Modelling a Maintenance Scheduling Problem with Alternative Resources

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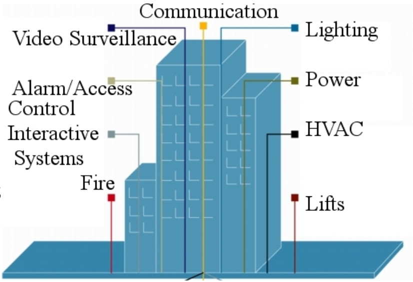
Abstract

- Building maintenance impact on building operation costs, energy use, and productivity of occupants.



- Building maintenance scheduling models
  - Primitive scheduling constraints
  - Global constraints: for alternative disjunctive resources.

- Evaluation shows the basic model is faster in smaller problems; however, the global constraint model scales better.

Outline

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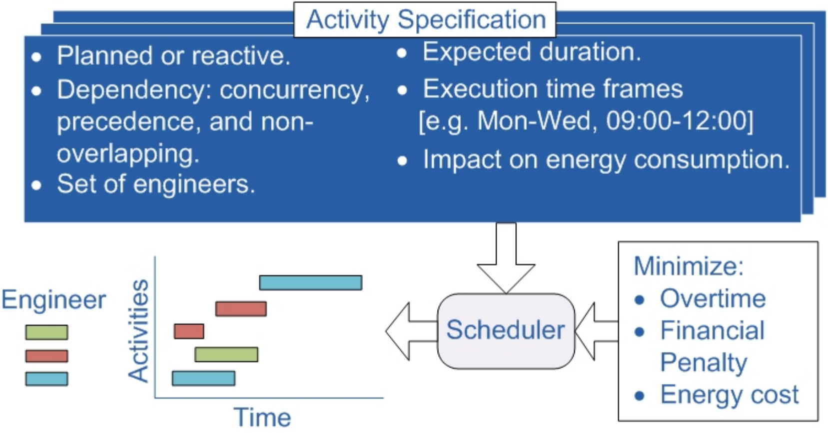
Problem Description



Outline

Basic Model (1/2)

Variables

- A set $T = \{1, \ldots n\}$ of activities and a set $R = \{1, \ldots m\}$ of engineers.
- Domains of variables are integers.
- For each activity $i \in T$:

$start_i$: start time	end_i: end time
d_i: expected duration	c_i: assigned engineer
x_i: scheduling cost.	s_i: links start time to costs

- p : schedule total cost.
- Constants for each activity $i \in T$
  - dt_i: array of start times
  - $tcost_i$: array representing the cost of each start time.

Basic Model (2/2)

Constraints

- $\forall i \in T$: $start_i + d_i = end_i$
- Due to irregular time windows and costs, we add
  - $\forall i \in T$: $dt_i[s_i] = start_i$
  - $\forall i \in T : tcost_i[s_i] = x_i$
- $\forall i, \forall j \neq i : c_i = c_j \rightarrow (end_i \leq start_j) \vee (end_j \leq start_i)$
- Depending on the problem instance, we add constraints
  - Concurrency: $start_i = start_j$
  - Precedence: $end_i \leq start_j$
  - Non-overlapping: $(end_i \leq start_j) \vee (end_j \leq start_i)$
  - $\forall S$, AllDifferent($\{c_i : i \in S\}$)
- Total cost of the schedule: $p = \sum_{i \in T} x_i$
- Objective function is to minimize p.

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Global Constraint Model

- Global constraints capture known relationships between activities and resources to improve propagation.
- For every $i \in T$ and $r \in R$, we define binary allocation variables $e_i^r = \{0,1\}$
  - based on e_i^r, the activity status is **optional**, **regular**, or **disabled**.
- Link c_i with e_i^r through: $\forall i \in T, \forall r \in R : c_i = r \leftrightarrow e_i^r = 1$
- We replace basic disjunctive constraints with the global constraints
  - $\forall r \in R$:AltDisj($[start_1..start_n], [d_1..d_n], [end_1..end_n], [e_1^r..e_n^r]$)
  - $\forall i \in T$: useResources(1, $start_i$, d_i, end_i, $[e_i^1...e_i^m]$, R)
- cumulative($[start_1..start_n], [d_1..d_n], [end_1..end_n], [h_1..h_n]$, m).

Outline

Alternative Disjunctive Constraint (1/3)

- From resource point of view, an activity is optional (Beck and Fox,2000).
- Disjunctive constraint assume activities are assigned to resources before problem solving.
- Extended disjunctive resource filtering algorithms (e.g., Edge Finding) by (Vilim *et. al*,2005) and (Kuhnert,2007) support reasoning for optional activities.
- Three alternative resources filtering rules are used in (Wolf and Schlenker,2004) to enable reasoning on activities with alternative resources.
- We combine work done on optional activities and activities with alternative resources.

Alternative Disjunctive Constraint (2/3)

- AltDisj($[start_1..start_n], [d_1..d_n], [end_1..end_n], [e_1^r..e_n^r]$).
- If each optional activity has a new set of variables defined over every alternative resource, then
  - A variable domain becomes empty? Backtrack (incorrect decision).
  - Variables modify the constraint network and interfere with reformulation methods and search heuristics.
- Hypothetical domain $Dh_i^r := Dm_i = [est_i, lct_i]$, with bound representation
  - est, lct: activity earliest start and latest completion times.

Alternative Disjunctive Constraint (3/3)

- We integrate alternative resources filtering rules in the disjunctive constraint
  - $\forall i \in T : e_i^r = \{0,1\} \wedge |Dh_i^r \cap Dm_i| < min(d_i) \Rightarrow e_i^r := 0$,
    - $min(d_i)$: activity minimum duration.
  - $\forall i \in T : e_i^r = \{0,1\} \wedge |Dh_i^r \cap Dm_i| \geq min(d_i) \Rightarrow Dh_i^r := Dh_i^r \cap Dm_i$

Example

Let activity 1 be with $Dm_1 = [5-11]$. Assume $Dh_1^1 = [5-11]$ and $Dh_1^2 = [8-11]$. If $Dm_1 = [5-7]$ then $Dh_1^2 = \emptyset$ and $e_1^2 = 0$

- Disjunctive resource filtering algorithms are triggered as normal when main and/or hypothetical domains are updated.

Outline

useResources Constraint

- The constraint is defined for activity i and a requirement $1 \leq k \leq m$ as: useResources(k, $start_i$,d_i, end_i, $[e_i^1, ...e_i^m]$, R)
- Integrates the boolean sum constraint $\sum_{j=1..m} e_i^j = k$ or $\sum_{j=1..m} e_i^j \geq k$ over binary allocation variables.
- Updates the activity main time window according to time windows available over alternative resouces.
  - $\forall i \in T, k = 1 : Dm_i := Dm_i \cap \bigcup_{1 \in e_i^r} Dh_i^r$
  - $\forall i \in T, k > 1 : Dm_i := Dm_i \cap \left[\min_{1 \in e_i^r}(k, est_i^r), \max_{1 \in e_i^r}(k, lct_i^r)\right]$

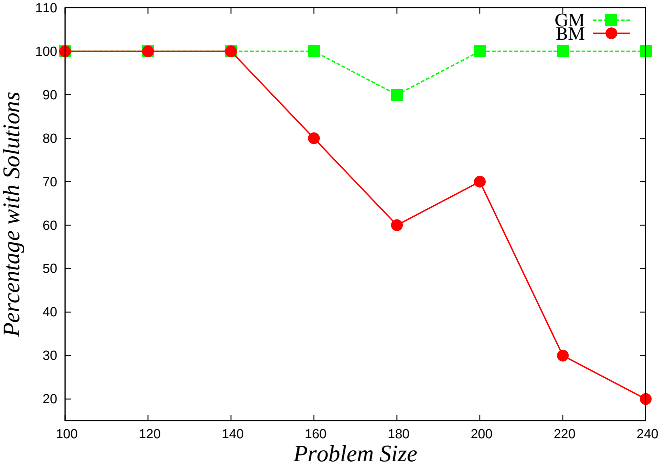
Outline

Experimental Results (1/2)

- Developed the presented models and global constraints in Choco (Laburthe and Jussien,2010).
- Scheduling activities within a time frame of one week.
- Evaluation using randomly generated problems (20, 50, 70, 100, 120) with ten scenarios per problem size
- Set a time limit of ten minutes.
- As expected, results show a significant reduction in the average number of backtracks and nodes explored in the global constraint model.

Run	Avg.FST (Secs)		Avg.LST (Secs)		Avg.TP (Secs)	
	GM	BM	GM	BM	GM	BM
20	0.071	0.027	0.091	0.027	0.119	0.038
50	0.511	0.110	0.828	0.128	0.879	0.156
70	1.126	0.276	2.004	0.355	2.081	0.415
100	2.649	0.859	103.949	40.828	**135.360**	161.572
120	4.019	2.194	**23.284**	43.425	144.436	136.458

Experimental Results (2/2): Larger Problems



Conclusion

- Developed models for the building maintenance scheduling problem using basic constraints and global constraints.
- Presented the modified alternative disjunctive constraint and the new useResources constraint.
    - Can be used in any scheduling problem with alternative resources
- Experimental evaluation shows the basic model is faster in small problems, while the global constraint model scales better.
- Outlook
    - Evaluate performance of the modified/new global constraints using benchmark scheduling problems.
    - Investigate a new three stage strategy inspired from scheduling and bin-packing problems.
    - Improve the constraint model by reformulation of redundant constraints.

Questions