Operator assignment problem in aircraft assembly lines: a new planning approach taking into account economic and ergonomic constraints

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Overview

Overview

Considered problem

A brief problem formulation

There is an aircraft assembly line. How to schedule assembly tasks and assign them to operators optimally? How to satisfy precedence, resource, time and ergonomic constraints?

RCPSP

Resource Constrained Project Scheduling Problem (RCPSP)

Considers resources of limited availability and activities of known durations and resource utilization, linked by precedence relations. The problem consists of finding a schedule of minimal duration by assigning a start time to each activity such that the precedence relations and the resource availabilities are respected. The objective is to minimize the project makespan.

Complexity

The problem is NP-complete in a strong sense (Garey, Johnson 1975).

Industrial motivation

Aircraft companies

- to reduce takt time;
- to minimize the number of human errors;
- to improve working conditions.

Challenges

Operational research

- very high-dimensional instances;
- the basic problem (RCPSP) is known to be NP-hard.

Ergonomics

- scoring methods for long work cycles (in contrast to the repetitive environment for other assembly lines e.g. automotive);
- consideration of cognitive and physical ergonomic factors.

Ergonomics

Physical ergonomics

- Loaded body parts: neck, trunk, upper limbs, whole body.
- Load types: static postures, movements, action forces, strains.
- Load parameters: duration, force intensity, hand position,
- Personal factors: age, sex, height.

Ergonomics

Physical ergonomics evaluation methods

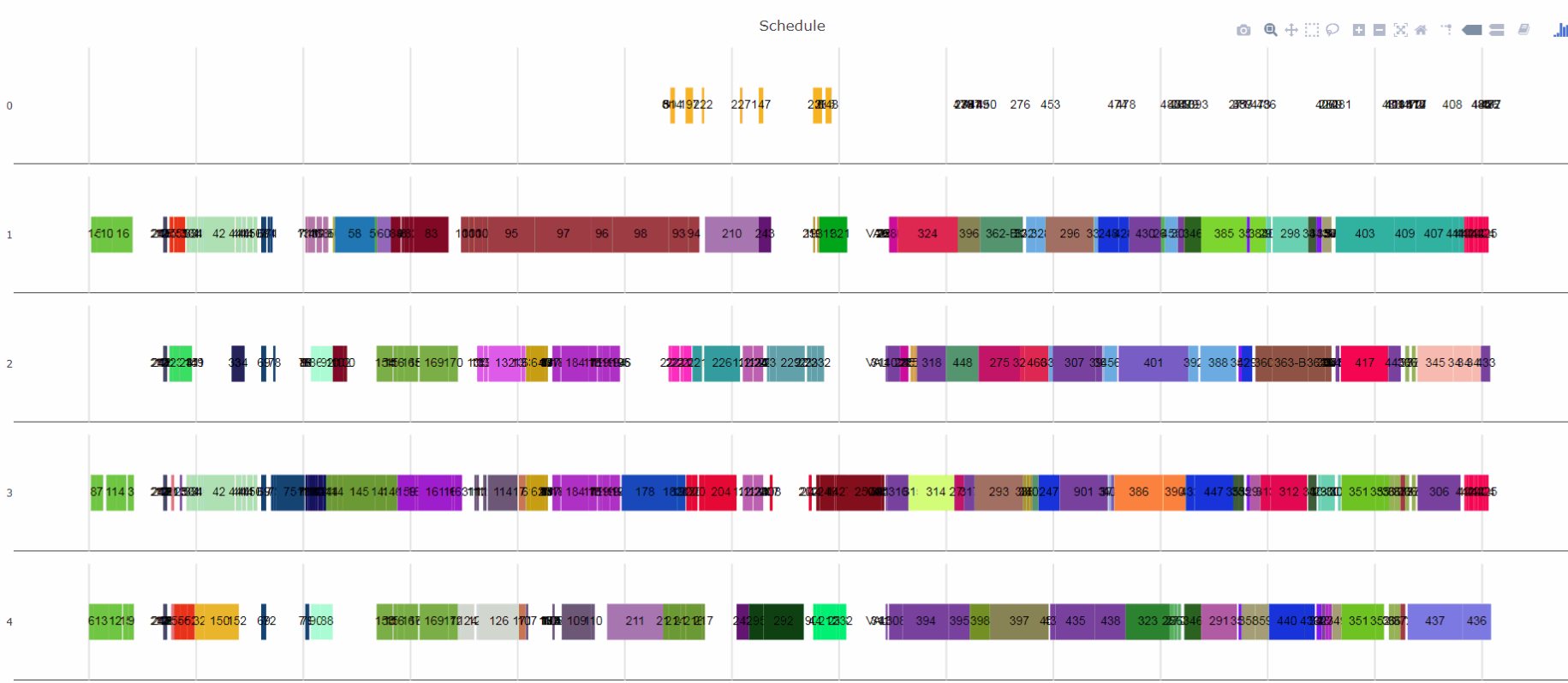
method name	description	papers	focus	individual parameters	neck	trunk	hands	legs	whole body	noise
NIOSH-Eq	NIOSH lifting equation	Waters, Putz-Anderson, Garg, & Fine, 1993	lifting tasks						+	
JSI-L	Job Strain Index	Liles, Deivanayagam, Ayoub, & Mahagan, 1984	lifting tasks	+					+	
RULA	Rapid Upper Limb Assessment	McAtamney & Corlett, 1993	assessment of postures		+	+	+			
REBA	Rapid Entire Body Assessment	Hignett & McAtamney, 2000	assessment of postures		+	+	+	+		
OCRA	Occupational Repetitive Action tool	Occhipinti, 1998	risk assessment of upper extremities				+			
JSI	Job Strain Index	Moore & Garg, 1995	risk assessment of upper extremities				+			
DND	Daily Noise Dosage	OSHA, 1993; NIOSH, 1998	noise							+
EAWS	Ergonomic Assessment Work Sheet	Schaub, Caragnano, Britzke, & Bruder, 2013	general risk assessment tools	+	+	+	+	+	+	
EnerExp	Energy Expenditure Method	Garg, Chaffin, & Herrin, 1978	general risk assessment tools	+					+	

Ergonomics

Cognitive ergonomics

- Type of actions: motor vs cognitive.
- Worker's personal factors: skill, age, sex.
- Learning, fatigue and motivation effects.

Operator assignment problem



Operator assignment problem

Data

- H – planning horizon (takt time);
- N – set of tasks;
- O – set of operators;
- S – set of operator skills, each operator has only one.

Operator assignment problem

Tasks

- r_j – release time;
- p_j – processing time;
- a_{jx} – amount of resource $x \in R$ required to process task j;
- b_{js} – number of operators with skill $s \in S$ required to process task j.

Operator assignment problem

Physical ergonomic risks

- M – set of ergonomic risk evaluation methods;
- erg_{mj} – ergonomic score evaluated by method $m \in M$ for one time unit of task $j \in N$;
- U_{mo} – an upper bound on total ergonomic impact for operator o evaluated by method m;

Overview

Constraint programming model for the aggregated demand

Decision variables

- $interval_j$ – interval variable associated to the execution of task $j \in N$, i.e. $interval_j = [S_j, C_j)$;

Objective function

The objective is to find a schedule π^* with the minimal makespan i.e.

$$\min_{\pi} \max_{j \in N} (S_j(\pi) + p_j). \quad (1)$$

Constraint programming model for the aggregated demand

Constraints

The task interval size has to be equal to the task processing time, i.e.

$$\forall j \in N : |interval_j| = p_j. \tag{2}$$

Task processing intervals must satisfy the precedence relations with time lags, i.e.

$$\forall e_{ji} \in E : S_j(\pi) + l_{ji} \leq S_i(\pi). \tag{3}$$

Constraint programming model for the aggregated demand

Resource capacity constraints

Resource capacity constraint:

$$F(x,t) = \sum_{j \in N} a_{jx} \cdot f(interval_j, t), \tag{4}$$

where $f(interval_j, t) = 1$ if $t \in interval_j$ and $f(interval_j, t) = 0$ otherwise.
Then resource capacity constraint can be formulated as

$$\forall x \in R, t: \ c_x \geq F(x,t). \tag{5}$$

MIP model for Operator assignment problem

Decision variables

- $assign_{oj}$ – binary variable equals to 1 if operator $o \in O$ assigned on task $j \in N$, otherwise $assign_{oj} = 0$.

Objective function

The objective function is to minimize the highest ergonomic impact calculated for each pair ($m \in M$, $o \in O$).

$$\min \max_{m \in M, o \in O} \sum_{j \in N} assign_{oj} \cdot erg_{mjs_o} \tag{6}$$

MIP model for Operator assignment problem

Constraints

For each task $j \in N$, the number of operators with skill $s \in S$ has to be equal to b_{js}

$$\forall j \in N,\ s \in S: \sum_{o \in O: s_o = s} assign_{oj} = b_{js}. \tag{7}$$

The total ergonomic impact of the tasks assigned to the same operator $o \in O$ measured by method $m \in M$ has to be less than the defined critical level U_{mo}, i.e.

$$\forall m \in M, o \in O: U_{mo} \geq \sum_{j \in N} erg_{mjs_o} \cdot assign_{oj}. \tag{8}$$

MIP model for Operator assignment problem

Incompatibility constraints

Since the schedule of the tasks is known, the incompatible sets E of tasks can be defined, i.e. the sets of the tasks e that cannot be performed by the same operator.

$$\forall e \in E, o \in O : \sum_{j \in e} assign_{oj} \leq 1. \quad (9)$$

Overview

Numerical experiments

Implementation

Software: IBM ILOG CPLEX 12.6
Processor: Intel(R) Core(TM) i5-4670 3.40GHz
RAM: 16 GB

Numerical experiments

Instance 1

- 289 tasks;
- 7 operators with 3 skills;
- 3 ergonomic evaluation methods.

Optimal solution found in 18 minutes.

Numerical experiments

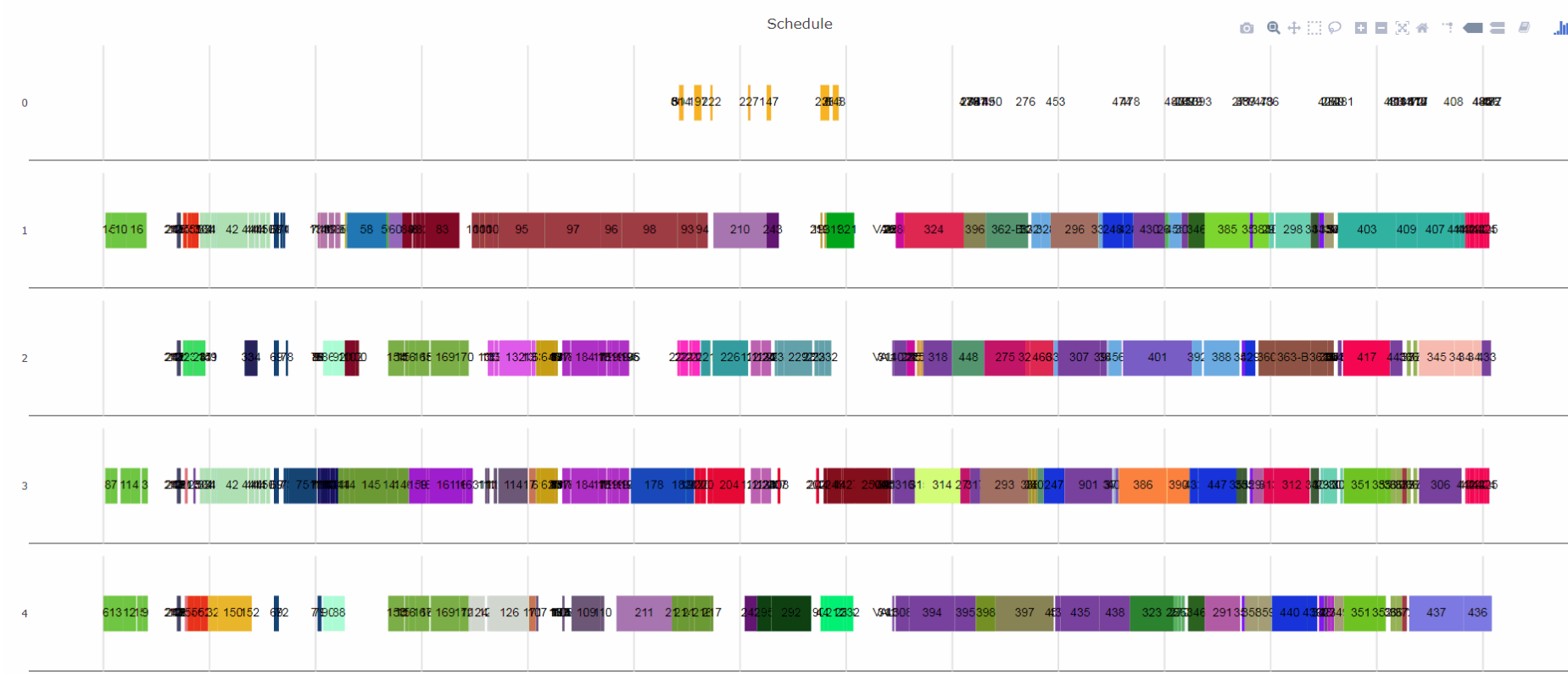
Instance 2

- 447 tasks;
- 5 operators with 2 skills;
- 3 ergonomic evaluation methods.

Optimal solution found in 20 minutes.

Numerical experiments

Gantt chart for the optimal solution for instance 2



Overview

Conclusion

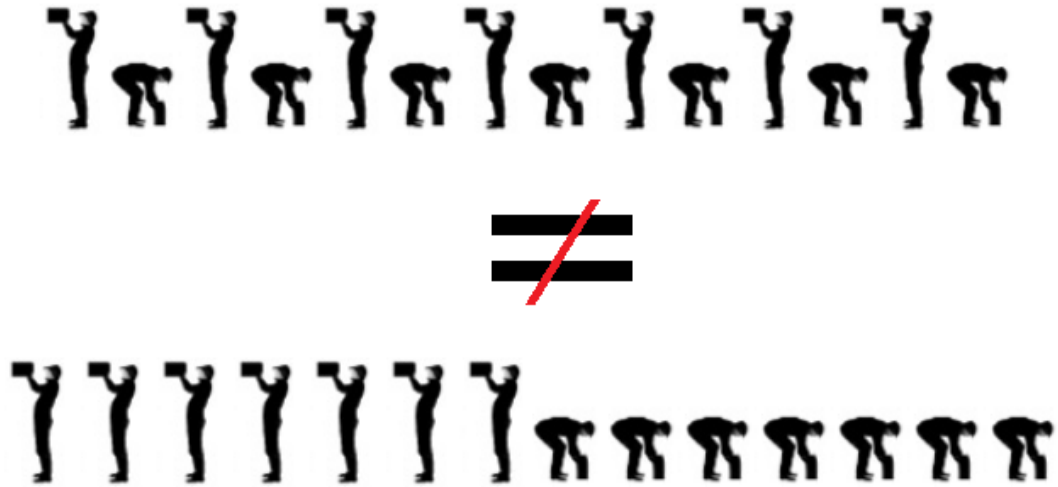
Obtained results

- Operator assignment problem for aircraft assembly line subject to ergonomic constraints was considered;
- Constraints programming and Integer linear programming models were developed;
- Optimal solutions were found for two industrial instances in reasonable time.

Conclusion

Future perspectives

- Consideration of cognitive and physical ergonomic factors together.
- Evaluation of impacts of sequences of tasks.



Thanks!
Questions?

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