

Experiments

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Constraint Based Production Scheduling

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Key Points



- This section describes the scheduling tool
- How to load/create data
 - From files
 - By instance generator
 - From benchmark problems
- How to run the solvers
 - Which solvers are supported
 - What to expect in terms of performance
- Experiments to try
 - Limited time
 - Possible "test before invest" continuation

Outline



The Scheduling Tool

Under the hood

Input Data

Result Output

Instance Generator

Predefined Problem Sets

Some Suggested Experiments

Summary

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Production Scheduling

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The Scheduling Tool



- We create the tool as basis for experiments
- To test ideas and solvers
- As a teaching tool
- Slightly higher standard than usual academic prototypes
- Not a commercial tool
 - But can use commercial solvers
 - Also open-source solvers
- Written in Java, JavaFX
- Uses our Java application framework generator
- Will become available in early 2025

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The Scheduling Tool

Under the hood

Google CPSSat

IBM CPOptimizer

MiniZinc

Which solver to use?

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Back-end solvers



- Provide both open-source and commercial solver interfaces
- Allow experimentation without having to buy commercial tools straightaway
- Gives a level playing field to compare solvers and models
- Provides out-of-the-box, generic performance

Google OR-Tools CPSat Solver



- Open-Source tool provided by Google
- Available at https://developers.google.com/optimization/cp/cp_solver
- Probably best open-source CP solver for scheduling
- This solver is packaged with scheduler

Example Problem

Below is a simple example of a job shop problem, in which each task is labeled by a pair of numbers (m, p) where m is the number of the machine the task must be processed on and p is the processing time of the task – the amount of time it requires. (The numbering of jobs and machines starts at 0.)

- job 0 = [(0, 3), (1, 2), (2, 2)]
- job 1 = [(0, 2), (2, 1), (1, 4)]
- job 2 = [(1, 4), (2, 3)]

In the example, job 0 has three tasks. The first, (0, 3), must be processed on machine 0 in 3 units of time. The second, (1, 2), must be processed on machine 1 in 2 units of time, and so on. Altogether, there are eight tasks.

A solution for the problem

A solution to the job shop problem is an assignment of a start time for each task, which meets the constraints given above. The diagram below shows one possible solution for the problem:



You can check that the tasks for each job are scheduled at non-overlapping time intervals, in the order given by the problem.

The length of this solution is 12, which is the first time when all three jobs are complete. However, as you will see below, this is not the optimal solution to the problem.

(from OR-Tools website)

CP Optimizer from IBM



- Commercial tool of IBM
- [https://www.ibm.com/
products/
ilog-cplex-optimization
cplex-cp-optimizer](https://www.ibm.com/products/ilog-cplex-optimization/cplex-cp-optimizer)
- Part of optimization suite
with Cplex, OPL
- We do **not** provide this
solver, we allow to
interface with it
- Academic licenses
available
- Well-known for capabilities
for scheduling

Resources



Applications of constraint
programming

Explore applications of constraint
programming including production problem
and scheduling use cases.

[Read the documentation →](#)

(from CPOptimizer website)

MiniZinc from Monash University



- Modelling language and backend tools from Monash University in Melbourne, Australia
- Available from <https://www.minizinc.org/>
- Widely used for teaching
- Allows different backend solver to run from same model
- Generic CP tool, not optimized for scheduling
- Requires separate installation, open-source

A screenshot of the MiniZinc website. At the top, there's a navigation bar with links for "Get started", "Windows 10 or later", "Latest release 2.8.7 (GitHub)" (with a download icon), "Tasks", "Sources", "Code", "Licence information", and "About". Below the navigation, a section titled "MiniZinc" describes it as a high-level constraint modeling language for discrete optimization problems. It includes a "Get started" button and a "Windows 10 or later" link. Further down, there's a "Tasks" section with a grid visualization. The grid has columns labeled "Mon", "Tue", "Wed", "Thu", and "Fri" at the top, and rows labeled with names: Anne, Boyd, Clara, Darby, Derry, Eileen, Green, Jason, Katie, Lloyd, Matrix, Niall, and Paula. The grid cells are colored in a 2x2 pattern of blue, yellow, and grey, representing different task assignments over time. A legend below the grid indicates: Blue = Night, Yellow = Evening, Grey = Day. A note states: "Anne, Boyd, Clara, Darby, Derry, Eileen, Green, Jason, Katie, Lloyd, Matrix, Niall, and Paula are developed at Monash University with support from QUTB66." A "Next" button is at the bottom right.

(from MiniZinc Website)

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Input Data



- We have defined a specific JSON data format to describe scheduling problems
- This is different from the native/XML data format of the application (do not use)
- Load with menu **File** – Load DataFile...
- Save with menu **File** – Save DataFile...
- The format is described in a document

Base Data

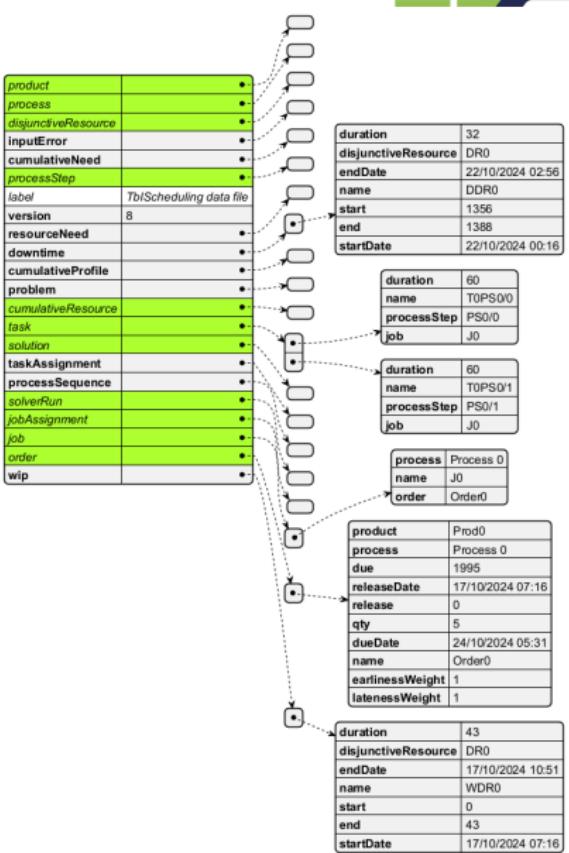


- Description of
 - Product
 - Process
 - DisjunctiveResource
 - CumulativeNeed
 - ProcessStep
 - ResourceNeed
 - CumulativeProfile
 - Problem
 - CumulativeResource
 - ProcessSequence



Schedule Input Data

- Description of
 - Downtime
 - Task (x2)
 - Job
 - Order
 - WiP



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Result Data



- We use the same JSON format to describe the results of the schedule
- Added field types for SolverRun, Solution, assigned Jobs and Tasks

Sample Results



- Description of
 - Solution
 - SolverRun
 - Job Assignment
 - Task Assignment

makeSpan	163
totalEarliness	1632
totalWeight	17110(2024 10:51)
totalWaitBefore	0
early	1
percentEarly	100
late	0
percentLate	0
maxEarliness	0
maxWaitAfter	0
onTime	0
opt	0
overAllocated	Runt
end	163
weightedEarliness	1632
waitBefore	0
maxWaitBefore	0
earliest	163
onTimeStatus	Optimal
late	0
totalWaitAfter	0
percentLate	0
weightEarliness	0
maxEarliness	0
done	Soft
objectiveValue	163
Execution	163
startDate	17/10/2024 10:51

problem	*
process	*
assignmentResource	*
representer	*
cumulativeNeed	*
duration	*
constraintType	*
problem	TH1SchedulingBatchNo
version	0
resourceNeed	*
duration	*
constraintType	*
taskAssignment	*
processResponse	*
constraint	*
process	*
job	*
wip	*

duration	80
waitAfter	0
process	TOPSO/3
assignmentResource	DPO
endDate	17/10/2024 15:51
name	TAS3
start	163
end	163
jobAssignment	JAD
waitBefore	0
startDate	17/10/2024 15:51

duration	80
waitAfter	0
process	TOPSO/1
assignmentResource	DPO
endDate	17/10/2024 23:51
name	TAS1
start	163
end	163
jobAssignment	JAD
waitBefore	0
startDate	17/10/2024 23:51

nrThreads	2
lengthEarliness	1
lengthWait	47
solverBackend	None
weightEarliness	1
process	TOPSO/1
waitBefore	0
waitAfter	0
description	Optimal
label	
rootType	CPO
enumerating	0
objectiveType	MakeSpan
timeout	30
nrOfJobs	1
nrOfQueues	0
nrOfCumulative	0
name	Runt
weightEarliness	1
start	163
end	163
processDuration	0
processEarliness	0
processWaitDuration	0
processWaitEarliness	0
processWaitDuration	0
processWaitEarliness	0
duration	163
addition	0
rate	0
endDate	17/10/2024 30:51
name	JAD
start	163
end	163
job	JAD
early	1632
startDate	17/10/2024 10:51

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Instance Generator

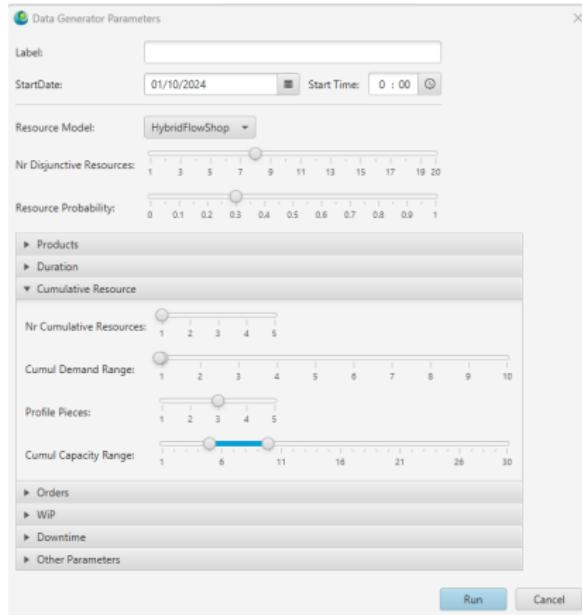


- Application allows to generate different types of test problems
- Different types of resource models
- Different numbers of orders, resources, WiP, downtime
- Useful to generate more life-like examples combining different constraint types

Instance Generator Dialog



- Resource Model
 - Select a resource model defining the overall structure of problem
- Nr Disjunctive Resources
 - Describe how many disjunctive resources are generated
- Resource Probability
 - The probability that a resource is compatible with a task
 - Only for some resource models



Resource Models



- Flow-Shop
 - Multiple stages, all jobs use machines in same order
- Job-Shop
 - Multiple stages, jobs use machines in different order
- Open-Shop
 - Multiple stages, no predefined order of machines
- Hybrid Flow-Shop (default)
- Hybrid Job-Shop
- Hybrid Open-Shop
 - Like x-shop, but with multiple machines per stage
- Random
 - Multiple stages, each stage using a random subset of machines
- All
 - Multiple stages, each stage allowing all machines

Instance Generator - Products



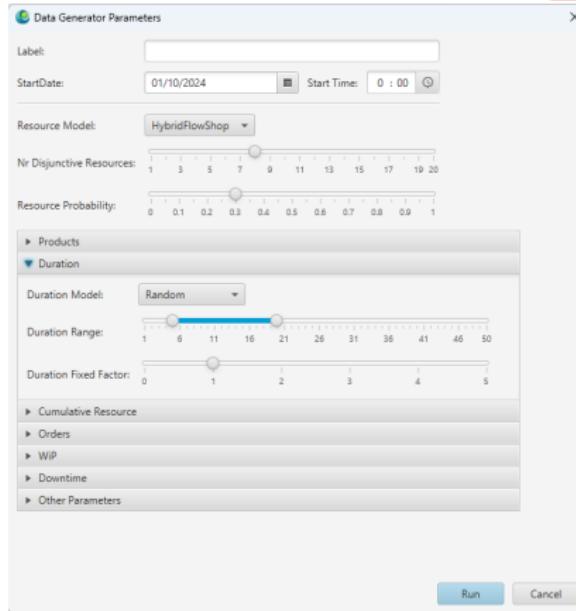
- Nr Products
 - Number of products to be generated
 - Products may be reused by multiple orders
- Stages Range
 - Range slider, sets lower and upper bound on number of stages

The screenshot shows the 'Data Generator Parameters' dialog box. It includes fields for 'Label', 'Start Date' (01/10/2024), 'Start Time' (0 : 00), 'Resource Model' (set to 'HybridFlowShop'), and two sliders: 'Nr Disjunctive Resources' (set to 9) and 'Resource Probability' (set to 0.3). A section titled 'Products' contains a 'Nr Products' input field set to 10, and a 'Stages Range' slider set between 4 and 8. Below these are expandable sections for 'Duration', 'Cumulative Resource', 'Orders', 'WIP', 'Downtime', and 'Other Parameters'. At the bottom are 'Run' and 'Cancel' buttons.

Instance Generator - Duration



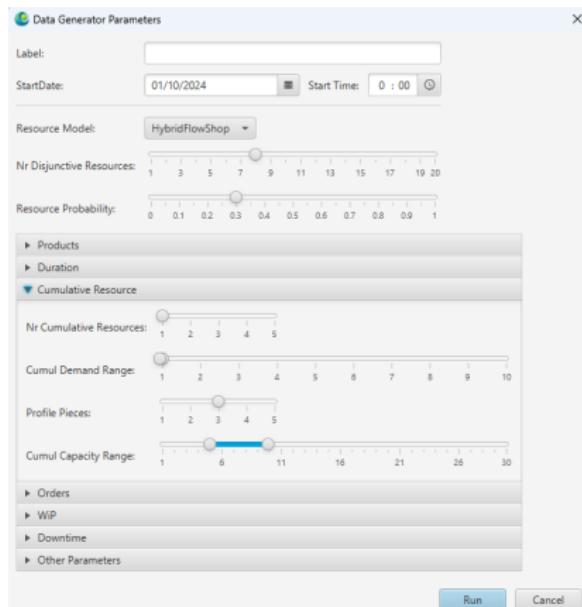
- Duration Model
 - Different ways to link duration of processSteps
- Duration Range
 - Range slider to set lower and upper bounds on perUnit duration
- Duration Fixed Factor
 - How fixed and perUnit duration values are linked



Instance Generator - Cumulative



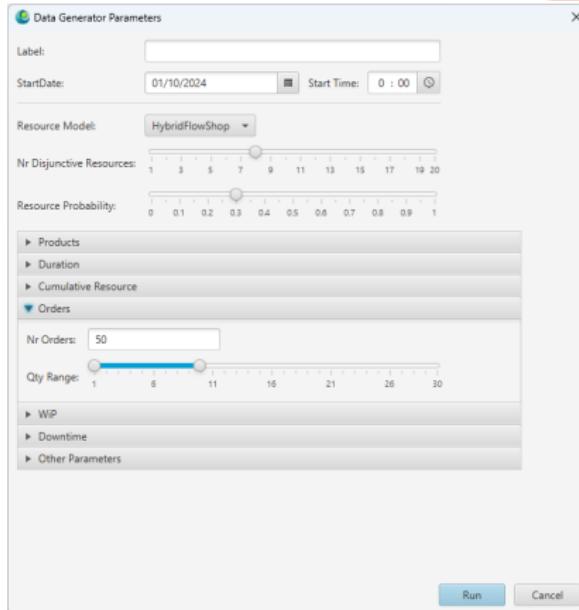
- Nr Cumulative Resources
 - Number of cumulative resources generated
- Cumul Demand Range
 - Range slider to select lower and upper bound on cumulativeResource-Need demands
- Profile Pieces
 - Number of segments of CumulativeProfile generated for each resource
- Cumul Capacity Range
 - Range slider to select lower and upper bounds on cumulative profile capacity values



Instance Generator - Orders



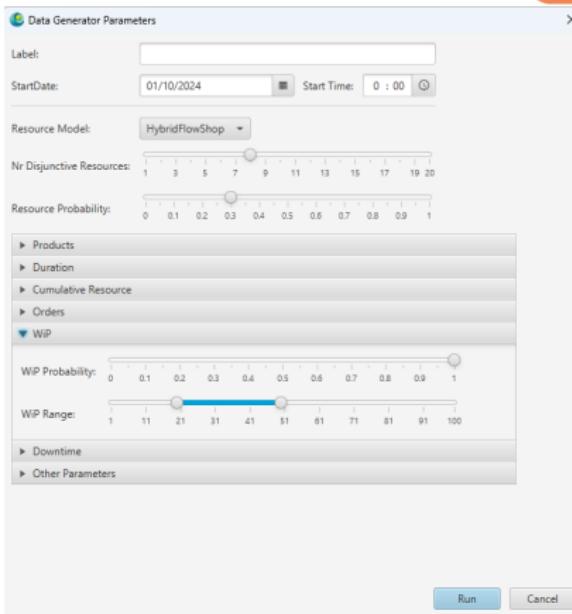
- Nr Orders
 - Number of orders generated, each order is assigned a random product/process
- Qty Range
 - Range slider to select lower and upper bounds on quantity for each order



Instance Generator - WiP (Work in Progress)



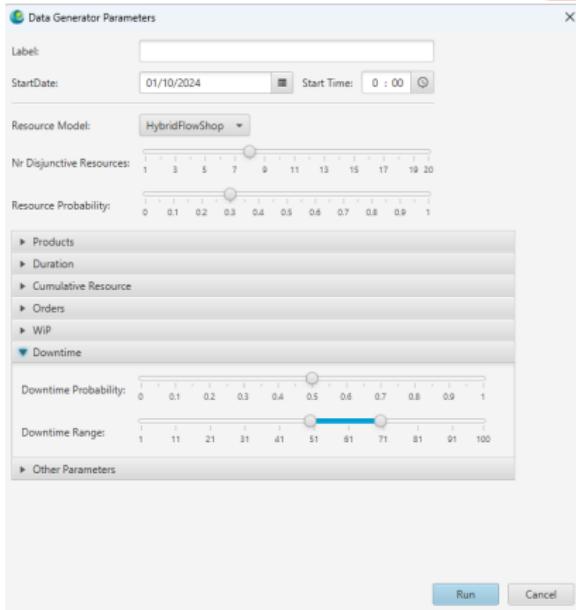
- WiP Probability
 - Probability of generating a WiP for a disjunctive resource
- WiP Range
 - Range slider to set lower and upper bound on WiP duration



Instance Generator - Downtime



- Downtime Probability
 - Probability of generating a downtime for a disjunctive resource
- Downtime Range
 - Range slider to select lower and upper bounds on downtime duration



Instance Generator - Other Parameters



- Earliest Due
 - Smallest allowed value for a due date
- Horizon Days
 - What planning horizon to consider (in days)
- Time Resolution
 - In minutes, links internal and external time presentation
- Random Seed
 - Random seed to make reproducible random choices

Data Generator Parameters

Label:

StartDate: 01/10/2024 Start Time: 0 : 00

Resource Model: HybridFlowShop

Nr Disjunctive Resources:

Resource Probability:

► Products

► Duration

► Cumulative Resource

► Orders

► WIP

► Downtime

▼ Other Parameters

Earliest Due:

Horizon Days:

Time Resolution:

Random Seed:

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Taillard

SALBP

Test Scheduling

Taillard Scheduling Benchmarks



- Three datasets of different sizes
 - Job-shop
 - Flow-shop
 - Open-shop
- Load with menu File – Load DataFile... – Taillard –
- Larger instances need more solver time to reach good solutions (600 s)

Simple Assembly Line Balancing Problem (SALBP)



- Will be discussed on more details as case study
- Design an assembly line setup by solving a scheduling problem
- Balance a set of operations across a number of stations of an assembly line
- Precedence graph is not a chain, can be very complex
- Specialized problem normally solved with specialized tools
- Load with menu File - Load SALBP Problem...

Test Scheduling Benchmark set from ABB



- Will be discussed in more details as case study
- Schedule a set of tests on a number of machines, minimizing total duration
- Single stage tests, possibly large number of resources
- Closely related to bin-packing
- Load with menu File – Load Test Scheduling Problem...

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Experiment 1



- Start the application
 - Our running example will be automatically generated
- Look at the process diagram Window–Product–Process Diagram
- Run the solver Scenario – Run ScheduleJobs Solver
- Observe the results in Gantt Chart
- Customize display
- Look at Cumulative Resource Chart
Window–Solution–Cumulative Resource Chart

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Summary



- We presented an overview of our generic scheduling tool
- Discussed available solvers, both commercial and open-source
- Described the JSON data format for input and output
- Gave an overview of the instance generator provided
- Shows example problems included with tool
- Suggested some experiments to run