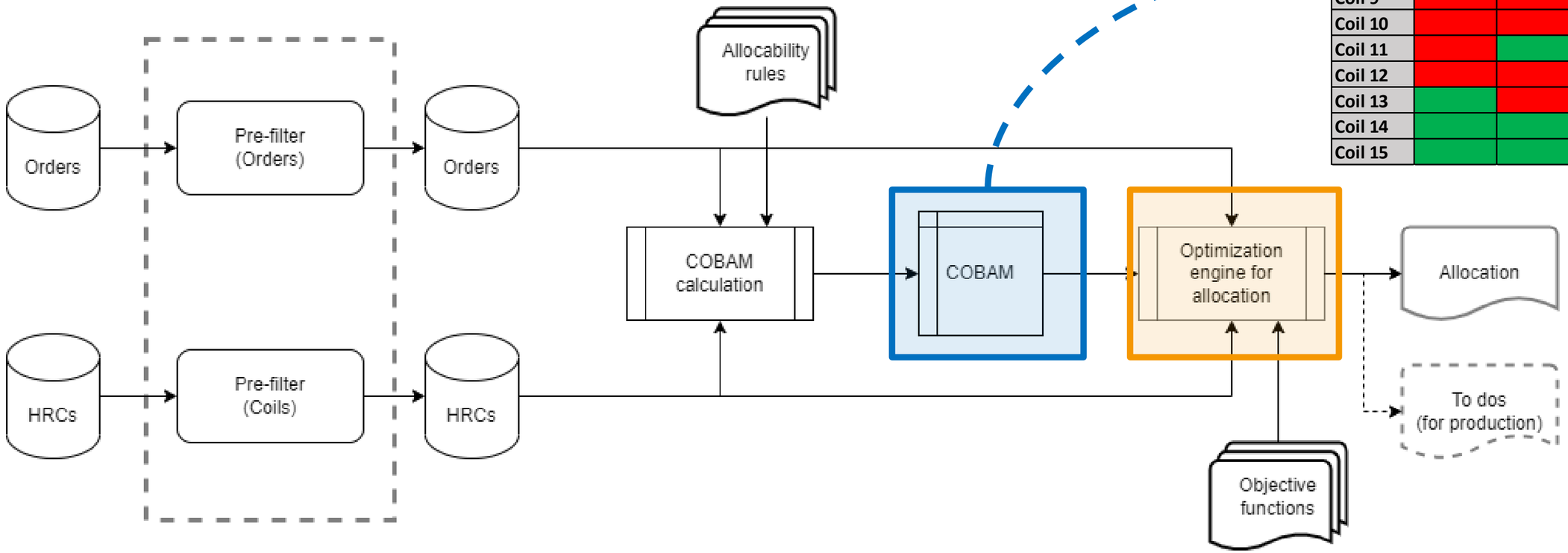
Number of orders: 726
Orders total required weight: 74839

Number of coils: 3753
Available steel weight in coils: 69124

Not all orders can be fulfilled
Priority *used*

Optimization approach

	Order 1	Order 2	Order 3	Order 4	Order 5
Coil 1					
Coil 2					
Coil 3					
Coil 4					
Coil 5					
Coil 6					
Coil 7					
Coil 8					
Coil 9					
Coil 10					
Coil 11					
Coil 12					
Coil 13					
Coil 14					
Coil 15					



Genetic Algorithms for COA

Combinatorial problem with **high dimensionality** and non linear **constraints**

- GAs performs well on these problems finding in reasonable time an optimal solution
- GAs operate by mimicking natural evolution principles such as selection, crossover, and mutation to evolve solutions to complex problems
- Solution coded and evolved in compliance with COBAM

Solution coding

coil1	coil2	coil3	coil4	coil5	coil6
o_3	o_7	o_1	o_9	*no*	o_{13}

Objective function (*minimization*)

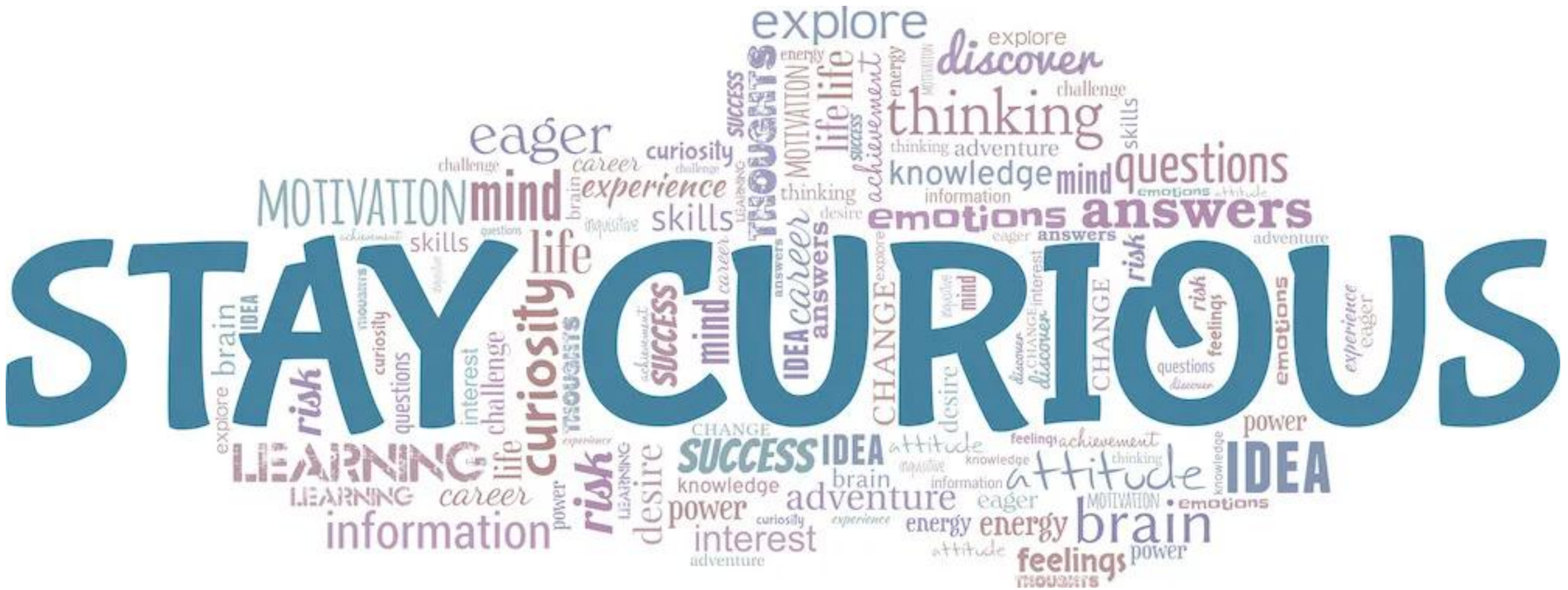
$$fitness(S) = \sum_{o_j \in O} D_j \cdot P_j$$

$$D_j = \frac{\left| \left(\sum_{c_i | (c_i, o_j) \in S)} W(c_i) \right) - RW(o_j)) \right|}{RW(o_j)}$$

Relative discrepanci for order o_j

$$P_j = \left(\frac{max(DDS) - DDS_j}{\sum_j DDS_j} \right)^2$$

***Normalized* days to due date for o_j**

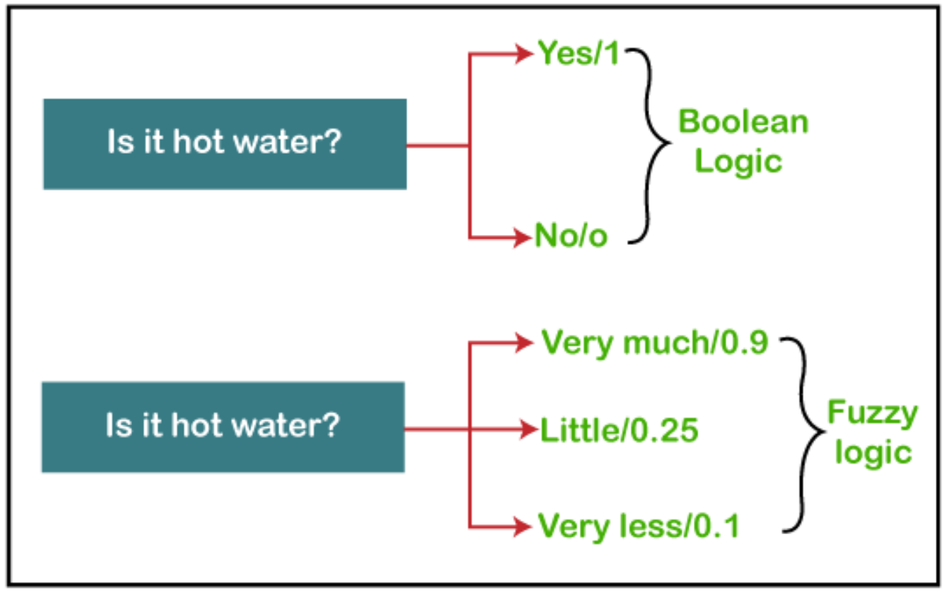


Curious about the results?
Wait, we have something else to show

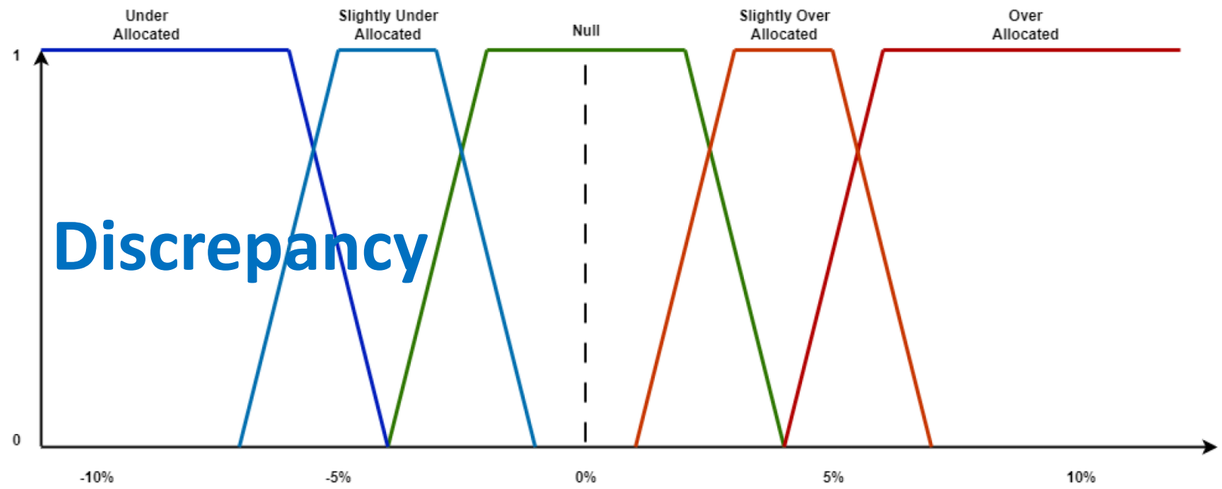
Embedding human reasoning with fuzzy reasoning

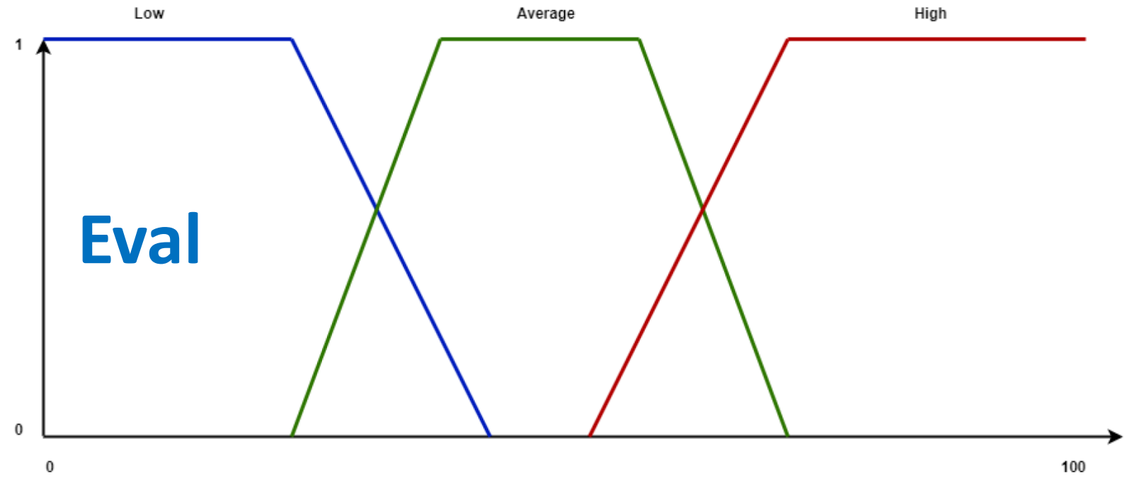
Crisp GA achieves good results but it misses the smoothness of human reasoning

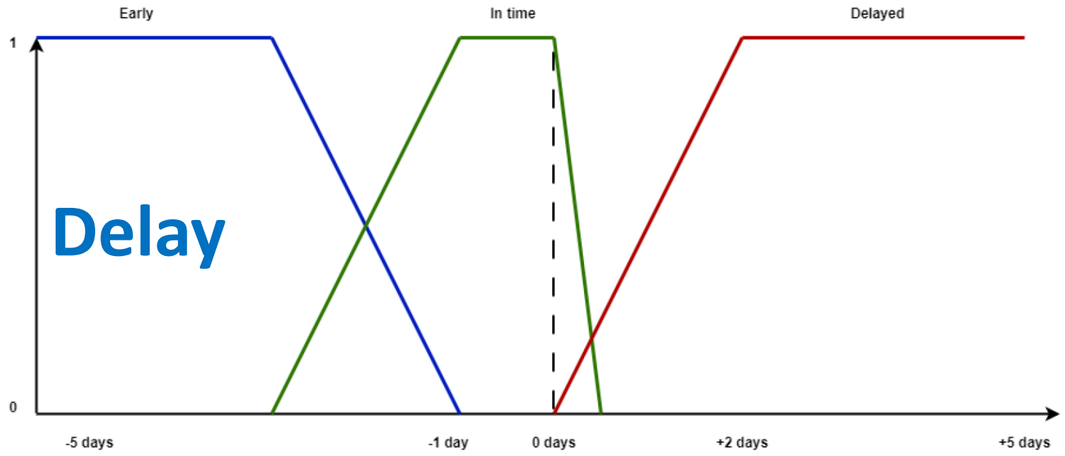
- **Fuzzy inference** can embed human knowledge, experience and uncertainties management through the use of smooth (fuzzy) concepts
- **A Fuzzy Inference System (FIS)** exploits a set of **rules** expressed by human operators via natural language. Qualitative concepts are modeled as fuzzy sets via membership functions
- **COA objective function components have been translated into fuzzy sets**



Embedding human reasoning with fuzzy reasoning

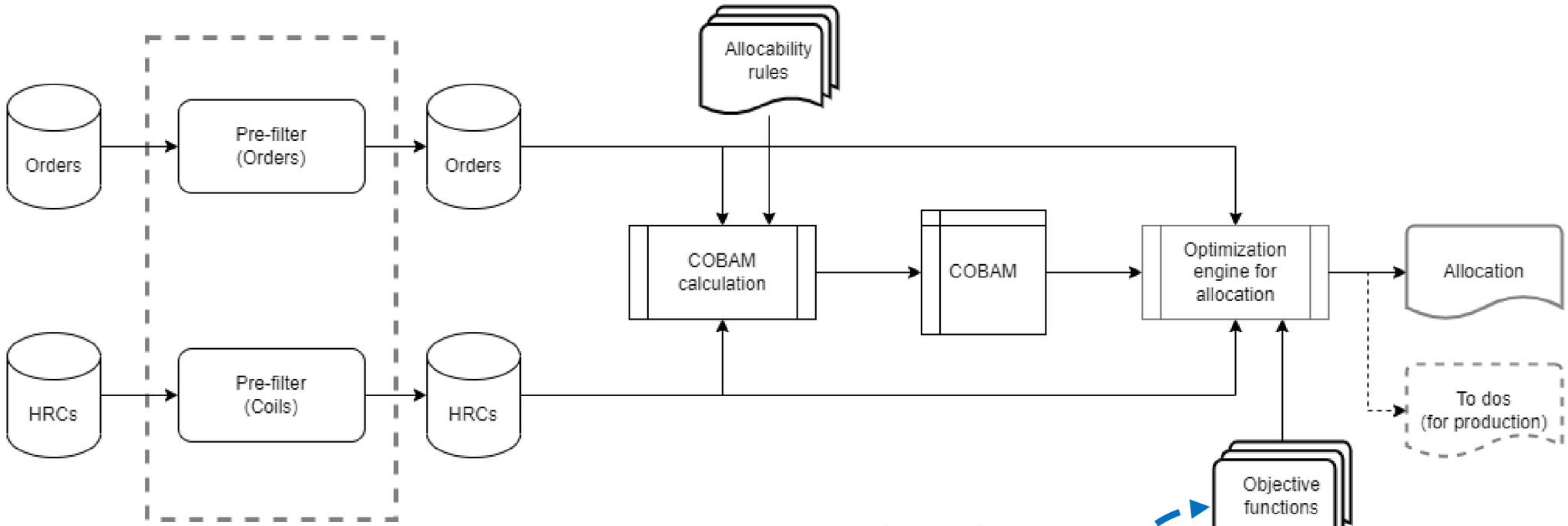


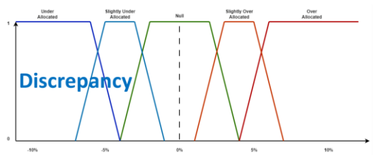


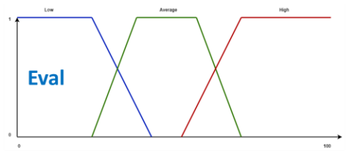


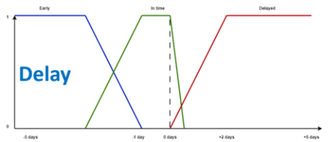
IF PWD is NULL AND DDS is INTIME THEN $EVAL$ is H,
IF PWD is OA THEN $EVAL$ is L,
IF PWD is UA THEN $EVAL$ is L,
IF PWD is NULL AND DDS is EARLY THEN $EVAL$ is H,
IF PWD is NULL AND DDS is DELAY THEN $EVAL$ is A,
IF PWD is SOA AND DDS is INTIME THEN $EVAL$ is A,
IF PWD is SUA AND DDS is INTIME THEN $EVAL$ is H,
IF PWD is SOA AND DDS is DELAY THEN $EVAL$ is L,
IF PWD is SUA AND DDS is EARLY THEN $EVAL$ is A,

Embedding human reasoning with fuzzy reasoning









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IF PWD is SUA AND DDS is EARLY THEN $EVAL$ is A,

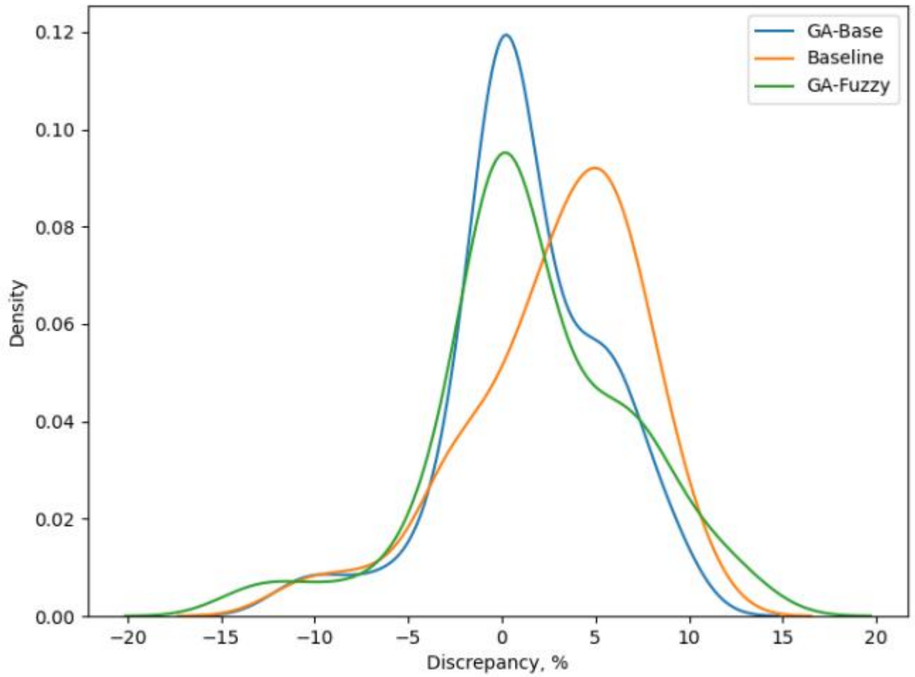
$$fuzzyFitness(S) = 100 - \frac{\sum_{o_j \in O} FIS(Alloc_j)}{N}$$

Experimental set-up

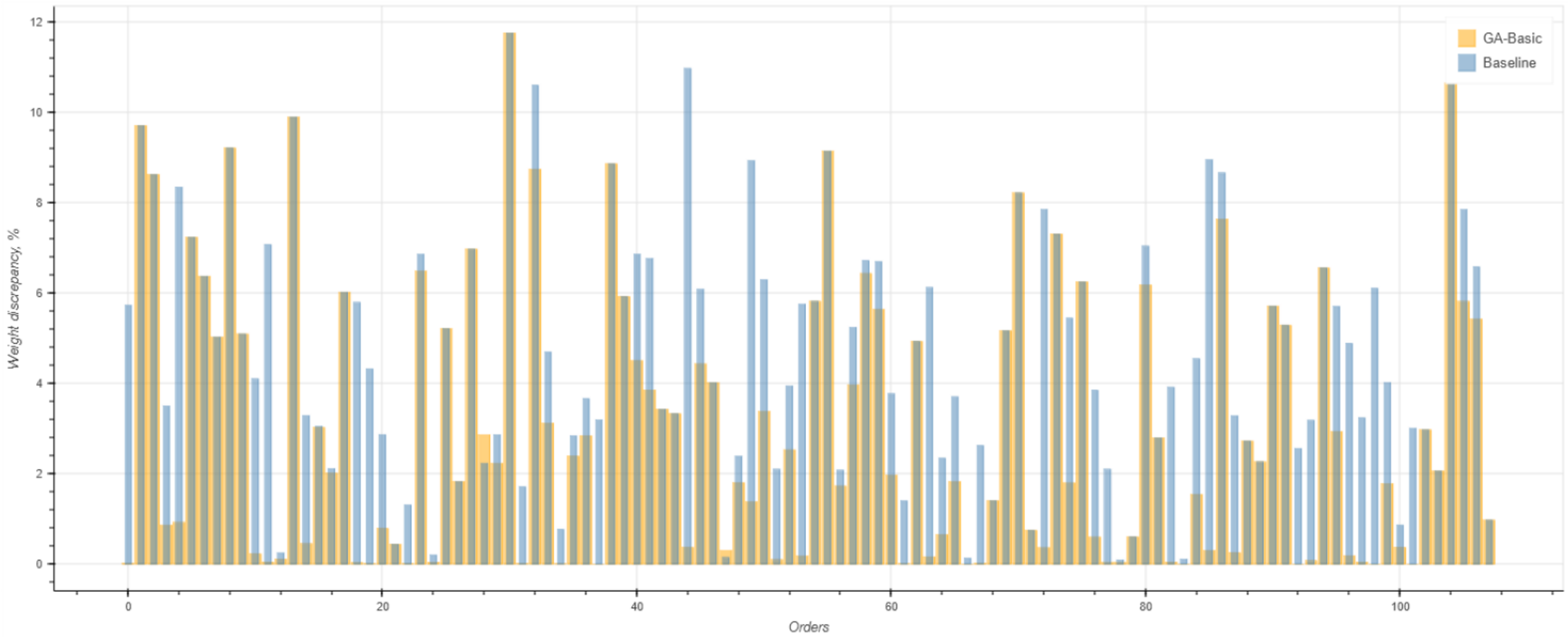
- **Adaptive GA** framework adopted for faster convergence and low risk of local minimum
  - Genetic recombination rates dinamically adjusted during optimization
  - **Hyper-parameters** empirically determined (accuracy-speed tradeoff)
- **100 chromosomes**, **500** max **generations** with early stopping

Results

	Baseline	GA-Standard	GA-Fuzzy
Completed orders, %	54	69	69
Ave. discrepancy, %	4.7	3.2	3.8
Ave. discrepancy, tons	3.5	2	2.3



Results

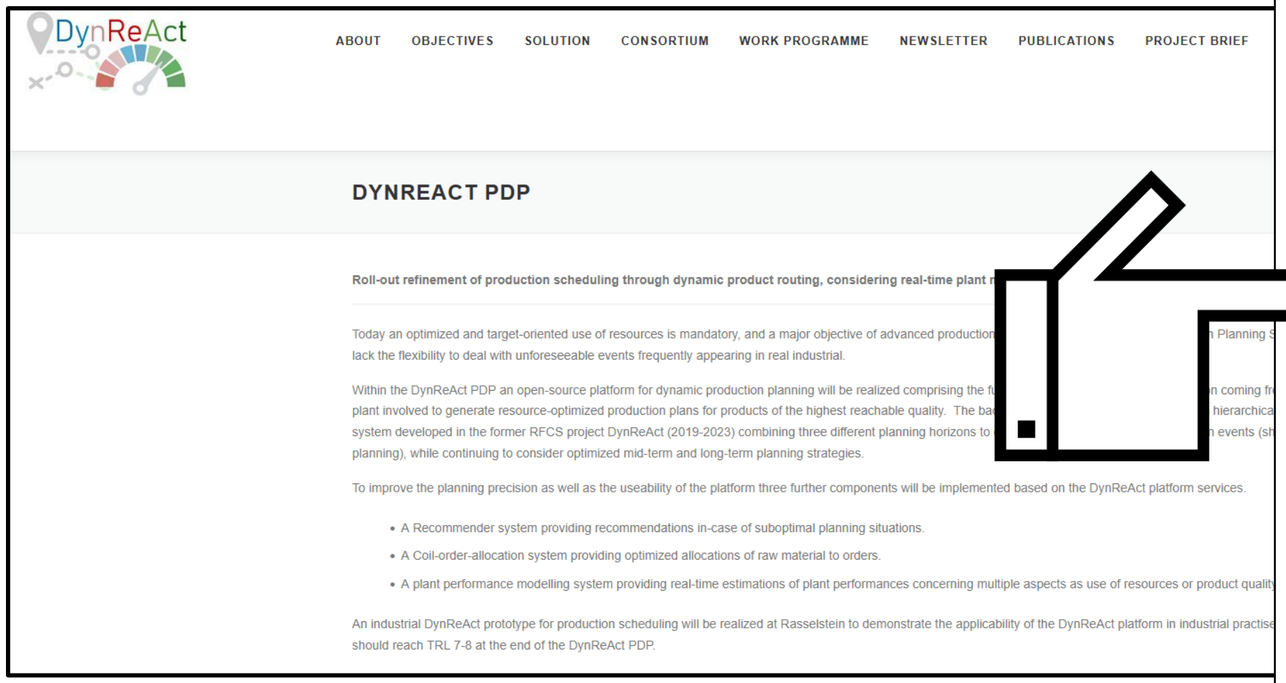

GA-Basic
Baseline
Weight discrepancy, %
Orders
0
2
4
6
8
10
12
0
20
40
60
80
100

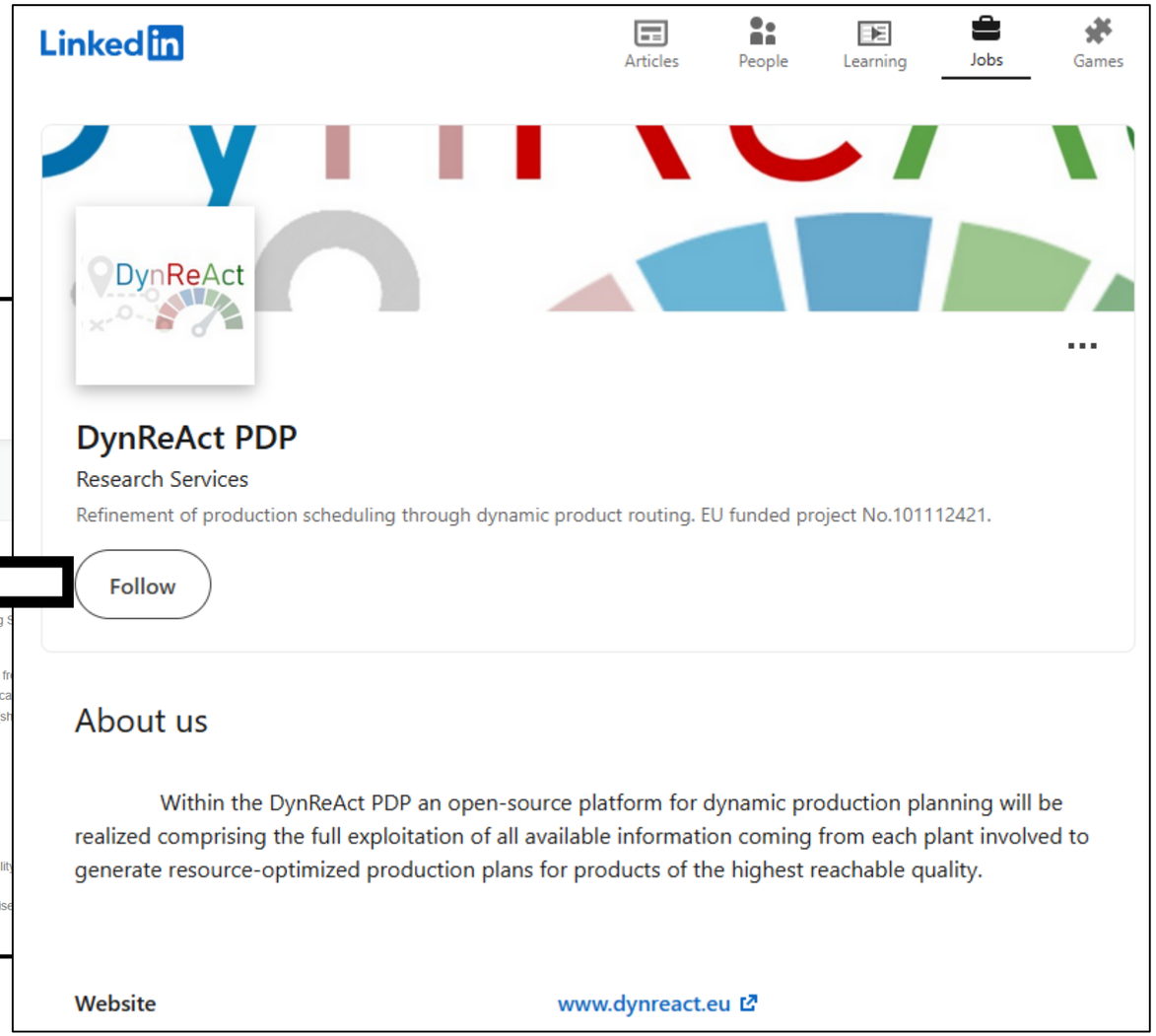
Conclusions and a sight on the future

- Extend to include **long term** and **mid term planning** of production
- Stronger embedding of FIS with more rules, criteria
- Within the ***DynReAct_PDP*** project, COA is part of a common open-source framework to be released at the end of the project
- Integration I/O with MES

Visit our project site!

https://dynreact.eu/





Thank you for your attention.

marco.vannucci@santannapisa.it

https://www.researchgate.net/profile/**Marco_Vannucci**

https://www.linkedin.com/in/**marco-vannucci-444548182**/

https://github.com/**taracchi**

https://t.me/**Taracchi**