Objectives

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Constraint Based Production Scheduling

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Key Points

- Why we search for good, but not always optimal solutions
- The different objectives provided in scheduling tool
- More complex optimization schemes involving multiple objectives
- Other criteria that might guide which solution we prefer
- An interesting research direction

1 Optimal vs. Good Solutions

Why have an Objective?

- For most scheduling problem, we define some form of objective
- A mathematical formula that we evaluate on a schedule to compare it
- It is not always clear whether that formula represents some direct business benefit
- But, there are far more bad solutions than good solutions!
- The objective tells us if the solution is more "good" or "bad"
- Different stakeholders will have different views what makes a solution "good" or even "acceptable"

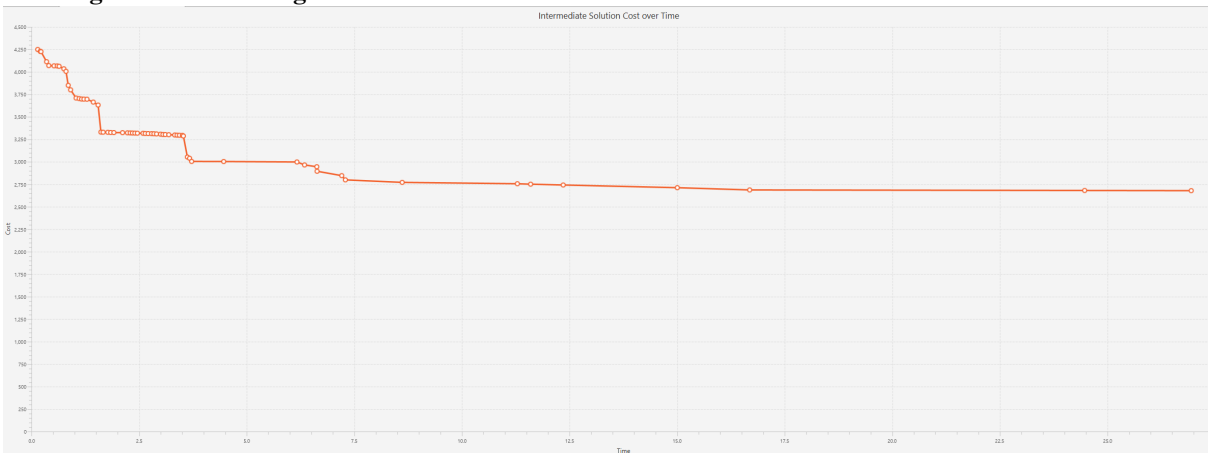
Minimizing Cost vs Maximizing Profit

- A lot of objectives aim to reduce cost of production
- This is not always a good thing
  - Doing nothing costs nothing
- But defining the profit obtained by a schedule is not easy
- Many intangible factors weigh in
  - Happiness of the customers (which customers are unhappy, does it matter?)
  - Happiness of personnel (finding and retaining skilled personnel is critical)
  - Happiness of stakeholders (sales, production, inventory, management)

Timeliness

- How quickly do we need a solution?
  - Sometimes we need a solution right now
  - We may also have time to wait a bit, or even more
  - Waiting five minutes, having a short break for a coffee, will often be acceptable
  - For some problems, running a scheduler overnight is possible
  - Do we need the ultimate in solution quality, or an acceptable solution right now?
- Benchmarks are often run with unlimited resources
  - "We used four years of computer time to solve these problems"

Diminishing Returns Running a Solver



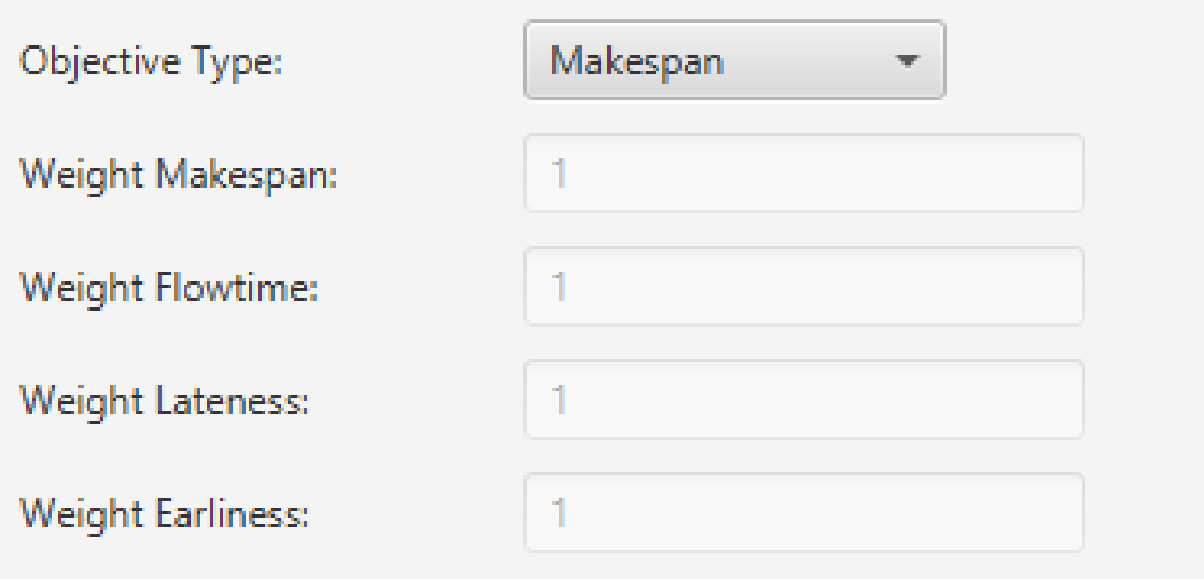
- Which compromise between quality and speed are we looking for?

1.1 Cost vs. Profit Based Objectives

2 Objective Types

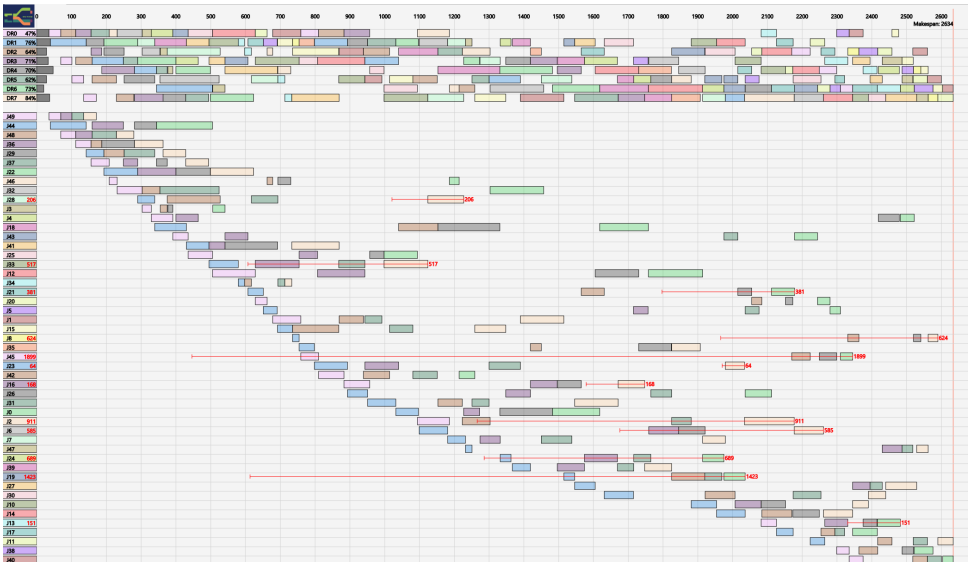
Setting the Objective

- We can select a predefined objective in solver dialog
- There are weight factors to give more impact to some cost terms in on-time and hybrid objectives



2.1 Makespan

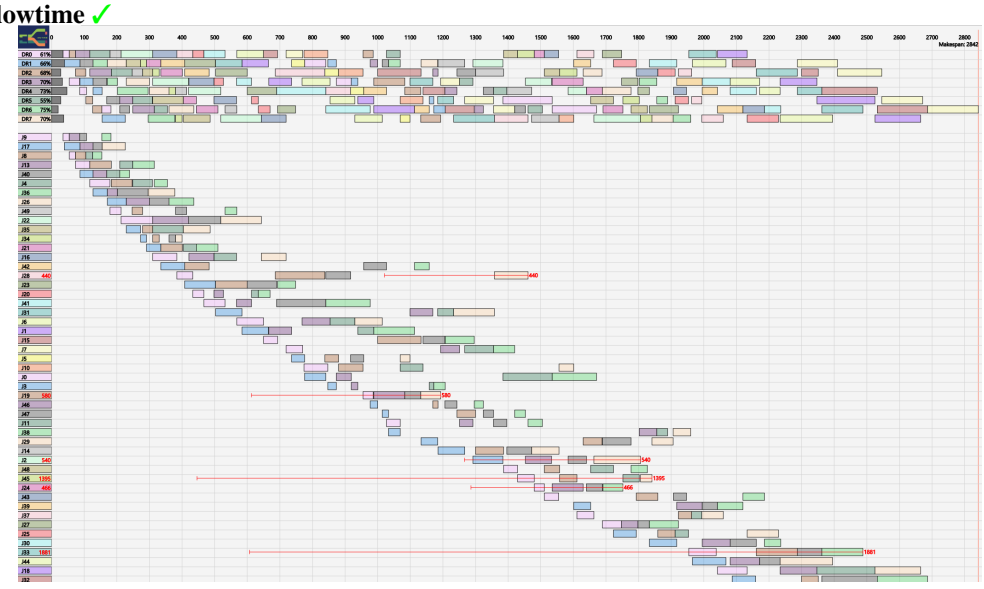
Makespan ✓



- Minimize the overall project end
- Very traditional objective in scheduling
  - Justified in project scheduling
  - Not so clearly justified in manufacturing
- A number of jobs are significantly late

2.2 Flowtime

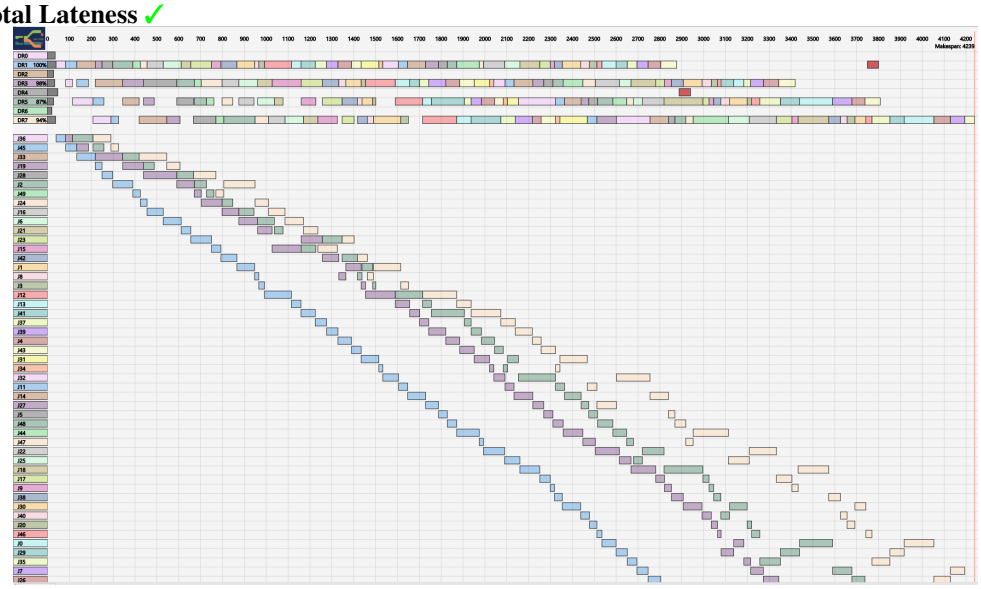
Flowtime ✓



- Minimize the sum of job ends
- Prefer all machine to end early
- Not always easy to find good solutions

2.3 Lateness

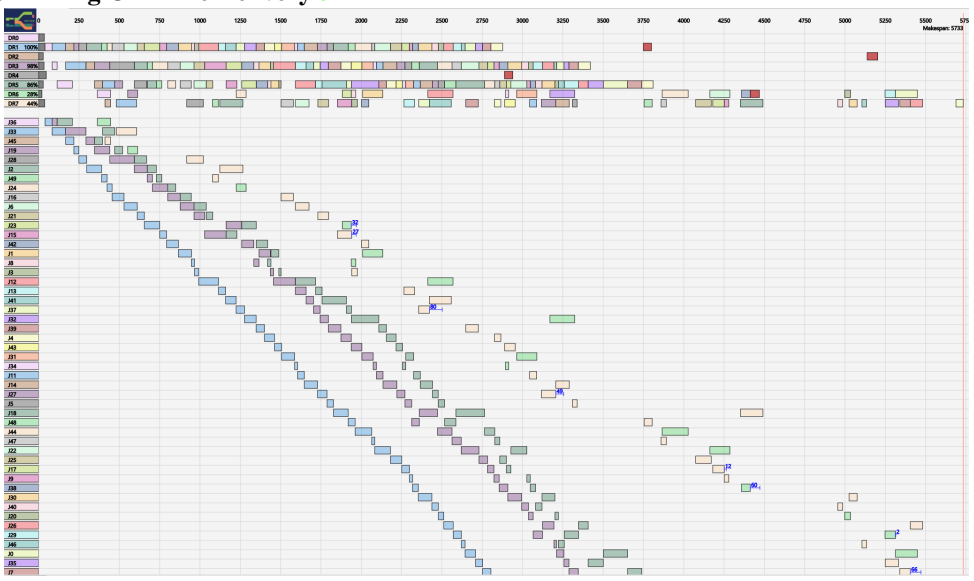
Total Lateness ✓



- Able to remove all delays on jobs
- Does not care about makespan or earliness
- In the example problem, many due dates far in the future

2.4 On-Time

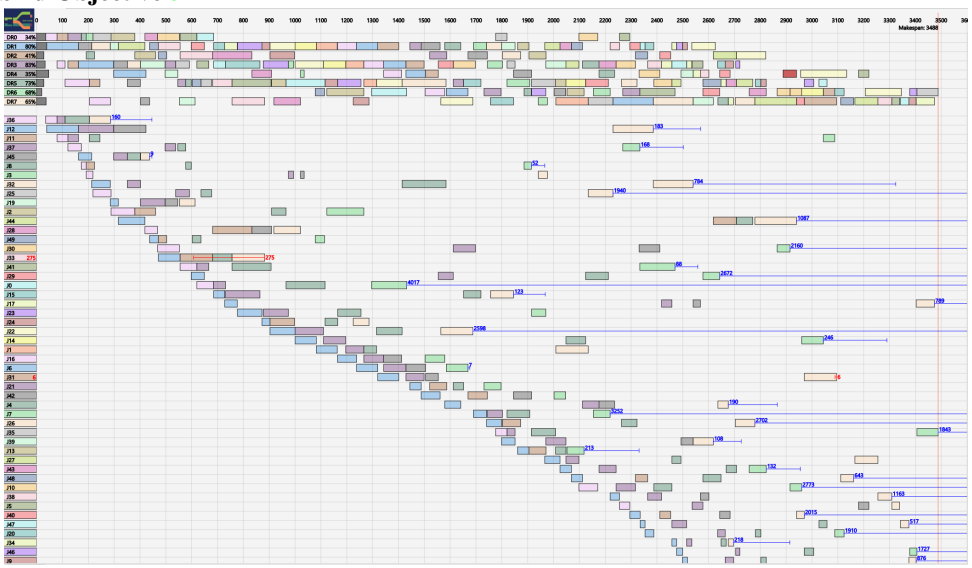
Maximizing On-Time Delivery ✓



- Weight 100 for lateness, weight 1 for earliness
- Removes all delays, very little earliness
- Makespan increased dramatically

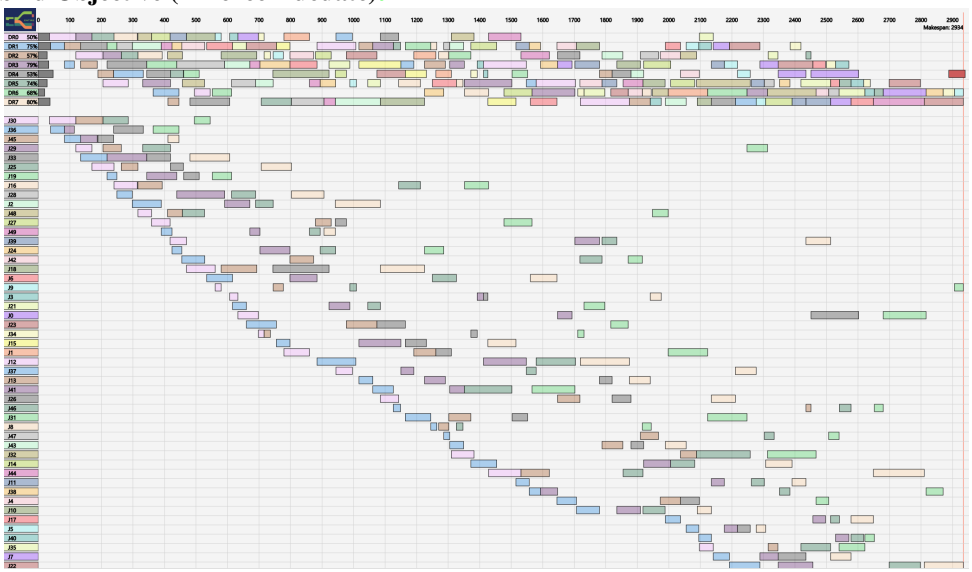
2.5 Hybrid

Hybrid Objective ✓



- Weights makespan:1000, flowtime:0, lateness:10, earliness:1
- Does not remove lateness completely
- Probably needs more time to improve

Hybrid Objective (Enforce Duedate)✓



- Sometimes enforcing a constraint is more powerful
- Here require that due dates are respected
- Leads to overall better solution

2.6 Comparison

Comparing Solutions with Different Objectives

SolverRun	ObjectiveType	ObjectiveValue	SolverStatus	Bound	GapPercent	Makespan	Flowtime	TotalLateness	MaxLateness	NrLate	WeightedLateness	TotalEarliness	MaxEarliness	NrEarly	WeightedEarliness	PercentEarly	PercentLate
Run1	Makespan	2,634	Solution	1,050.00	60.14	2,634	86,339	7,618	1,899	12	7,618.00	76,688	4,887	38	76,688.00	76.00	24.00
Run2	Flowtime	66,356	Solution	39,248.00	40.85	2,842	66,356	5,575	1,881	7	5,575.00	94,628	5,045	43	94,628.00	86.00	14.00
Run3	TotalLateness	0	Optimal	0.00	NaN	4,239	119,745	0	0	0	0.00	35,664	1,494	50	35,664.00	100.00	0.00
Run4	OnTime	328	Optimal	328.00	0.00	5,733	155,081	0	0	0	0.00	328	80	8	328.00	16.00	0.00
Run5	Hybrid	3,554,610	Solution	1,150,697.00	67.63	3,488	117,180	281	275	2	281.00	38,510	4,017	34	38,510.00	68.00	4.00
Run6	Hybrid	2,992,627	Solution	1,155,981.00	61.37	2,934	96,782	0	0	0	0.00	58,627	4,530	43	58,627.00	86.00	0.00

- System tries to reduce the objective
- May mean other aspect of solution is poor
  - *Total Lateness* bad if just reducing *Makespan*
  - *Makespan* bad if just reducing *Total Lateness*
- Hybrid objectives can find better compromises
- Using constraints to restrict search can help
- Needs more work on lower bounds

2.7 Other objectives

Optimizing Resource Levels ✗

- We have already discussed this in the Resources section
- Sometimes we aim to optimize resource use, not time or delay
- Typical is minimizing
  - The number of disjunctive machines needed
  - A cumulative resource capacity
  - The manpower required to perform all tasks
- We may do this for understanding the problem
- The optimized schedules will be brittle
  - Any resource breakdown will cause an issue
  - Spare capacity is a good thing (if it is not too expensive)

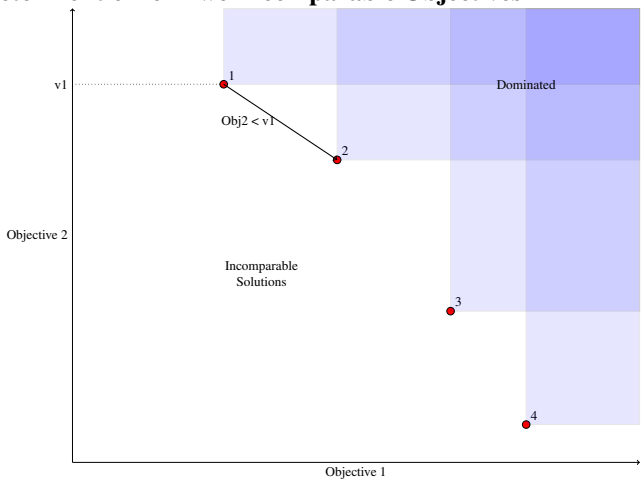
Including Optional Work ✗

- So far, the set of orders had to be fulfilled
- The resulting jobs needed to be included in schedule
- Sometimes, there are optional orders that we may or may not include in schedule
- The more work we do in this schedule, the better
  - Assumes a fixed horizon to limit the available space
- But we can reject some of the orders
- The objective is to maximize the value of the accepted orders
- Related to *Knapsack problem*, a well known combinatorial problem

Multi-level Objectives ✗

- In some situations, a hybrid objective combining different aspects is not enough
- We need to find all best compromises between the different objective types
  - Without an a-priori weight to state which is more important
- A solution *dominates* another solution, if for all objective types, it is better than the other
- Two solutions are *incomparable* if for some objective type one solution is better, but for some other objective, the other solution is better
- *Pareto frontier*: Set of all non-dominated, incomparable solutions

Pareto Frontier for Two Incomparable Objectives



- Finding Pareto frontier by repeated optimization of objective1

3 Other Quality Vectors

Other Quality Vectors

- There are other scales on which we may measure whether a solution is "good"
  - Fairness
  - Robustness
  - Product Quality
  - Customer Satisfaction
  - Diversity

Fairness

- Typically involves humans
- If we assign operators, do we
  - Treat all operators in a fair way?
  - Give effective workers always more work
  - Provide opportunities for training and skill development

  - De-risk dependency on key personnel
- Also, use multiple machines of same type consistently
  - Balanced
  - Not balanced

Robustness

- By scheduling, we create a plan
- Often, reality does not follow the plan
  - Unforeseen events, machine breakdowns, sick-leave
  - Delays in raw material delivery, inventory problems
  - Rush orders
  - Small variations in plan execution
- Can we protect the plan against certain types of unplanned events?
- Is the plan still useful when things change?
- Or, can we update the plan quickly enough to adapt to changes

Product Quality

- The tighter the schedule, the more risk there is of cutting corners
- Example
  - If we minimize curing times to speed up production, quality may be affected
- The fastest machine is not always the best in terms of quality, cost

Customer Satisfaction

- Our objectives for minimizing lateness are lacking context
- Some customers are more important than others
- Some orders are more important to the customer than others
- A phone call by a human can capture more detail than an electronic order form
- We can adjust our schedule if we know what is important and what is not
  - But where do we get this information?
  - How do we avoid that a customer says "all my orders are critical"

Diversity

- Is it sometimes useful to present different solutions to a user to choose from
- These solutions should be substantially different to make choice meaningful
- Unfortunately, solvers often find very similar solutions
- Typically, there are far too many solution to enumerate them all
- We can add constraints to ask for the next solution to be quite different from the previous ones
- Needs good definition to define similarity
- Hamming distance on machine order a good starting point

4 Key Performance Indicators

Key Performance Indicators (KPI)

- Performance indicators can be computed from a given schedule, and allow to compare different schedules to each other
- Often, these are business oriented, not process driven
- There is a difference between an objective and a performance indicator
  - The objective drives the search for a solution
  - The KPI evaluates the quality of a solution, can be totally unrelated to objective
- Ideally, the KPI are expressed in such a way that solutions for different problems can be compared
  - Number of late orders, allows comparison of two solutions of the same problem
  - Percentage of late orders, allows comparison of two different schedules

KPIs for Sample Solutions

- Comparing different solutions of running example with enabling/disabling some constraints
- Compare *Makespan* to *On-time Delivery* objective
- There is no *Setup Time* constraint specified for this problem

Makespan	Flowtime	TotalLateness	MaxLateness	NrLate	WeightedLateness	TotalEarliness	MaxEarliness	NrEarly	WeightedEarliness	PercentEarly	PercentLate	Duration	Start	End
2,688	83,425	10,083	1,959	11	10,083.00	82,067	4,938	39	82,067.00	78.00	22.00	2,653	35	2,688
2,690	85,051	0	0	0	0.00	70,358	4,133	50	70,358.00	100.00	0.00	2,655	35	2,690
2,136	58,403	0	0	0	0.00	97,006	4,956	50	97,006.00	100.00	0.00	2,101	35	2,136
2,324	62,494	0	0	0	0.00	92,915	4,751	50	92,915.00	100.00	0.00	2,289	35	2,324
5,733	154,918	0	0	0	0.00	491	122	10	491.00	20.00	0.00	5,538	195	5,733

TotalWaitBefore	TotalWaitAfter	MaxWaitBefore	MaxWaitAfter	TotalIdleBefore	TotalIdleAfter	MaxIdleBefore	MaxIdleAfter	TotalSetupBefore	TotalSetupAfter	MaxSetupBefore	MaxSetupAfter	TotalActiveTime	TotalProductionTime	ActiveUtilization	SetupPercent	IdlePercent
23,297	23,297	1,943	1,943	6,823	6,823	435	435	0	0	0	0	19,917	13,094	65.74	0.00	34.26
24,903	24,903	1,611	1,611	5,901	5,901	342	342	0	0	0	0	18,995	13,094	68.93	0.00	31.07
12,081	12,081	449	449	785	785	80	80	0	0	0	0	13,879	13,094	94.34	0.00	5.66
0	0	0	0	4,211	4,211	111	111	0	0	0	0	17,305	13,094	75.67	0.00	24.33
0	0	0	0	28,641	28,641	773	773	0	0	0	0	41,735	13,094	31.37	0.00	68.63

KPIs Already Defined ✓

Makespan Max of job ends

Flowtime Sum of job ends

Total Lateness Sum of job lateness (tardiness)

Max Lateness Max of job lateness

NrLate Number of late jobs

WeightedLateness Weighted sum of job lateness

PercentLate percentage of late jobs

...Earliness same indicators, but for earliness

Duration Difference between overall start and overall end

Start start of earliest job

End end of last job

KPIs Already Defined (cont'd) ✓

TotalWait Sum of Wait time before/after a task of a job

MaxWait Max wait time before/after a task of a job

TotalIdle Sum of Idle times of disjunctive machines

MaxIdle Max Idle Time on a disjunctive machine

TotalSetup Total setup times

MaxSetup Max setup time

TotalActiveTime Total active time between first and last use of a machine

TotalProductionTime Sum of all task duration

ActiveUtilization Percentage of production time compared to active time

SetupPercent Percentage of setup time compared to active time

IdlePercent Percentage of idle time compared to active time

KPI Ranking ✗

- If we have multiple solutions, we want to rank them based on a comparison of different KPIs
- Different stakeholders will rank different KPIs in very different way
- This seems to require some customization of the formulas used
- We can also try to infer a ranking method based on some comparison queries asked to users
  - Do you prefer this or that solution?
  - With enough answers, we can postulate a ranking method

5 Interactive Scheduling

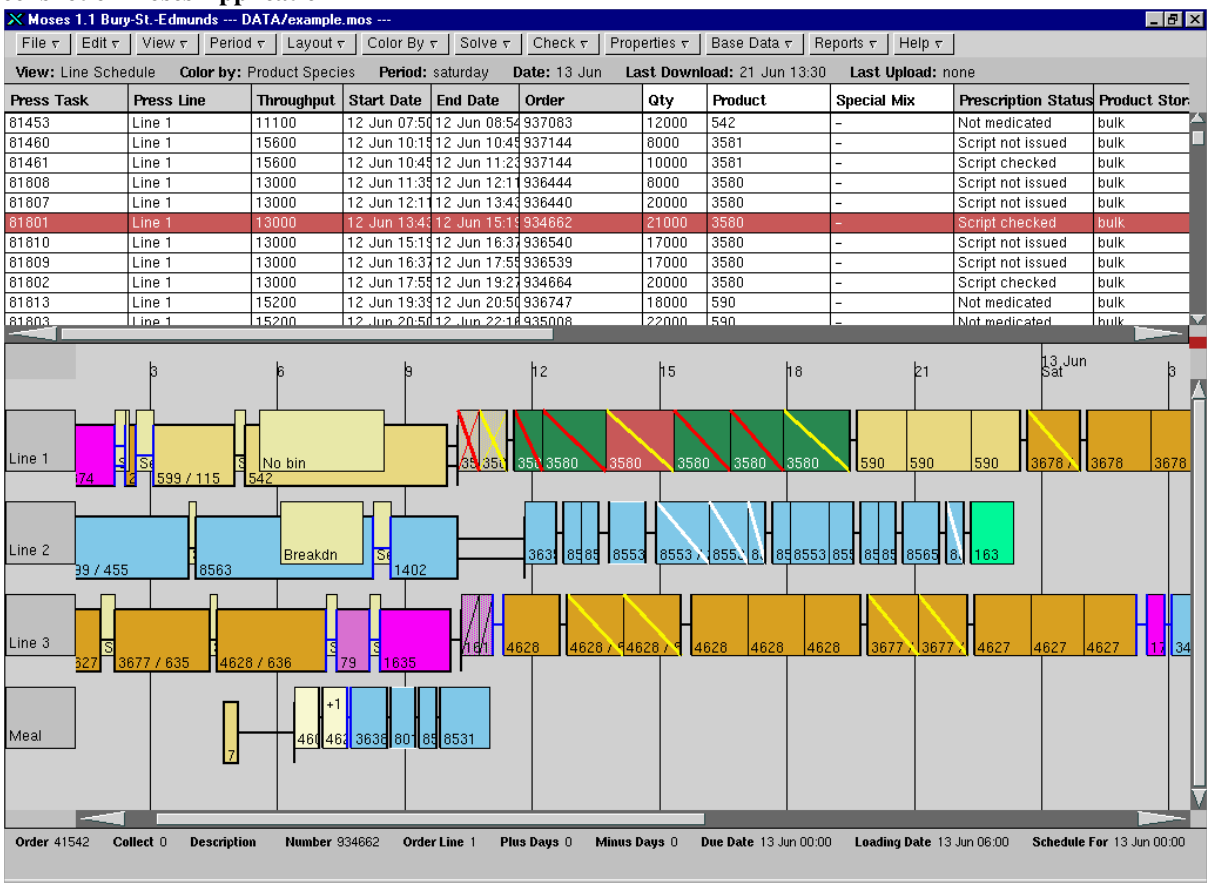
Interactive Scheduling ✗

- Some human schedulers are happy to accept a produced plan
  - Perhaps change some constraints, or weights
- Other human schedulers want to modify the plan by hand
  - This is not always easy to do
  - How can a scheduling tool handle this?
  - How much control is given to the user, who checks the constraints?
  - Do we allow the user to create invalid schedules?

Example: Moses System

- Scheduling application for animal feed mills in the UK
- Produces overnight schedule for delivery on next day
- Operator updates the schedule whenever a task is finished
- Change duration of task if it is delayed
- Move tasks by hand, changing sequence of tasks to be performed
  - System updates constraints, and warns if constraint is violated
- User can protect part of schedule from modification by system
  - Freeze all tasks up to the selected task
  - Unfreeze the schedule after the selected task
- Related to explainability

Screenshot of Moses Application



Summary

- Describe the need and role of objectives
- Presented different objectives available in the scheduling tool
- Discussed some more advanced possibilities for handling objectives
- Important to keep user on control of system