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Maximizing throughput, due date compliance and other partially conflicting objectives in semiconductor production

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https://aissi-project.com

Outline

- Overview SYSTEMA GmbH
- Use case: Epitaxy Production at Nexperia Hamburg
- Optimization Requirements
- Process Simulation
- Constraint Optimization Solver & Dispatching
- Reinforcement Learning
- Summary & Discussion

SYSTEMA

- Globally acting specialist in manufacturing business process automation and optimization
- Enable manufacturers to improve their business, delivering transparency and control with software solutions and consulting for automation & optimization
- 25+ years of experience in High Automation
- 200+ experts worldwide

Optimization Challenge

Epitaxy Nexperia Hamburg

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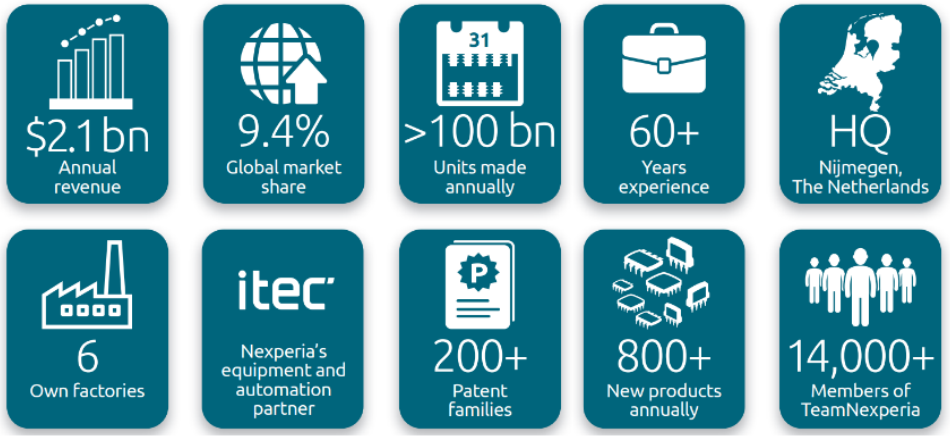
Use Case: Epitaxy Production at Nexperia Hamburg

- Optimize throughput and other objectives in the epitaxy area at Nexperia Hamburg
- Initial process step for majority of flow definitions
- Epi is a rate-limiting process step

- Establish analytical model to quantify production improvements and ROI
- Improvements could be better execution planning but also other types of process changes

nexperia

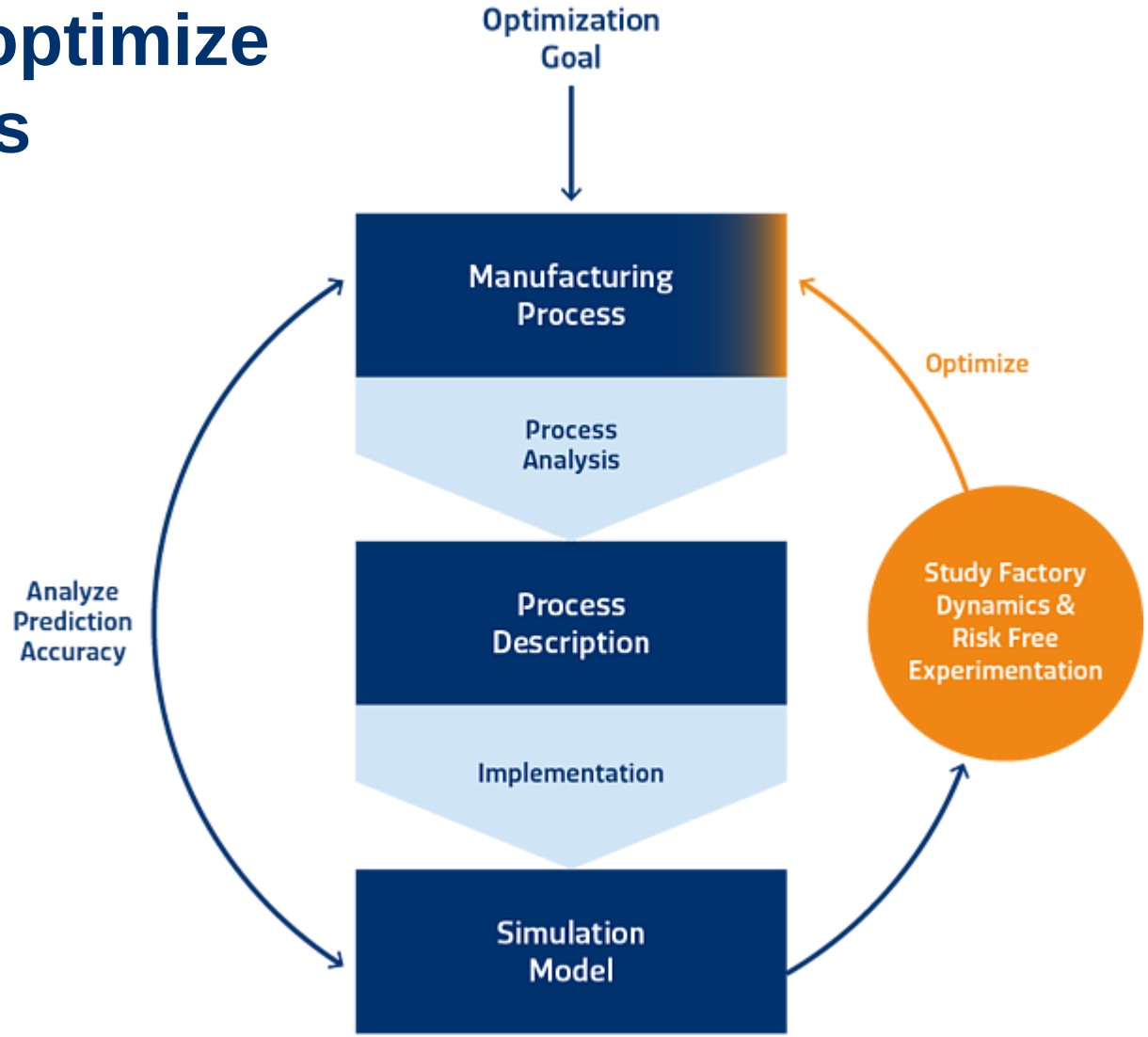
EFFICIENCY WINS.



https://www.nexperia.com/about.html

Use model-based analysis to optimize complex production processes

Assess more complex changes to production execution planning using process simulation & modelling



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Optimization Criteria: Epitaxy Process

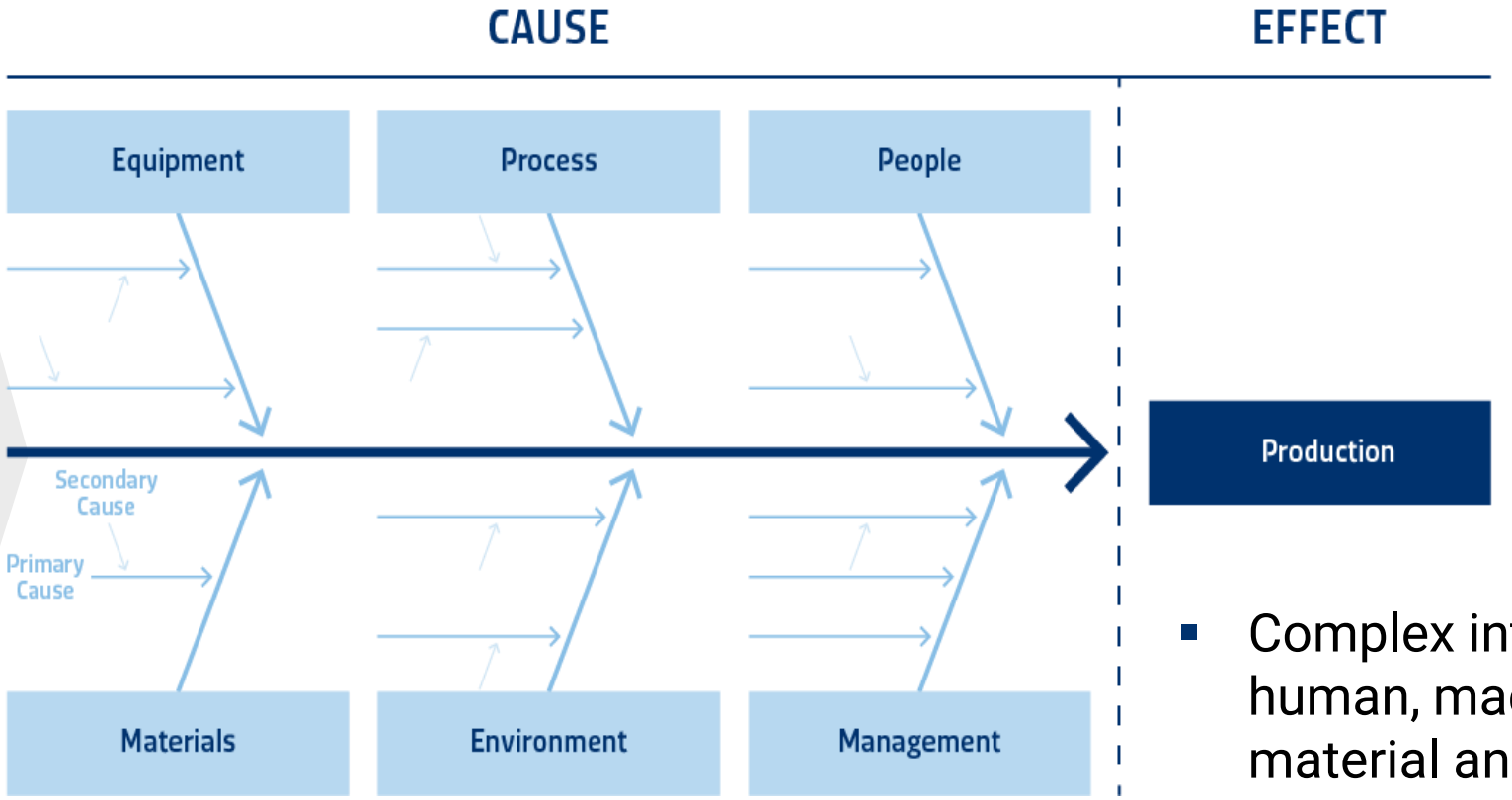
- **Task Assignment Uniformity:** Maximize and level tool utilization within tool group
- **Minimize Set Up:** Consider tool setup state when building schedule
- **Shift Hand Over Overlap:** Tasks should not start during a shift handover period
- **Minimize Cycle Time:** Schedule tasks as early as possible
- **Ensure Due Date Compliance:** Make sure lots are finished before their due date
- **Minimize Material Transport:** Consider shelf-location when scheduling lots to tools

→ Balance conflicting production targets

→ Complex cost function with constraints

Material Types
Hold Status
Material Ownership
Cycle Times
Due Dates
Equipment Capabilities
Anticipated Downtimes
Equipment State
Dummy/Baffle Filler Material
Tests/Experiment Conditions
Date/Time Calculations
Downstream Resource State
Up/Downstream Inventory
Timer Expirations
Critical Ratios
Kanban
Raw Material States
Recipes
Process Times
…

Semiconductor Front End Operations



- Complex interplay of human, machine, material and methods
- Not always following intuition

Simulation Model

Epitaxy Area Hamburg

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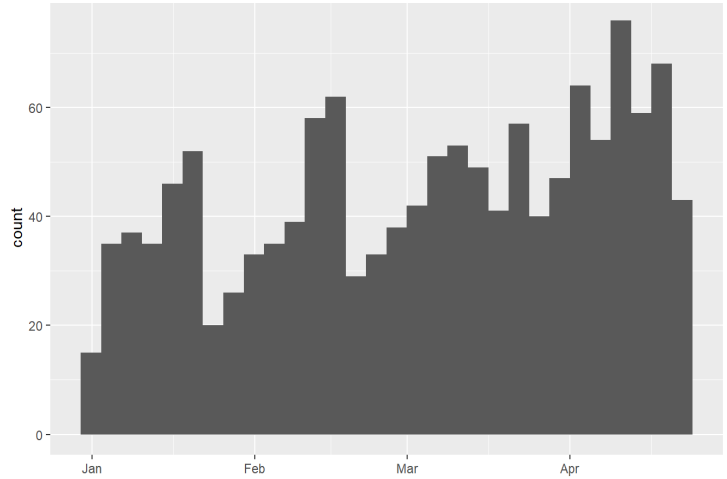
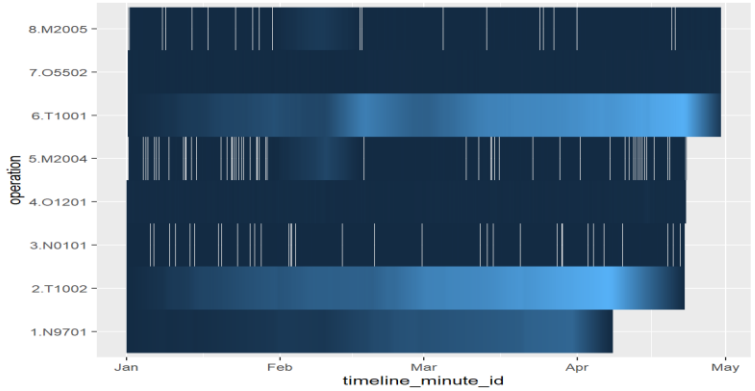
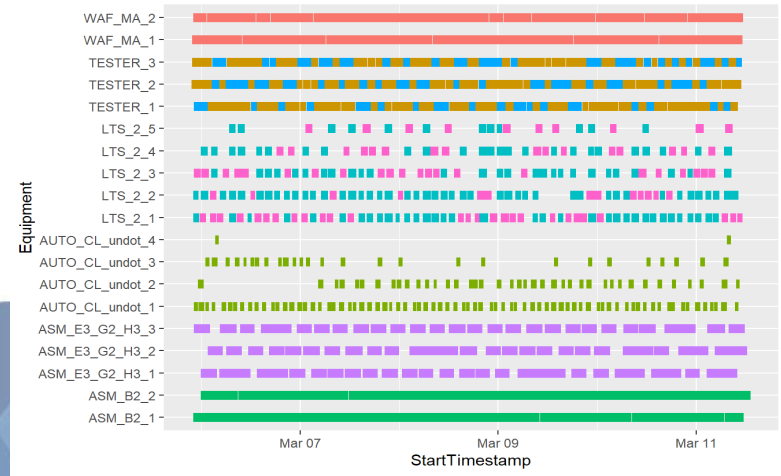
SYSTEMA Semiconductor Frontend Simulation Toolbox

- Discrete-event Frontend fab simulation model
- Realistic flows (cyclic routes, split/merge, rework, scrap)
- Lot & Tool granularity (with options for abstraction)
- Qualification (Stochastic, Rule-Based, Expiration)
- Tool properties (rates, load ports, batching)
- Flexible statistic and rule-based lot release
- Tool down, maintenance, personnel
- “Warm start” using material & tool state data
- Fast: simulate **a year** of production **in just seconds**

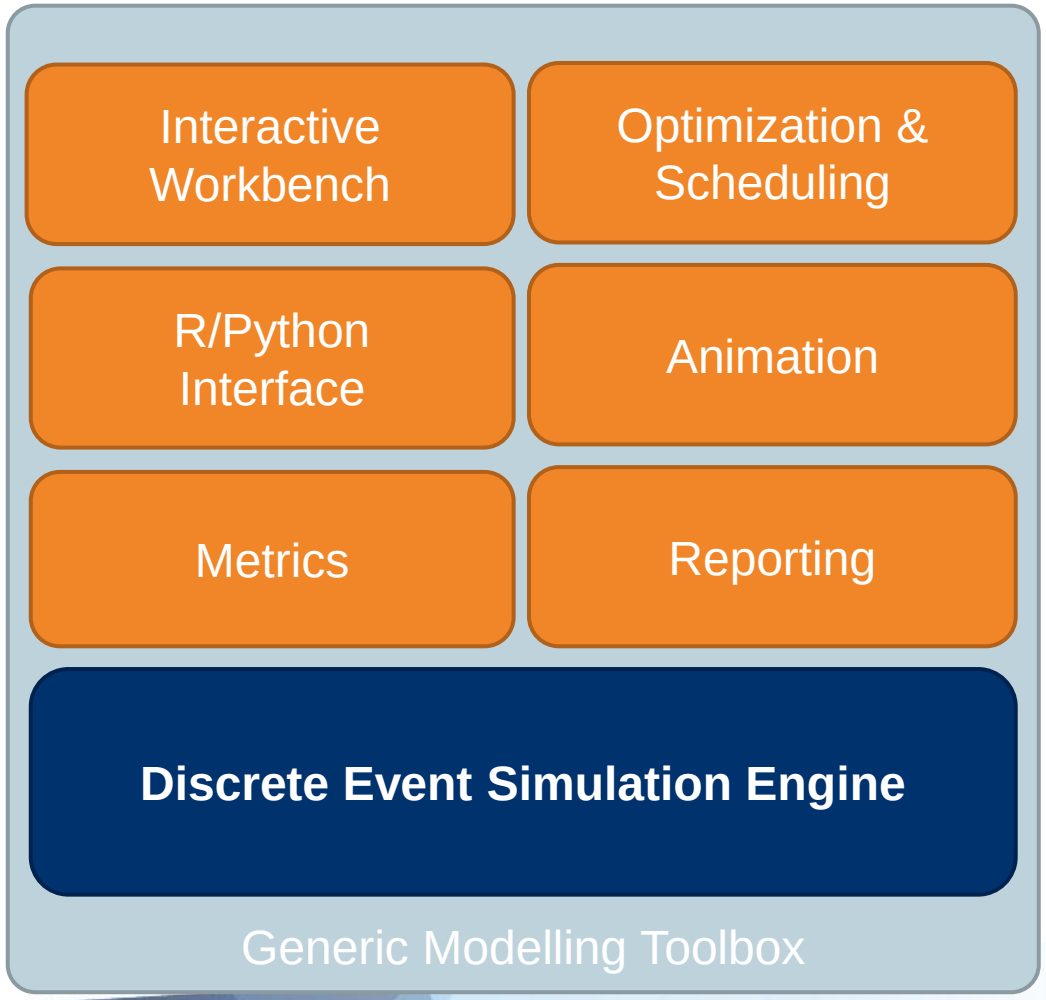






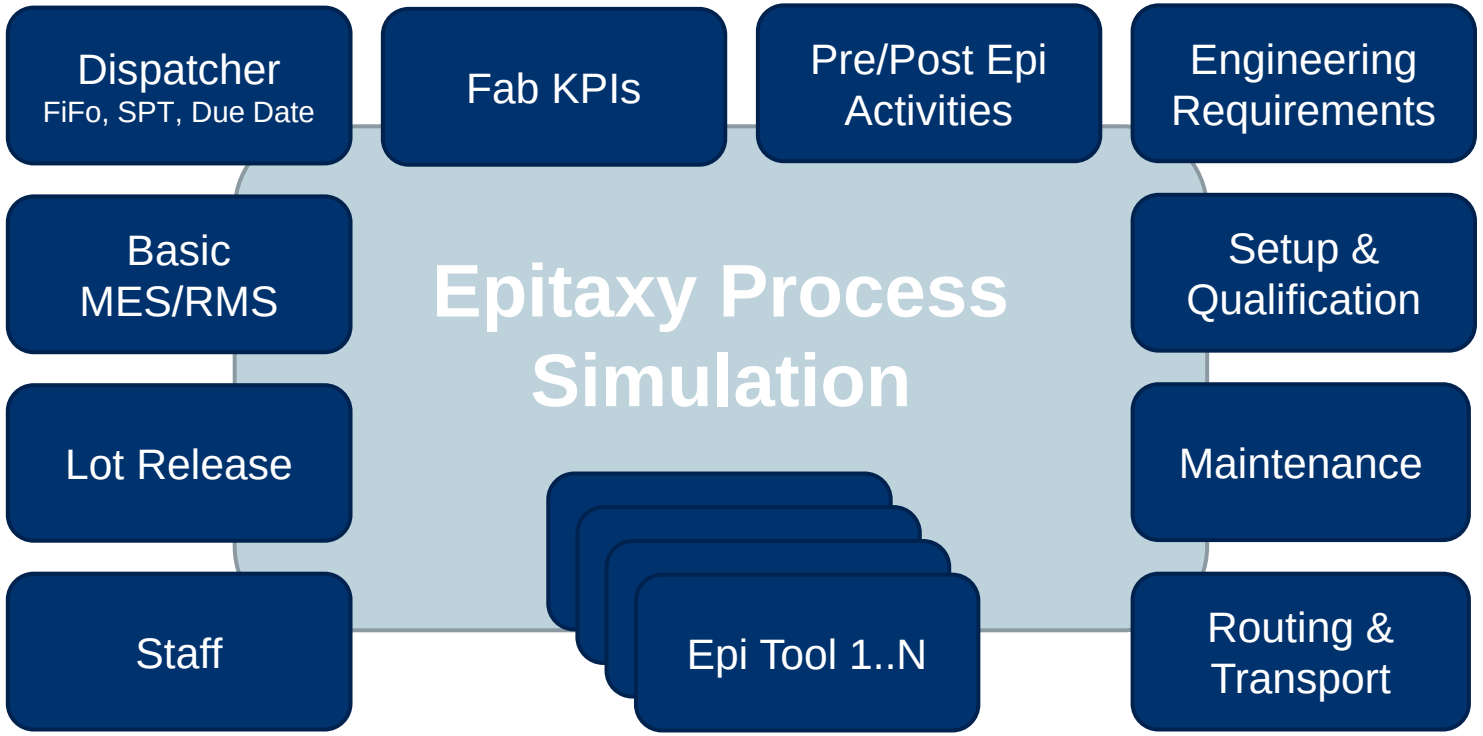
Modelling & Simulation Toolbox: Core Features

- kalasim - Fast generic process-oriented discrete event simulation engine
- Simulation entities have a generative process descriptions that define the interplay with other entities
- Rich process interaction vocabulary
- Built-in monitoring and statistics gathering across the entire toolbox
- MIT License, hosted at github, documentation & examples https://www.kalasim.org



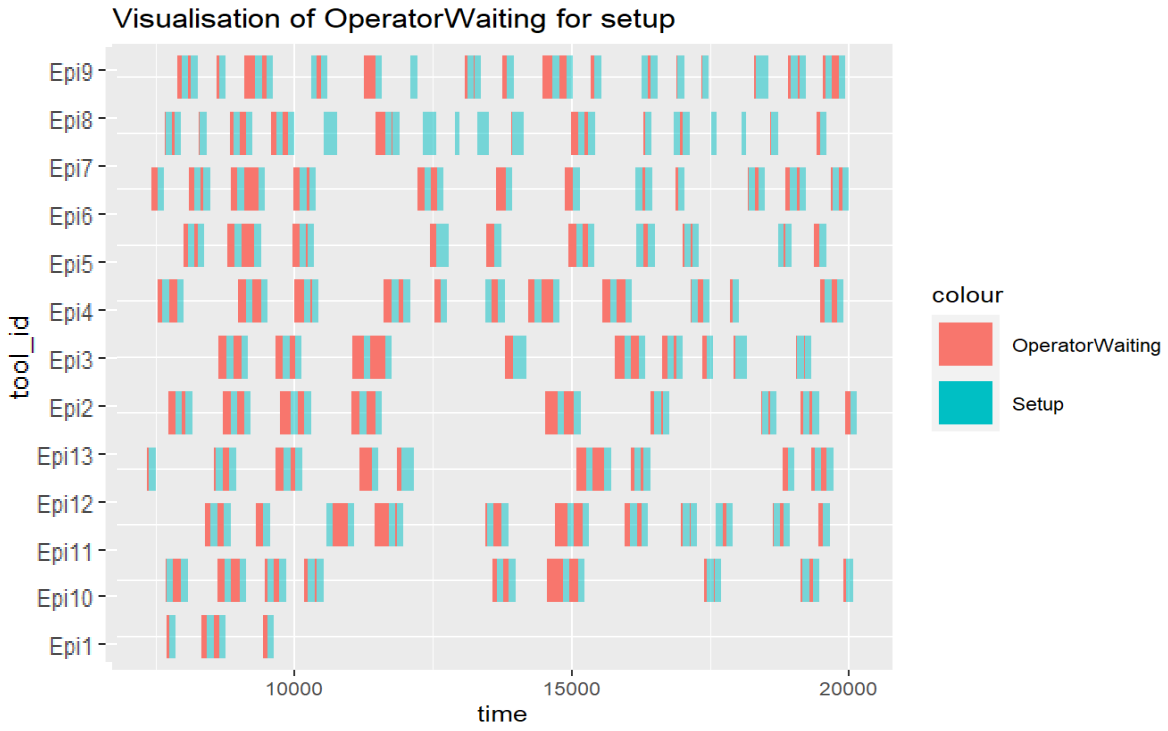
Epitaxy Process Simulation

- Parametrized using various data snapshots from MES, ERP and maintenance planning



Epitaxy Process Simulation: Tool State & Setup

Area throughput limited by multiple resources (lot provisioning, operators, tools, maintenance)



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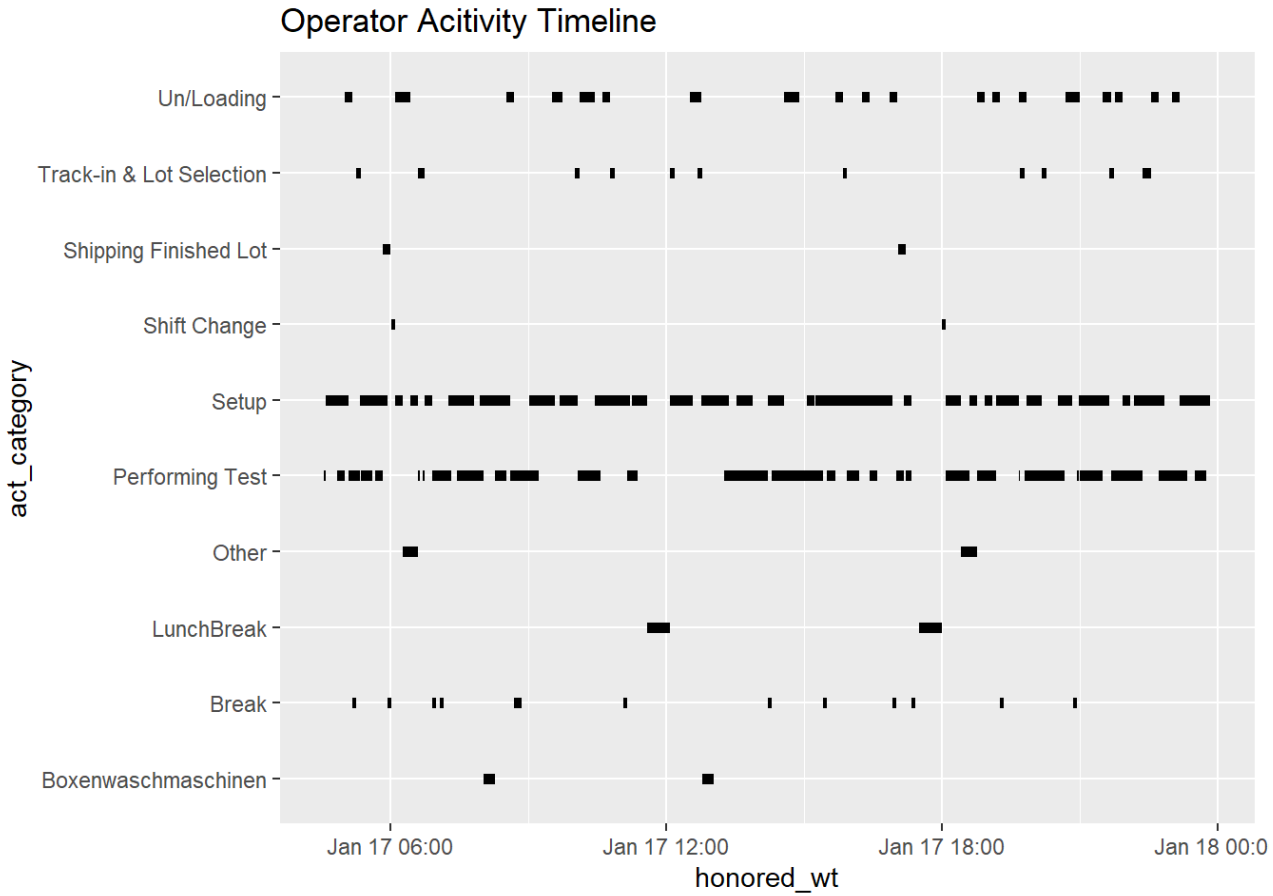
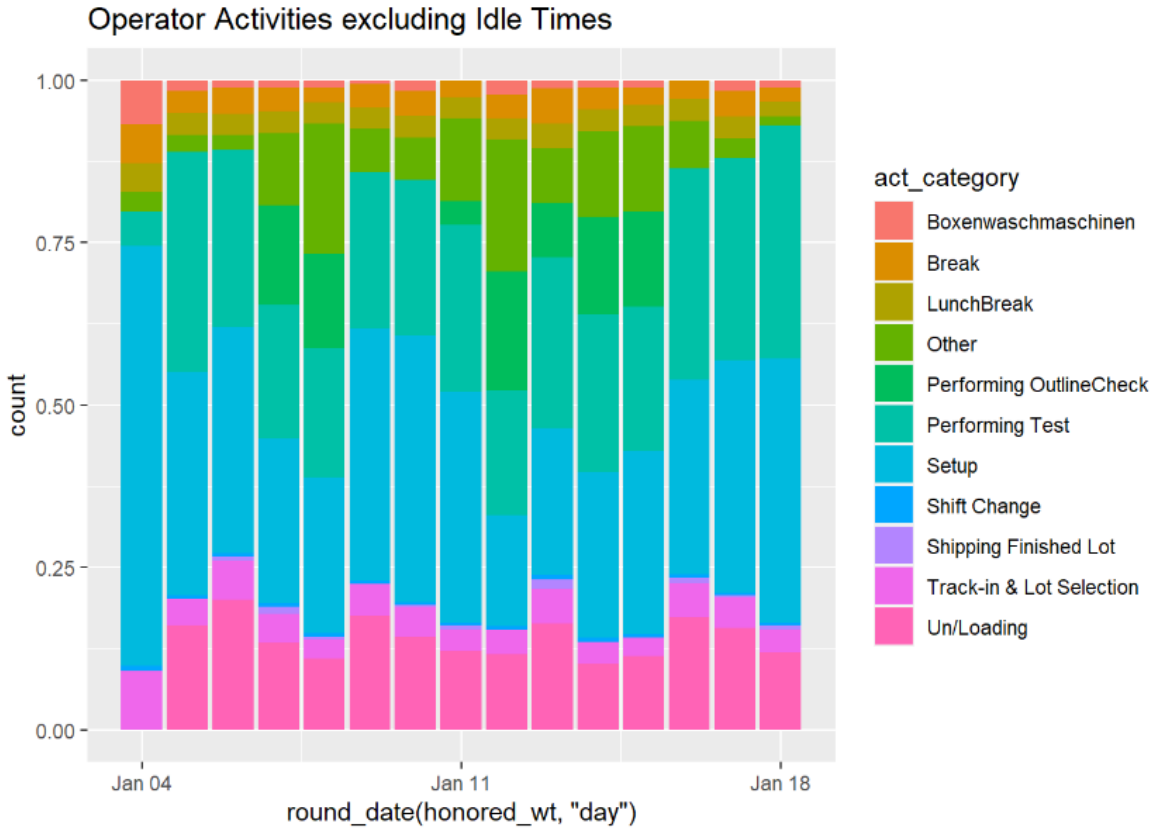
Epitaxy Process Simulation: Operators





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Maintenance Planning

- Maintenance tasks are defined in external ERP system
- Tools loose qual if maintenance does not happen within defined time window

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Simulation-enabled

Production Optimization

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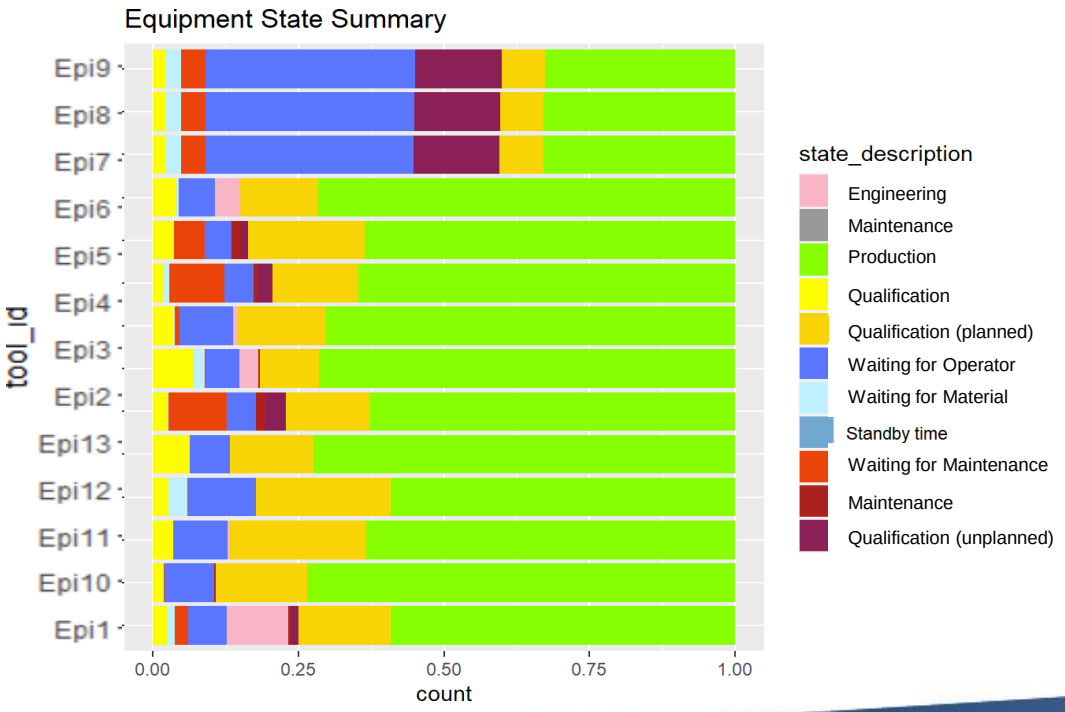
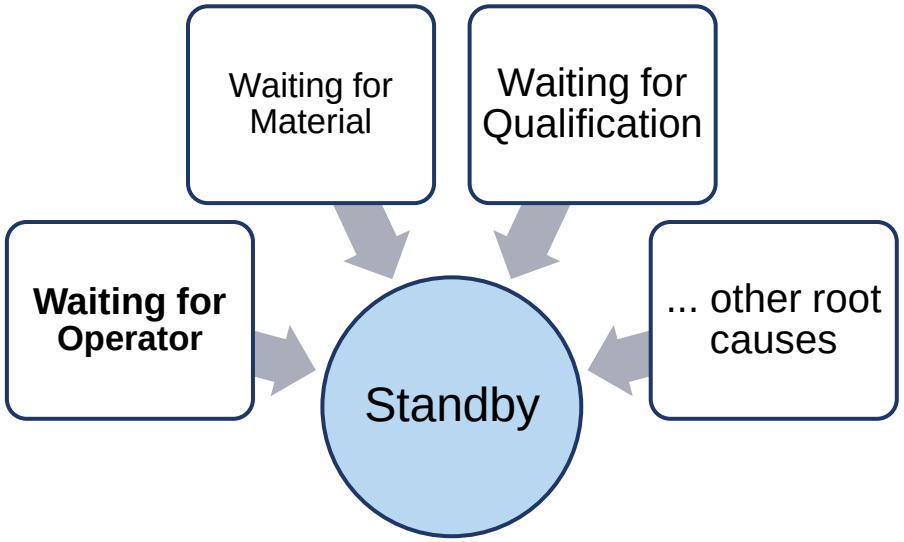
Optimize Bottleneck Tool Groups by Reducing Standby

- "Standby" status very present in all reference tool groups
- Multifactorial problem



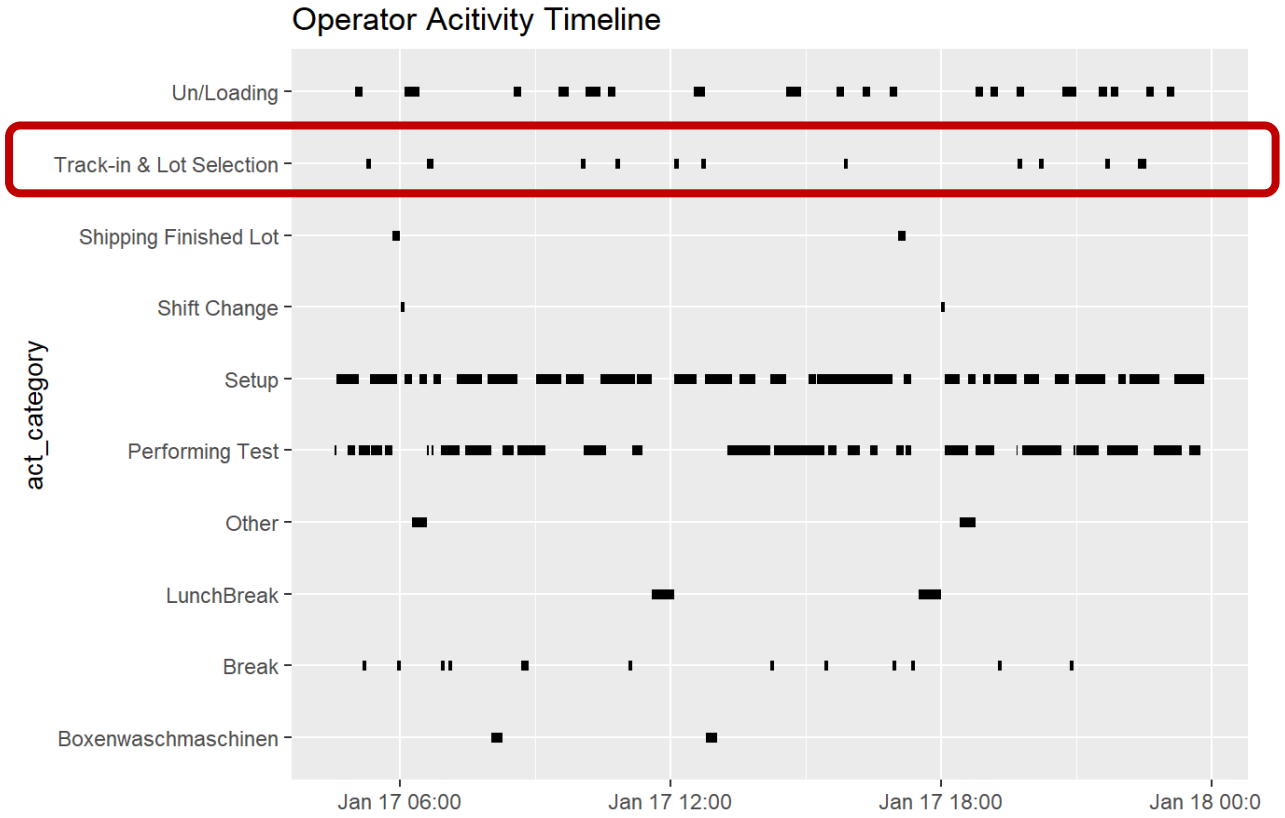


How much throughput could be gained with a simpler operator interface?

- Fewer degrees of freedom
- Less information

Operator Workload in Epitaxy Area

- Understaffed area: waiting for qual and operators are a major productivity constraint
- Detailed area model including operator activities
- ~5min spent to select next lot and to track it into MES
- What if we could streamline the operator guidance process to save just these five minutes?



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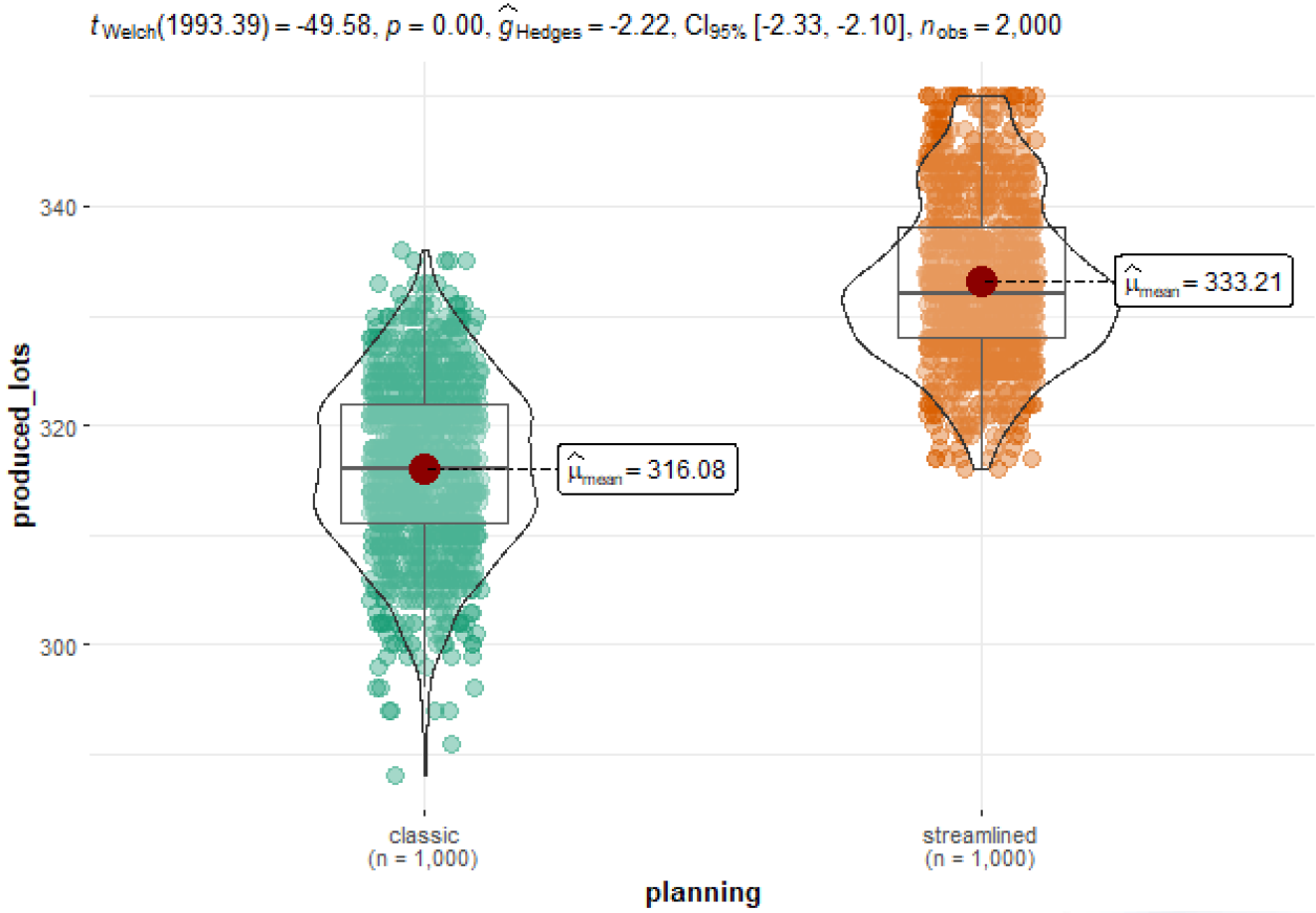
Improved Operator Guidance and Interface → +5% Throughput

Considered two simulation scenarios

- *Classic* – it takes 5 mins to select and track-in a lot
- *Streamlined* – it takes a negligible time to do so

- 14 days (with repetition)
- Significant productivity boost from better operator guidance
- Improved productivity in bottleneck areas



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SYSTEMA Event-Driven Dispatcher

Optimize production with rules & heuristics

Capabilities and rules configured by Engineers

- Generate equipment specific dispatching lists
- Uses Planning / Scheduling Information
- Engineers directly configure the system

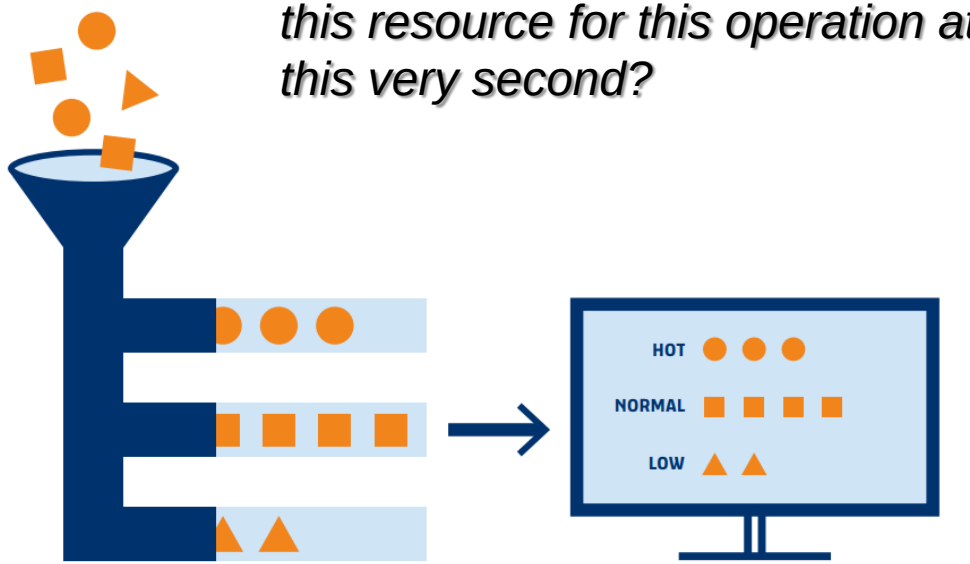
Effective setup and monitoring by Line Control

- Rules for configuring Fab Optimization Criteria
- Bottleneck management
- Real-time monitoring and control

Efficient use by Operators

- Including all required information at one glance
- Look ahead, batching, timers

What is the best material to run at this resource for this operation at this very second?



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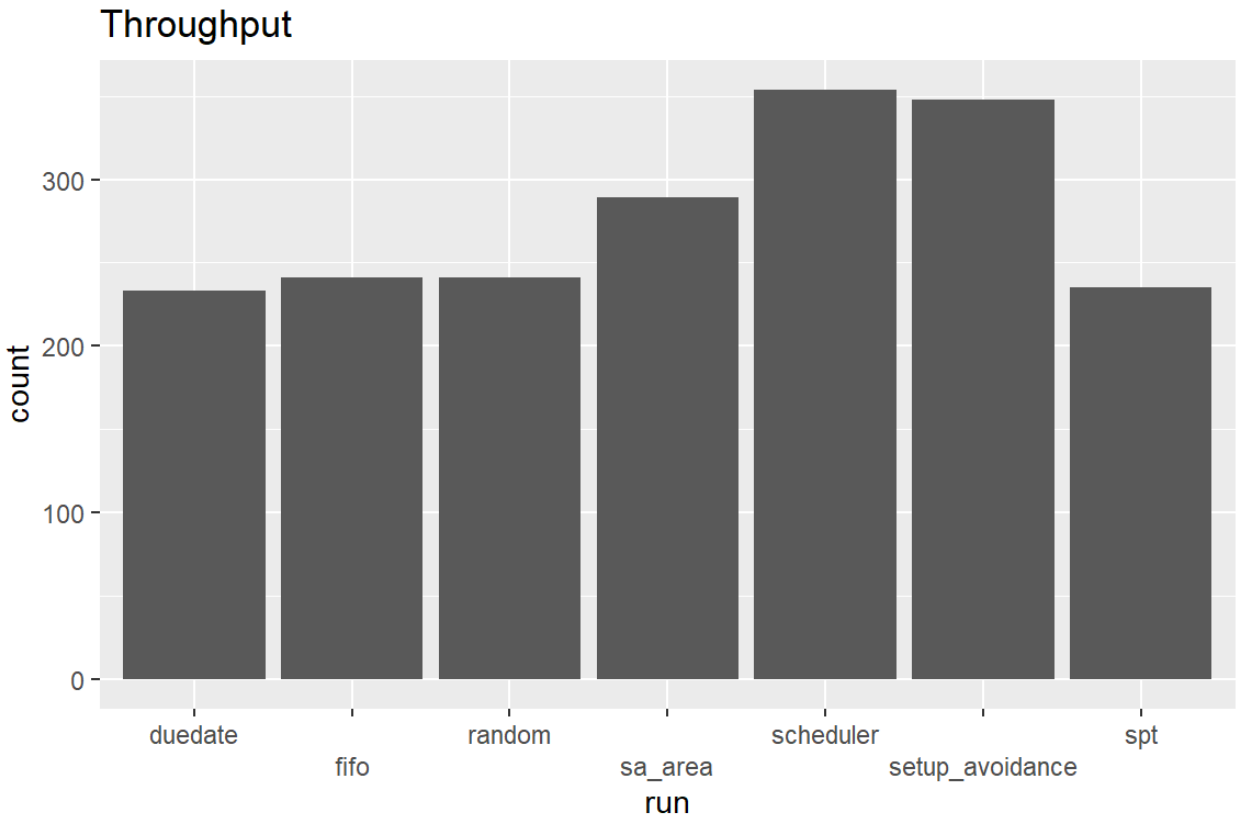
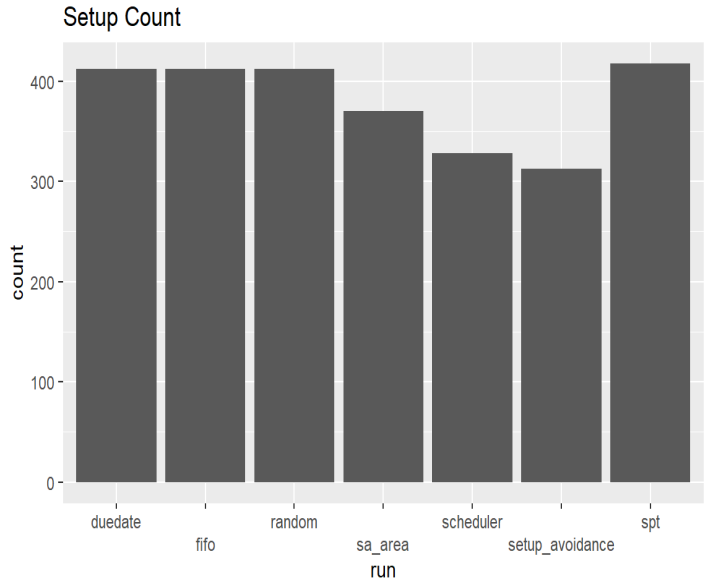
SYSTEMA Shopfloor Scheduler

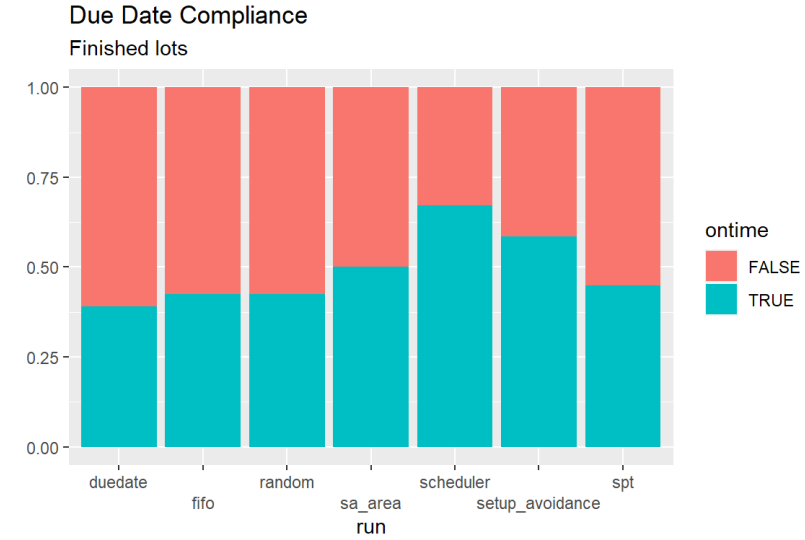
- AI constraint solver
- Based on lightweight, embeddable planning engine
- Extensions for 4M semi-production optimization (Staffing, Material, Routes)
- Over-constrained planning
- Continuous, event-driven planning
- Planning entity pinning
- Multi-stage planning

Planning Method Performance Analysis

- Scheduler outperforms baseline dispatching rules







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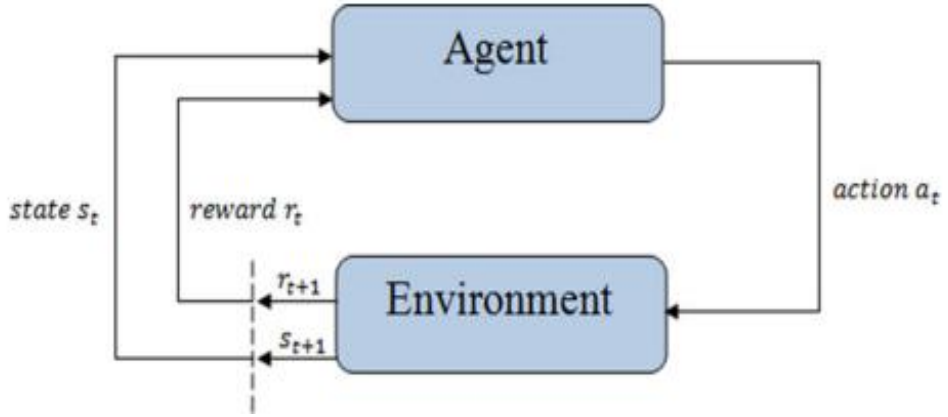
Reinforcement Learning Enabled Shopfloor Execution Planning

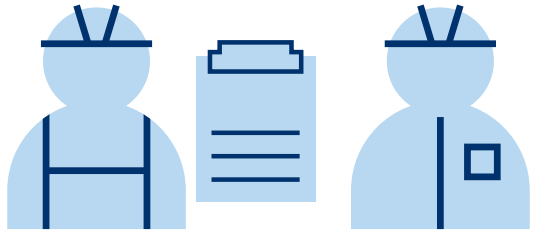
- RL learns complex system mechanics/dynamics from exploration and correlation and can generalize these information to new situations
- Part of ongoing governmental funded research collaboration AISSI http://aissi-project.com
- Extended model proposed in:

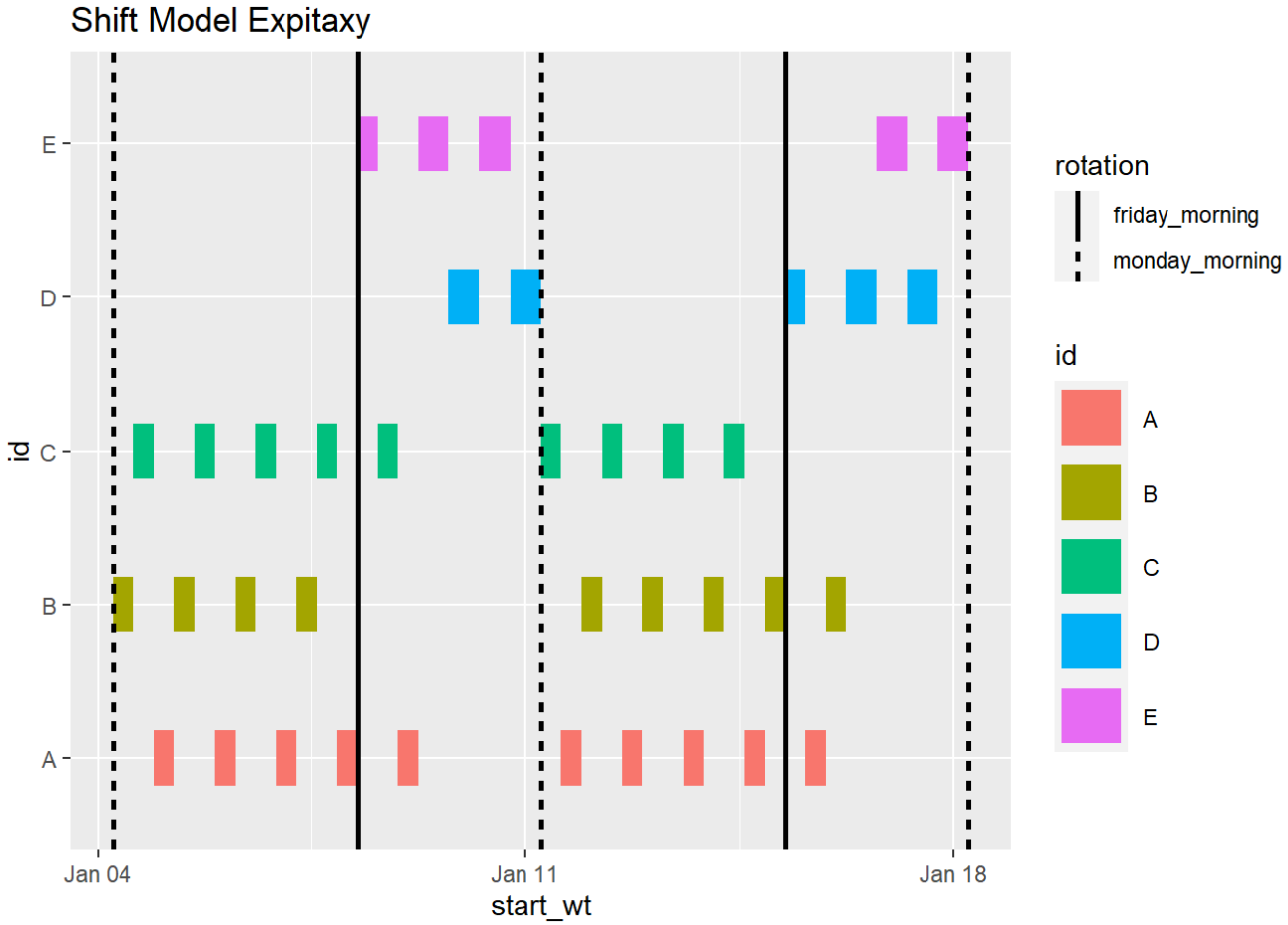
Tassel, Pierre, Martin Gebser, and Konstantin Schekotihin. "A reinforcement learning environment for job-shop scheduling." *arXiv preprint arXiv:2104.03760* (2021)



Extended RL model with due-date and shift-handover

- Operators need to hand over area to next shift
- During shift-handover, new lots won't be started since operators are busy





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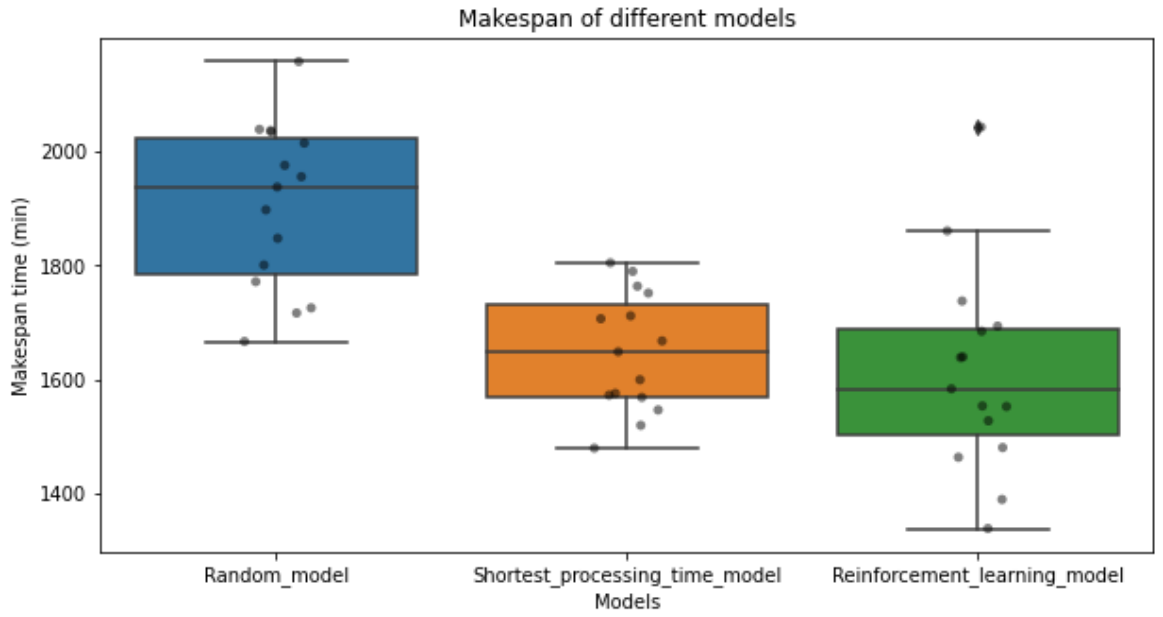
RL Results & Discussion - Many remaining challenges

- Only assessed very small WIP configuration
- Poor generalization
- Not all optimization requirements of Nexperia could be modelled with the RL agent



- Suitable problem formulation
- MCTS compute requirements
- Unclear AI Ops Process & Roles

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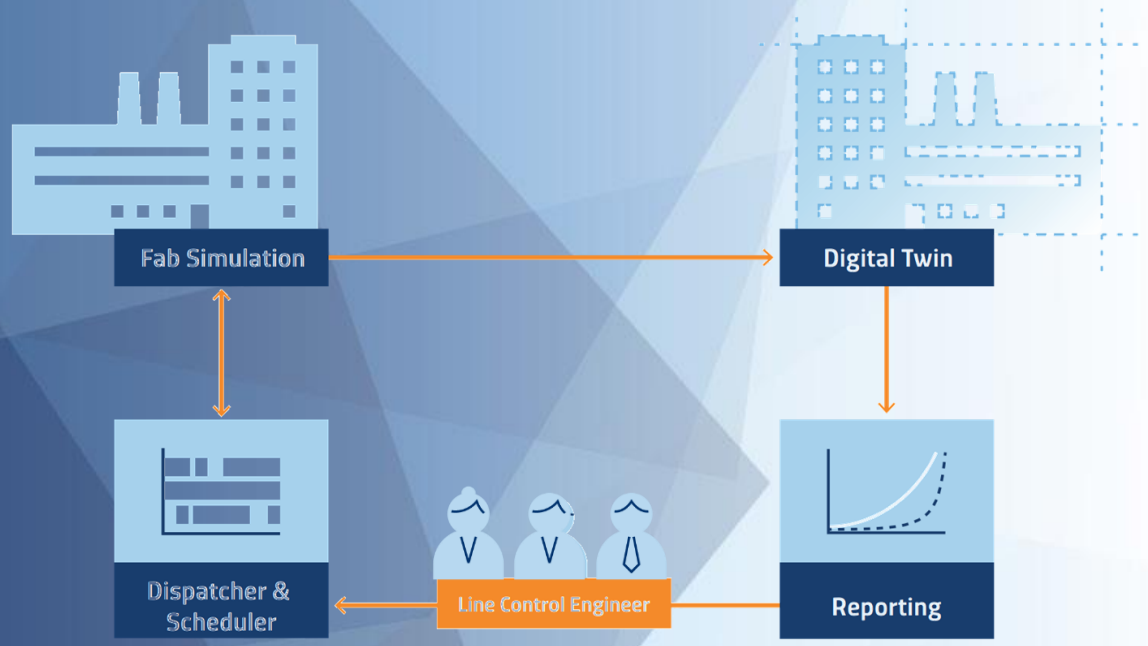
Maximizing throughput, due date compliance & other partially conflicting objectives in semiconductor production

1. Start simple with rule-based optimization

   → **Event-Driven Dispatcher**

2. Establish analytical process
   → **Process Analytics & Consulting**

3. Improve execution planning with scheduling to further optimize production
   → **SYSTEMA Scheduler**



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