Creating Tests for a Family of Cost Aware Resource Constraints

Helmut Simonis and Tarik Hadzic

Cork Constraint Computation Centre
Computer Science Department
University College Cork
Ireland

CSCLP 2010, Berlin

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Background

- Funded by Science Foundation Ireland (SFI)
- TIDA project: Application oriented research
- Cooperation with IBM, United Technologies
- Objective: Develop scheduling tools for energy cost aware scheduling

Background

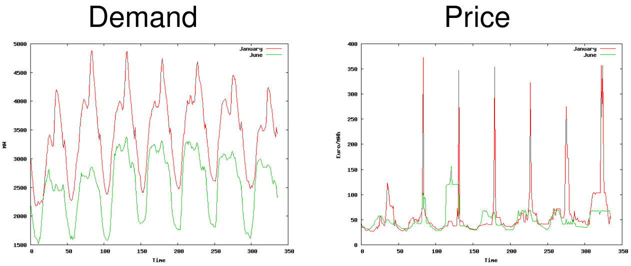


Figure: Electricity Demand and Price, ROI, Comparing January and June data

Background

So far our work has considered the core algorithms to include resource costs into scheduling constraints:

- *An energy cost aware cumulative.* BPPC'10, Bologna, Italy, June 2010.
- *Constraint-based scheduling for reducing peak electricity use.* CompSust'10, Boston, MA, June 2010.
- *A resource cost aware cumulative.* ModRef 2010, St Andrews, Scotland, September 2010.
- *A Family of Resource Constraints for Energy Cost Aware Scheduling*. CROCS 2010, St Andrews, Scotland, September 2010

Background

- We considered an extension of the *Cumulative* constraint
- We extended that work for other resource types: *Disjunctive*, *Parallel-Disjunctive*, *Machine Choice*
- We have proposed different algorithms to compute *lower bounds* on the resource cost of a schedule, and compared their theoretical and practical power
- The best results use an adaptation of the *linear programming model* for the cumulative constraint from [1]. Lower bounds better than 98% of the optimal value can be achieved
- *Reduced cost based filtering* based on these bounds can remove a significant number of domain values

[1] John Hooker, *Integrated Methods for Optimization* (Springer, New York, 2007)

However

- To validate and improve our findings we require test cases on which we can systematically test the performance of our methods
- None of the existing resource constraint benchmarks includes a cost element
- We want to evaluate the quality of different constraint implementations

This Work

Therefore

- We created our own instance generator
- Written in Java
- Produces an XML instance format
- Can be directly integrated into Java code
- Available on the website of the authors

Definition

Constraint `CumulativeCost` expresses the following relationships:

$$\forall\, 0 \leq t < p: \quad pr_t := \sum_{\{i | s_i \leq t < s_i + d_i\}} r_i \leq l \tag{1}$$

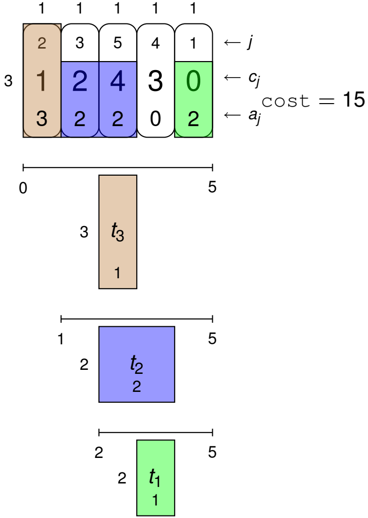
$$\forall\, 1 \leq i \leq n: \quad 0 \leq \underline{s_i} \leq s_i < s_i + d_i \leq \overline{s_i} + d_i \leq p \tag{2}$$

$$\mathrm{ov}(t, pr_t, A_j) := \begin{cases} \max(0, \min(y_j + h_j, pr_t) - y_j) & x_j \leq t < x_j + w_j \\ 0 & \textit{otherwise} \end{cases} \tag{3}$$

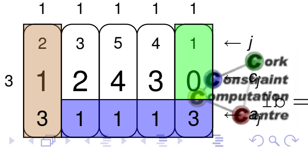
$$\forall\, 1 \leq j \leq q: \quad a_j = \sum_{0 \leq t < p} \mathrm{ov}(t, pr_t, A_j) \tag{4}$$

$$\mathrm{cost} = \sum_{j=1}^{q} a_j c_j \tag{5}$$

Problem and Optimal Solution



LP Solution



LP Lower Bound

$$\texttt{lb} = \min \sum_{j=1}^{q} a_j c_j \quad (6)$$

$$\forall\, 0 \le t < p: \quad pr_t \in [0, l] \quad (7)$$

$$\forall\, 1 \le i \le n, 0 \le t < p: \quad y_{it} \in \{0, 1\} \quad (8)$$

$$\forall\, 1 \le j \le q, \forall\, x_j \le t < x_j + w_j: \quad z_{jt} \in [0, h_j] \quad (9)$$

$$\forall\, 1 \le j \le q: \quad 0 \le \underline{a_j} \le a_j \le \overline{a_j} \le w_j h_j \quad (10)$$

$$\forall\, 1 \le i \le n: \quad s_i = \sum_{t=0}^{p-1} t y_{it} \quad (11)$$

$$\forall\, 1 \le i \le n: \quad \sum_{t=0}^{p-1} y_{it} = 1 \quad (12)$$

$$\forall\, 0 \le t < p: \quad pr_t = \sum_{1 \le i \le n} \sum_{t' \le t < t' + d_i} y_{it'} r_i \quad (13)$$

$$\forall\, 0 \le t < p: \quad pr_t = \sum_{j=1}^{q} z_{jt} \quad (14)$$

$$\forall\, 1 \le j \le q: \quad a_j = \sum_{t=x_j}^{x_j + w_j - 1} z_{jt} \quad (15)$$

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The `DisjunctiveCost` constraint allows one task to be run on a machine at any time. We can describe the constraint by adding

$$\forall\, i, j | i \neq j : \quad s_i + d_i \leq s_j \vee s_j + d_j \leq s_i \tag{16}$$

to constraints (1) -(5).
In the LP/MIP model, we extend constraints (6) - (15) with the condition

$$\forall\, 0 \leq t < p : \quad \sum_{1 \leq i \leq n} \sum_{t' \leq t < t' + d_i} y_{it'} \leq 1 \tag{17}$$

The `ParallelMachineCost` constraint consists of constraints (1) -(5) plus the constraints

$$\forall\, 1 \leq k \leq b,\ \forall\, i,j | i \neq j : \quad m_i \neq m_j \vee s_i + d_i \leq s_j \vee s_j + d_j \leq s_i \tag{18}$$

We can express this condition in the LP/MIP model by adding constraints of the form

$$\forall\, 1 \leq k \leq d,\ \forall\, 0 \leq t < p : \quad \sum_{\{i | m_i = k\}} \sum_{t' \leq t < t' + d_i} y_{it'} \leq 1 \tag{19}$$

to constraints (6) - (15).

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Definition

Constraint `MachineChoiceCost` expresses the following relationships:

$$\forall\, 0 \le t < p: \quad pr_t := \sum_{\{i | s_i \le t < s_i + d_{im_i}\}} r_{im_i} \le l \tag{20}$$

$$\forall\, 1 \le i \le n: \quad 0 \le \underline{s_i} \le s_i < s_i + d_{im_i} \le \overline{s_i} + d_{im_i} \le p \tag{21}$$

$$\mathrm{ov}(t, pr_t, A_j) := \begin{cases} \max(0, \min(y_j + h_j, pr_t) - y_j) & x_j \le t < x_j + w_j \\ 0 & \textit{otherwise} \end{cases} \tag{22}$$

$$\forall\, 1 \le j \le q: \quad a_j = \sum_{0 \le t < p} \mathrm{ov}(t, pr_t, A_j) \tag{23}$$

$$\mathtt{cost} = \sum_{j=1}^{q} a_j c_j \tag{24}$$

Instance Generator

The instance generator is available in the form of a Java jar file *CostInstance.jar* which can be downloaded from

`http://4c.ucc.ie/~thadzic/CostInstance.jar`

To create an instance, execute:

```
java -cp CostInstance.jar Instance <parameters>
```

where <*parameters*> are:

Instance Generator

`-instanceType`	0 - `CumulativeCost`, 1 - `DisjunctiveCost`, 2 - `ParallelMachineCost`
`-n`	number of required tasks
`-m`	number of required areas
`-d_max`	maximum duration of a task
`-r_max`	maximum resource consumption of a task
`-s_diff_portion`	portion of the horizon restricting the start time domain
`-util`	utilization of the total available area
`-cost_distr`	cost distribution, 0 - explicitly given, 1 - random
`-w`	width of each area
`-machineNo`	number of machines for parallel machine instances
`-randomSeed`	initial random seed
`-maxCost`	maximal random cost of an area
`-costFileName`	a valid file name containing a vector of costs (or input "`no-file`")

Parameter: `s_diff_portion`

Let p denote the horizon and s_{max} denote $p \cdot$ `s_diff_portion`. Then the instance generator enforces:

$$0 \leq \underline{s_i} \leq s_i \leq \overline{s_i} \leq \underline{s_i} + s_{max}$$

If `s_diff_portion` is set to a negative value then each task i has a maximal feasible start-time interval $[0, p - d_i]$.

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Parameter: `util`

An integer value between 0 and 100 designating the percentage of the required *utilization*. For `CumulativeCost` and `ParallelMachineCost` the instance generator enforces:

$$l = \frac{\sum_{i=1}^{n} d_i \cdot r_i}{\mathtt{util} \cdot p} \tag{25}$$

where l is a maximal resource level. For `DisjunctiveCost` the generator enforces:

$$p = \frac{\sum_{i=1}^{n} \mathrm{d}_i}{\mathtt{util}}. \tag{26}$$

Note that due to rounding to integer values, exact utilization levels might not be achieved.

Parameter: `cost_distr`

- For *random cost distribution* (`cost_distr`=1), we select a cost for each area from interval $[0, \texttt{maxCost} - 1]$.
- For *explicitly given costs* (`cost_distr`=0), we cyclically repeat vector of costs given in the file `costFileName`. For example, for a vector of costs 10, 20, 30 and $m = 5$ areas, we generate costs $10, 20, 30, 10, 20$.
- For *explicitly given costs* (`cost_distr`=0) and no external file (`costFileName = "no-file"`) we use default, hardcoded vector of electricity costs which consists of 48 values, covering 24 hour period for a particular day on the Irish electricity market.

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XML Output Example


```
<?xml version = "1.0" encoding = "UTF − 8" standalone = "yes"? >
< instance resource − limit = "6" horizon = "21"
  xmlns : xsi = "http : //www.w3.org/2001/XMLSchema − instance"
  xsi : noNamespaceSchemaLocation = "resourcecost.xsd"/ >
< tasks number = "5" >
< task id = "0" start_min = "4" start_max = "4" duration = "3" resource = "2"/ >
< task id = "1" start_min = "1" start_max = "5" duration = "4" resource = "5"/ >
< task id = "2" start_min = "8" start_max = "8" duration = "6" resource = "5"/ >
< task id = "3" start_min = "0" start_max = "10" duration = "3" resource = "2"/ >
< task id = "4" start_min = "3" start_max = "9" duration = "3" resource = "3"/ >
< /tasks >
< areas number = "7" >
< area id = "0" x = "0" y = "0" width = "3" height = "6" cost = "14"/ >
< area id = "1" x = "3" y = "0" width = "3" height = "6" cost = "11"/ >
< area id = "2" x = "6" y = "0" width = "3" height = "6" cost = "7"/ >
< area id = "3" x = "9" y = "0" width = "3" height = "6" cost = "7"/ >
< area id = "4" x = "12" y = "0" width = "3" height = "6" cost = "0"/ >
< area id = "5" x = "15" y = "0" width = "3" height = "6" cost = "7"/ >
< area id = "6" x = "18" y = "0" width = "3" height = "6" cost = "7"/ >
< /areas >
< machines number = "2" >
< machine id = "0" tasks = "2 4 3"/ >
< machine id = "1" tasks = "0 1"/ >
< /machines >
```

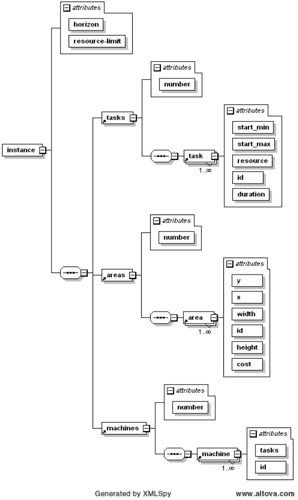

Figure: The XML schema, describing the output format of the output XML file.

Existing Benchmarks for Resource Constraints

- To the best of our knowledge, this is the first generator of scheduling instances involving cost-aware resources
- A number of scheduling instances were collected previously:
  - Patterson: A Comparison of Exact Approaches for Solving the Multiple Constrained Resource, Project Scheduling Problem,1984
  - Alvarez et al: Heuristic algorithms for resource-constrained project scheduling: A review and an empirical analysis, 1989
  - Taillard: Benchmarks for basic scheduling problems,1993
  - Kolisch et al: Characterization and generation of a general class of resource-constrained project scheduling problems, 1995
  - Baptiste and Le Pape: Constraint propagation and decomposition techniques for highly disjunctive and highly cumulative project scheduling problems, 2000

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Existing Benchmarks for Resource Constraints

- The most comprehensive instance generator is presented in the body of work by Kolisch et al.
    - Authors introduce instance generator *ProGen* for the general class of *project scheduling instances*
    - The generator produces *multi-modal* instances over *multiple resources*
    - Tightness of *precedence relationships* is controlled by generating the *activity-on-node* network
    - Scarcity level of resource is controlled through a *resource strength*, $RS \in [0, 1]$.
- In comparison, we could classify our generator as producing *cost-aware*, *single-modal* instances over a *single resource*, *without precedence relationships*. Instead, our generator uses *restricted start times* (`s_diff_portion`) and *utilization* parameter (`util`) to control the tightness and the scarcity level.

Integration into JSR-331

We are integrating our code into the *JSR-331: Constraint Programming API*. We extended a standard standard *Resource* class with *ResourceWithCost* class that supports a cost-declaring method:

```
Var setCost(int x1,int x2,int y1,int y2,int cost)
```

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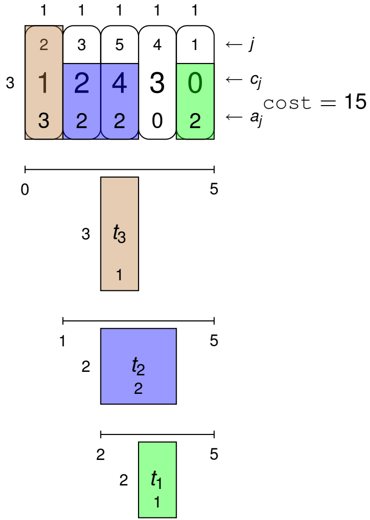
Our Working Example in JSR-331

Problem and Optimal Solution



Our Working Example in JSR-331

```
setStart(0);
setEnd(5);

Activity T1 = activity("Task1", 1);
Activity T2 = activity("Task2", 2);
Activity T3 = activity("Task3", 1);
post(T1, ">=", 2);
post(T2, ">=", 1);

ResourceWithCost myResource = new ResourceWithCost(this, 3);
T1.requires(myResource, 2);
T2.requires(myResource, 2);
T3.requires(myResource, 3);

int[] x1 = {0,1,2,3,4};
int[] x2 = {1,2,3,4,5};
int[] y1 = {0,0,0,0,0};
int[] y2 = {3,3,3,3,3};
int[] cost = {1,2,4,3,0};
```

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Our Working Example in JSR-331

```
utilVars = new Var[5];
for (int i = 0; i < utilVars.length; i++) {
 utilVars[i] = myResource.setCost(x1[i],x2[i],y1[i],y2[i],cost[i]);
}
Var totalCost = scalProd(cost, utilVars);
```

Integration of Instance Generator into JSR-331

```
Instance instance;

public void createInstance() {
 int instanceType = 0;
 int n = 50;
 int m = 10;
 int d_max = 7;
 int r_max = 5;
 double s_diff_portion = 0.5;
 int util = 50;
 int cost_distr = 1;
 int units_per_area = 1;
 int machineNo = 1;
 long randomSeed = 123456;
 int max_cost = 10;
 String costFileName = new String("no-file");

 instance = new Instance(instanceType, n, m, d_max, r_max,
                         s_diff_portion, util, cost_distr,
                         units_per_area, machineNo, randomSeed,
                         max_cost, costFileName);
}
```

Integration of Instance Generator into JSR-331

```
setStart(0);
setEnd(instance.p);

ArrayList<Activity> Tasks = new ArrayList<Activity>();
for (int i=0; i<instance.task.length; i++){
    Activity Ti = activity("Task_"+i, instance.task[i].d);
    post(Ti, ">=", instance.task[i].s_min);
    post(Ti, "<=", instance.task[i].s_max);
    Tasks.add(Ti);
}

ResourceWithCost myResource = new ResourceWithCost(this, instance.l);

for (int i=0; i<instance.task.length; i++){
    Tasks.get(i).requires(myResource, instance.task[i].r);
}
```

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Integration of Instance Generator into JSR-331

```
utilVars = new Var[instance.area.length];
int[] areaUnitCosts = new int[instance.area.length];
for (int i = 0; i < utilVars.length; i++) {
    int x1 = instance.area[i].x;
    int x2 = instance.area[i].x + instance.area[i].w;
    int y1 = instance.area[i].y;
    int y2 = instance.area[i].y + instance.area[i].h;
    int cost = instance.area[i].c;
    areaUnitCosts[i] = cost;
    utilVars[i] = myResource.setCost(x1, x2, y1, y2, cost);
}

Var totalCost = scalProd(areaUnitCosts, utilVars);
```

Conclusions

- We created an instance generator for cost-aware scheduling problems
- Generator produces instances in XML format
- It can be integrated directly into Java code
- Publicly available at

  `http://4c.ucc.ie/~thadzic/CostInstance.jar`
- Currently being integrated into the JSR-331 Constraint Programming API

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