



Enterprise  
Ireland



Funded by the  
European Union  
NextGenerationEU

**EDIH** | European  
Digital Innovation  
Hubs Network



# Visit To MTU

**Helmut Simonis**

## Constraint Based Production Scheduling



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# Acknowledgments



This publication was developed as part of the ENTIRE EDIH project, which received funding from Enterprise Ireland and the European Commission.

Part of this work is based on research conducted with the financial support of Science Foundation Ireland under Grant number 12/RC/2289-P2 at Insight the SFI Research Centre for Data Analytics at UCC, which is co-funded under the European Regional Development Fund.

# Overview



- Insight SFI Centre for Data Analytics
- Some Recent Applications
- Survey Constraint Programming and Scheduling
- EDIH Skills Development Course Scheduling
- Generic Scheduling Tool

# Insight is one of the largest data research and innovation centres in Europe...



Ollscoil na Gaillimhe  
UNIVERSITY OF GALWAY



UCC  
University College Cork, Ireland  
Coláiste na hOllscoile Corcaigh



Trinity College Dublin  
Coláiste an Tríonóide, Baile Átha Cliath  
The University of Dublin



<b>4</b> Co-Lead Universities 9 partner institutions	Built on <b>20</b> years of research in Data Analytics and AI
<b>450+</b> Academics, Postdocs, PhDs, RAs	<b>3400+</b> Scientific conference and journal papers
<b>175+</b> Funded collaborations with industry partners	<b>350+</b> Research Awards
<b>16</b> Spin out companies 72 license agreements	<b>135+</b> H2020 consortia, 500+ collaborations, 40+ countries
<b>1,137+</b> school visits, 28,000 students	<b>276</b> PhDs graduated

# Background



- Mathematics @ TH Darmstadt
- 1986-1990 ECRC GmbH, Munich
- 1990-2000, Technical Director, Cosytec SA, Orsay
- 2000-2005, Imperial College London, Parc Technologies Ltd
- 2013-2014, President, Association for Constraint Programming
- Best Application Paper Awards, CP 2009, CP 2013
- Program Chair, CP 2020, CPAIOR 2014
- Distinguished Service Award, ACP

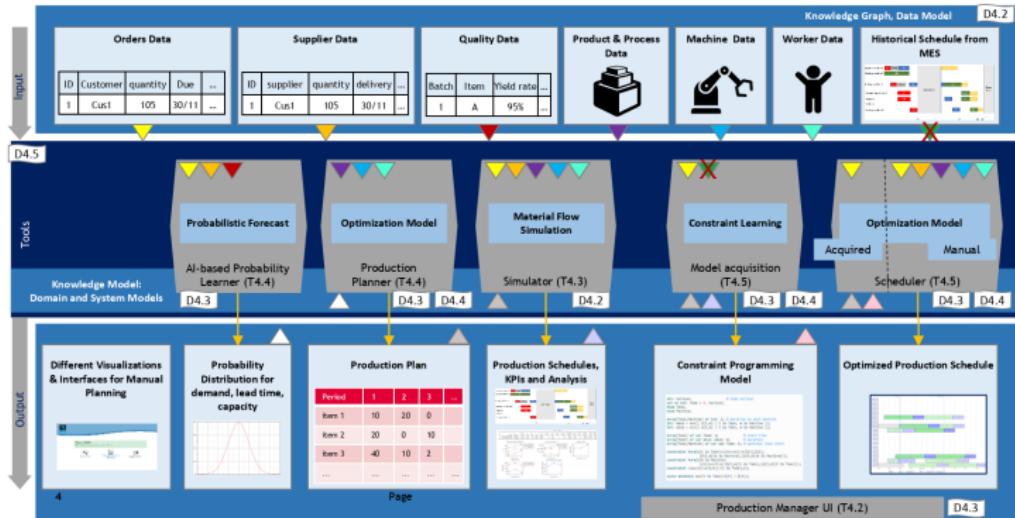


# ASSISTANT Project Overview

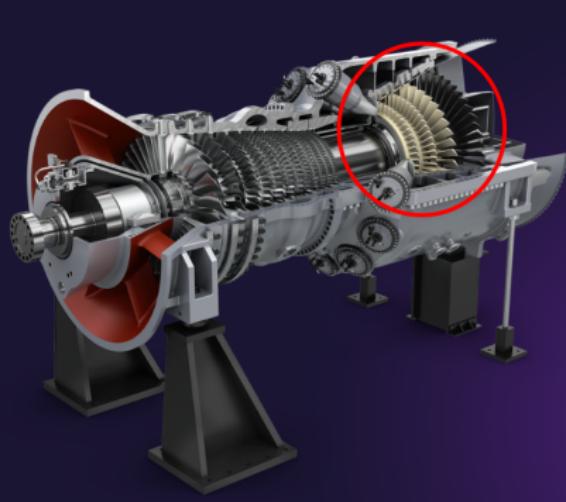


Intelligent digital twin for process planning and scheduling

ASSISTANT



# Assistant Siemens Energy Use Case

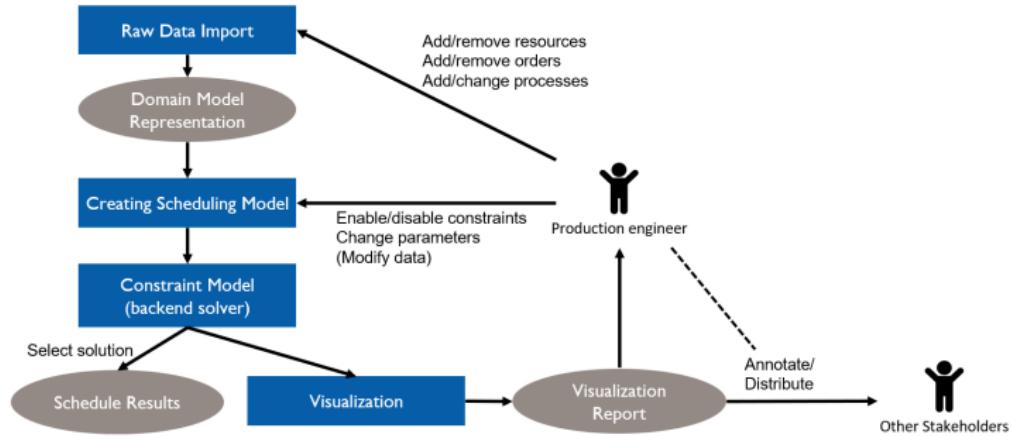


The image shows a detailed cross-section of a gas turbine engine. A red circle highlights the compressor section, which is the first stage of the engine where air is compressed before entering the combustion chamber. The engine is mounted on a stand with two legs.

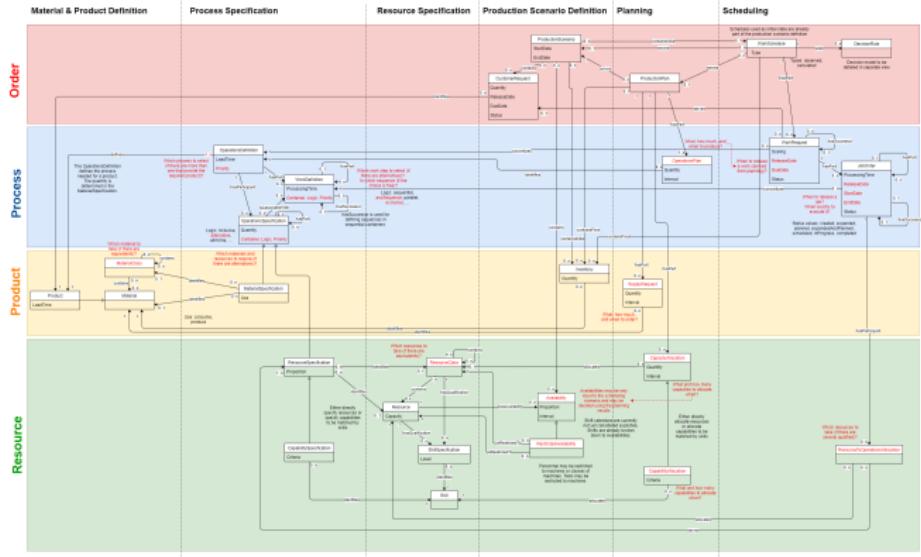
### Use Case Scenarios

- Schedule *validation* of gas turbine blades and vanes manufacturing operations in Berlin plant
- Schedule *optimization* to manage short-term, mid-term and long-term load fluctuations
- Generate *Make-or-Buy proposals* for workload balancing within the manufacturing network

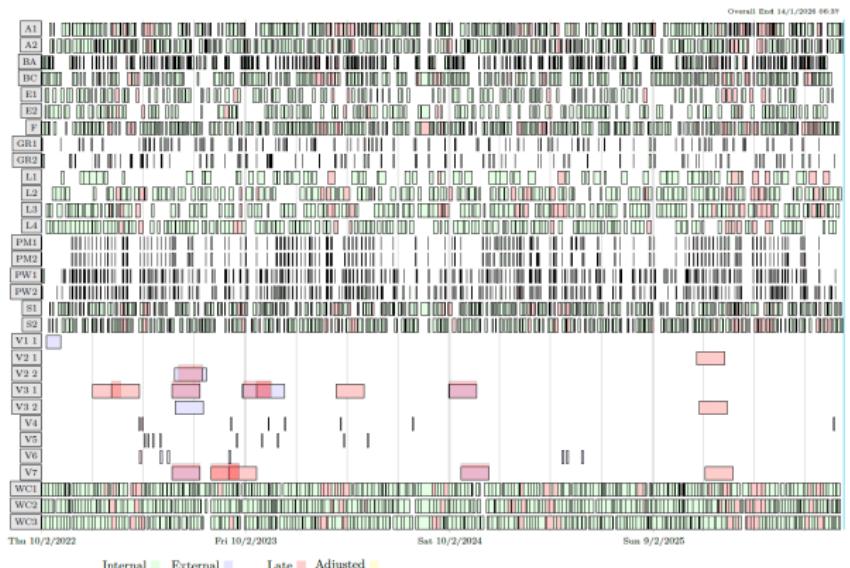
# Optimizer High Level Structure



# Domain Model - Knowledge Graph



# Solution for Berlin 08a - Shows Only 20% of Tasks in Model



# Implementation

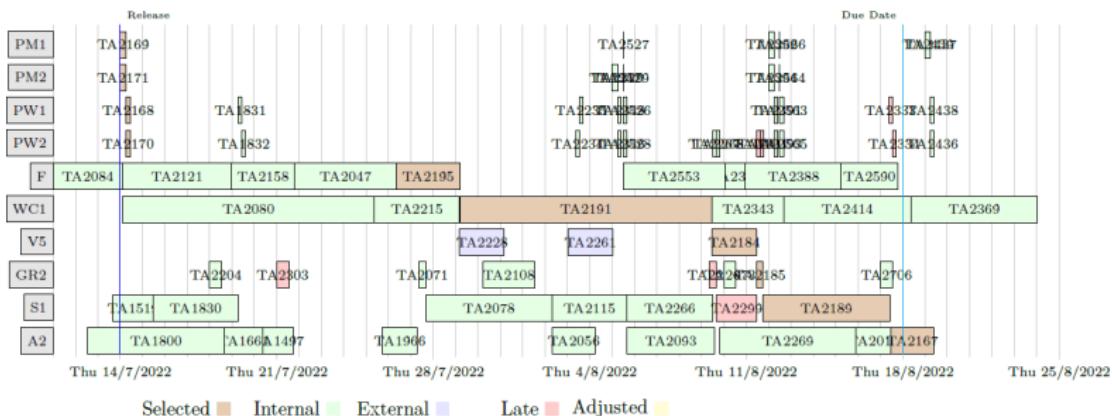


- Requirement capture done inside project
- Data checking/cleaning most time consuming aspect
- Some specified functionality was rejected by Betriebsrat
- Built in Java
- Uses IBM's CPOptimizer back-end
- 120k LoC, 110k generated, 3k solver
- Outperforms both
  - Current in-house tool
  - Simulation based tool based on commercial simulator
- System installed at SE site, but not in daily use

# Explaining Late Delivery



- Explain why some orders are delivered late
  - Find root-cause, show schedule in context



# Evaluation - KPIs



KPI	Baseline	Optimizer
OTD	> 80 %	92 %
Bottleneck machine utilization	99.5 %	100 %
Manufacturing defects	10-15 %	< 10 %
Scenarios in 8 hours	15-20	> 100,000

# Oven Scheduling - Detailed vs. Long-term Scheduling Objectives



- Another example from the ASSISTANT EU project
- Oven schedule for one of the industrial partners
- Schedule tasks on a set of ovens
- Tasks can share oven only if they are compatible
- Conflicting objectives
  - Energy use of ovens very significant, reduce when ovens are used
  - Waiting for an oven affects quality of product
- Jobs only visible when previous process step starts
- Currently scheduled by hand, industry partner expressed strong need for change

# What does this look like in the real world?

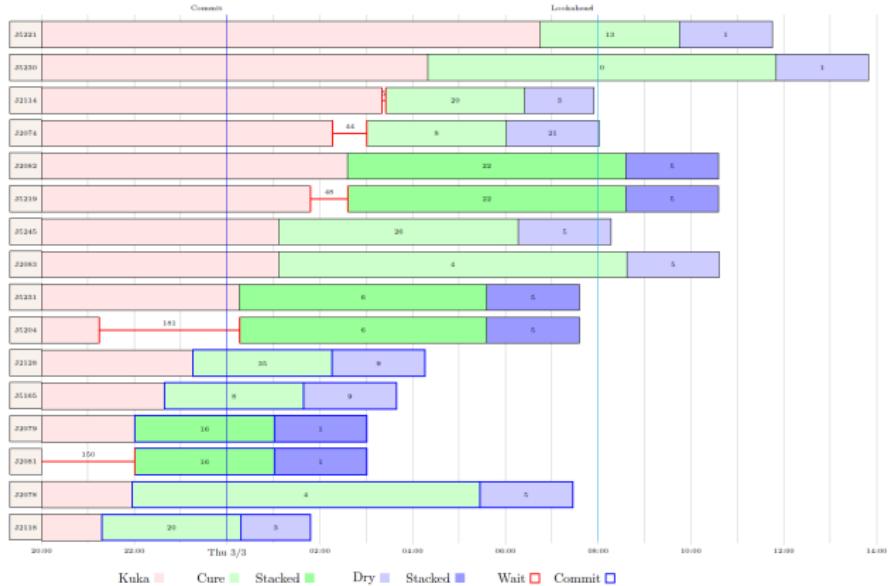


Industrial Oven



Rotors in Compressor

# Short-Term Schedule: Job View



Kuka   Cure   Stacked   Dry   Stacked   Wait   Commit

# Long Term Schedule: Detailed Schedule



Tue 1/3 Thu 3/3 Sat 5/3 Mon 7/3 Wed 9/3 Fri 11/3 Sun 13/3 Tue 15/3 Thu 17/3 Sat 19/3 Mon 21/3 Wed 23/3 Fri 25/3 Sun 27/3 Tue 29/3 Thu 31/3 Sat 2/4 Mon 4/4

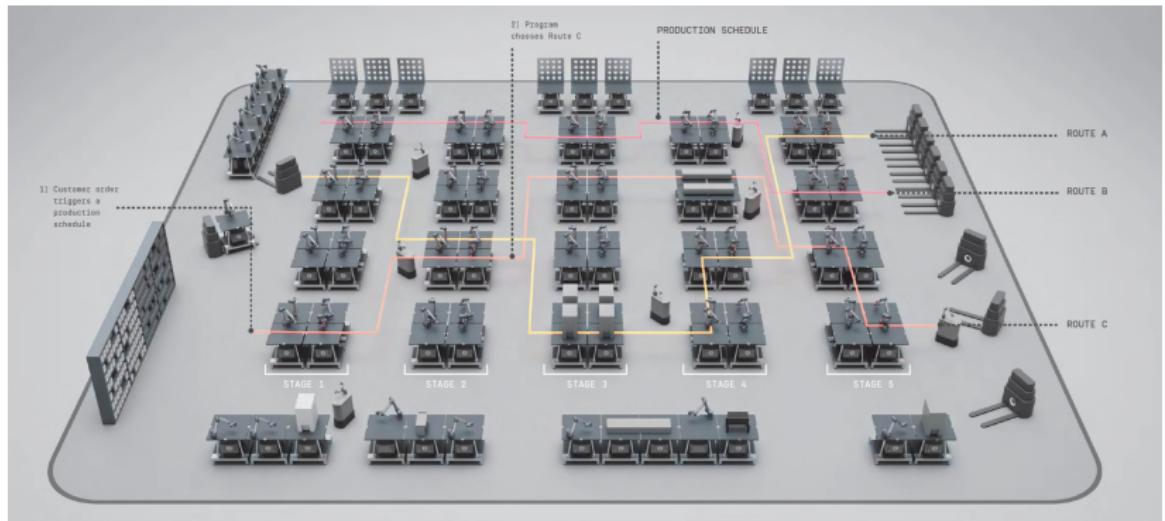
Cure ■ Stacked ■ Dry ■ Stacked ■

# Factory Design via Detailed Scheduling



- CONFIRM project with J&J
- Schedule and layout future factory
- Hybrid, flexible flow-shop with transportation times
- Compare different solution approaches
- Hybrid of NEH and Constraint Programming

# Flexible Workcells

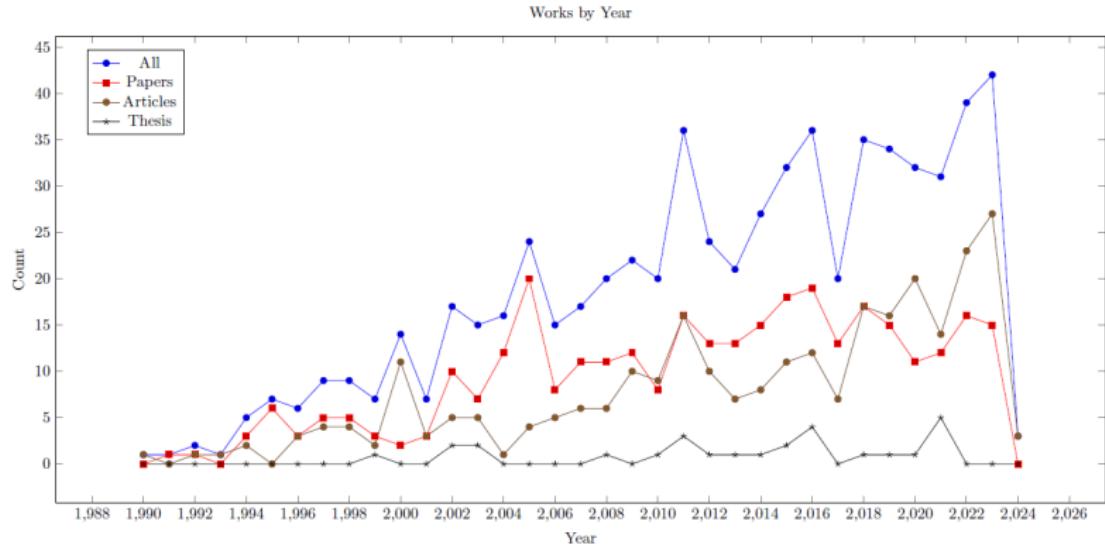


# A Survey of the Existing Literature

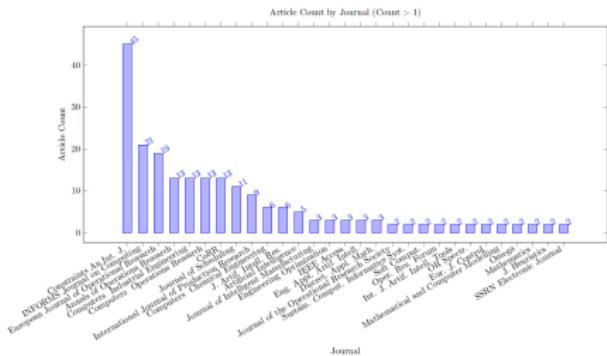
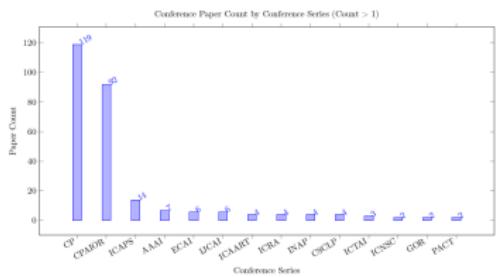


- Joint work with Cemalettin Ozturk, MTU
- What is out there
- Where to start
- Where to publish
- I'm interested in some specific topic, what is relevant
- Draft results available at  
<https://hsimonis.github.io/pthg24/>

# Overall Analysis (Based on 671 Works)



## Origin of Papers/Articles



# Training Course on Constraint-Based Production Scheduling



- Skills development program as part of ENTIRE project
- European Digital Innovation Hub
- Munster region, Ireland
- For Irish SMEs, public sector
- Initial, two day course on 21/22 Nov 2024
- Modelling focus
- Link 

## About ENTIRE

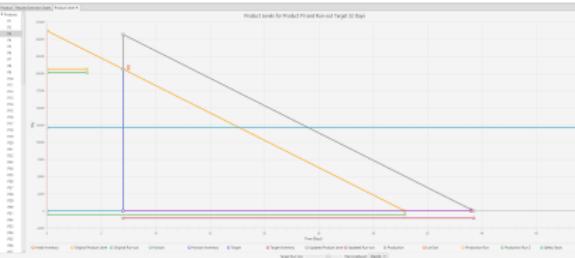
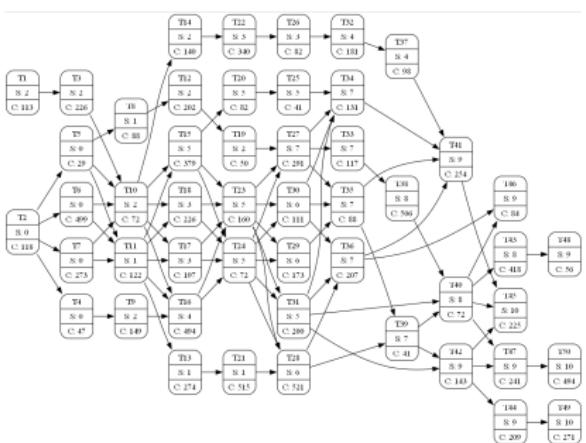
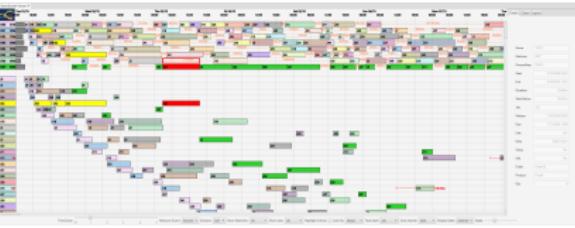
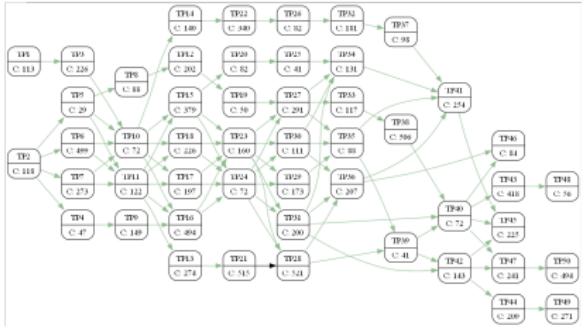


# A Generic Scheduling Tool



- No programming, configured by JSON input data
- Compositional use of different constraint types
- Different commercial or open-source back-end solvers
- Developed in Java
- Interactive JavaFX front-end
- Can be used as back-end scheduling tool/server
- Instance generator included
- Readers for multiple benchmark types included
- Release planned early 2025

# Scheduling Tool GUI Examples



# Conclusions



- Presented some of my work at Insight
- Strong links with MTU
- Current focus on teaching and scheduling
- Application centered research