Optimization of an industrial aluminum parts casting process based on simulated annealing

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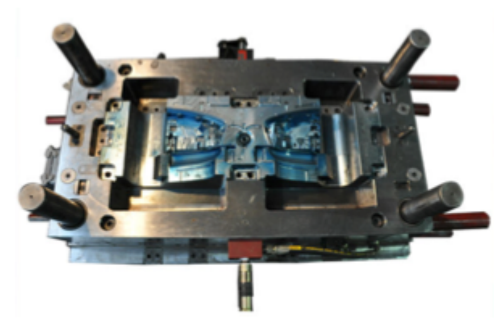
Abstract. In this work, we aim to optimize an aluminum casting process to create parts for the automotive sector. The company has six aluminum injection molding machines to produce different parts. There are a total of 81 injection molds for 160 different types of parts, including molds for a single part, two or even three different parts. We must account for constraints regarding which molds can be used in each machine, mold changes (up to four a day, which may be non-simultaneous mold or not coincide with worker shift changes), stock of parts, time set aside for machine breakdowns and scheduled machine maintenance processes.

The objectives for a two-week planning period are to maximize accumulated demand satisfaction in the two weeks of the different pieces, minimize the delay in parts production with respect to the specified delivery date, minimize energy costs (electricity and gas consumption) and minimize the total number of mold changes performed. A heuristic is used to derive an initial feasible solution. Simulated annealing is then applied to derive the optimal solution. To do this, different neighborhood definitions are created based on the total or partial elimination or introduction of injections or on injection mold changes, whose use dynamically varies throughout the search process.

PROBLEM DESCRIPTION

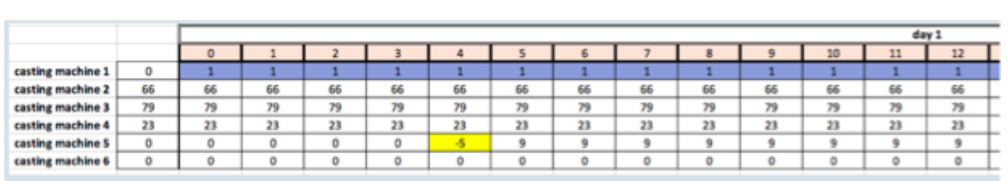
- 6 aluminum injection molding machines:
  - 3 Frech Deck 315DV
  - 1 Frech Deck 450RC
  - 1 Frech Deck 720RC
  - 1 Buehler 630
- 81 injection molds, including molds for a single part, two (50% each) or three different parts.
- 160 different types of parts (automotive sector)
- Daily demands
- Time period → two weeks

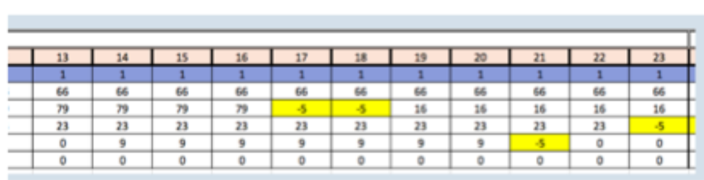


- Available molds (81).
- Certain molds can be used in each machine → assignment matrix.
- Up to four a day mold changes, which may be non-simulta-neous mold or not coincide with worker shift changes (5:00-7:00, 13:00-15:00 and 21:00-23:00) .
- Maximum stock of parts.
- Time set aside for machine breakdowns (6%)
- Scheduled machine maintenance processes
  - One day maintenance → Non operation period
  - Three days maintenance → 40% operation capability
- Only some machines may be available on weekends.

SIMULATED ANNEALING

Two-week planning period Integer 6 ×336 matrix





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Leyend	
0	stopped machine
1	machine casting mold i=1,…81
…	
81	
-2	festive
-3	maintenance
-4	time set aside for machine breakdowns
-5	mold change

Initial feasible solution x_0 → Heuristic (use the injection mold including the most demanded part if possible) → Deterministic feasible solution

Moves			Stopping criterion	
complete removing	partial removing	Insertion	% improvement	iterations
0,1	0,4	0,5	0,0005	1000

Weights in fitness function				T update	
demands	delays	costs	mold changes	L	alpha
0,5	0,4	0,05	0,05	1500	0,95

Initialization: Do $x^* = x_0$, $f^* = f(x_0)$, $i = 0$. Select the initial temperature $t_0 = T$ (t_i temperature in step i)

Repeat until stopping criterion is satisfied:

Randomly generate $y_i \in N(x_i)$
If $f(y_i) - f(x_i) \leq 0$, then

$x_{i+1} = y_i$
If $f(x^*) > f(y_i)$, then $x^* = y_i, f^* = f(y_i)$

Else

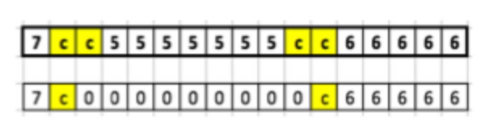
$p \sim U(0,1)$
If $p \leq e^{-(f(y_i)-f(x_i))/t_i}$, then $x_{i+1} = y_i$
Else $x_{i+1} = x_i$

Update temperature, $i = i + 1$

- F_1: minimize the **unmet demand** in the two weeks of the different parts.
- F_2: minimize the **delay** in parts production with respect to the specified delivery date (number of parts × number of days)
- F_3: minimize energy **costs** (electricity and gas consumption)
- F_4: minimize the total number of **mold changes** performed

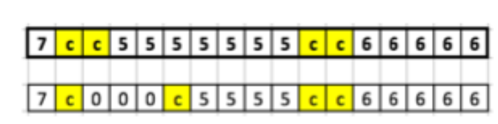
$$\min \; F = w_1F_1 + w_2F_2 + w_3F_3 + w_4F_4$$

COMPLETELY REMOVING AN INJECTION



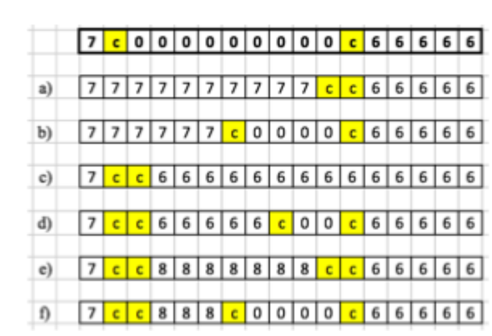
Randomly selected injection

PARTIALLY REMOVING AN INJECTION



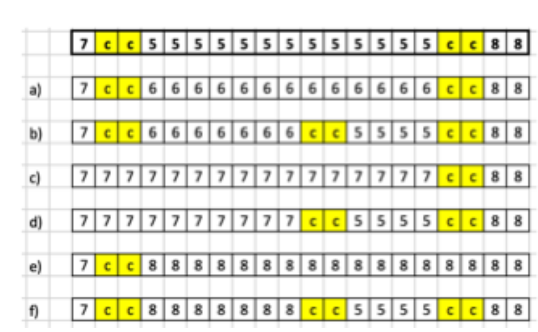
Randomly selected injection and removing proportion

INSERT AN INJECTION



Random selection of non-operation period and the mold to inject

MUTATION

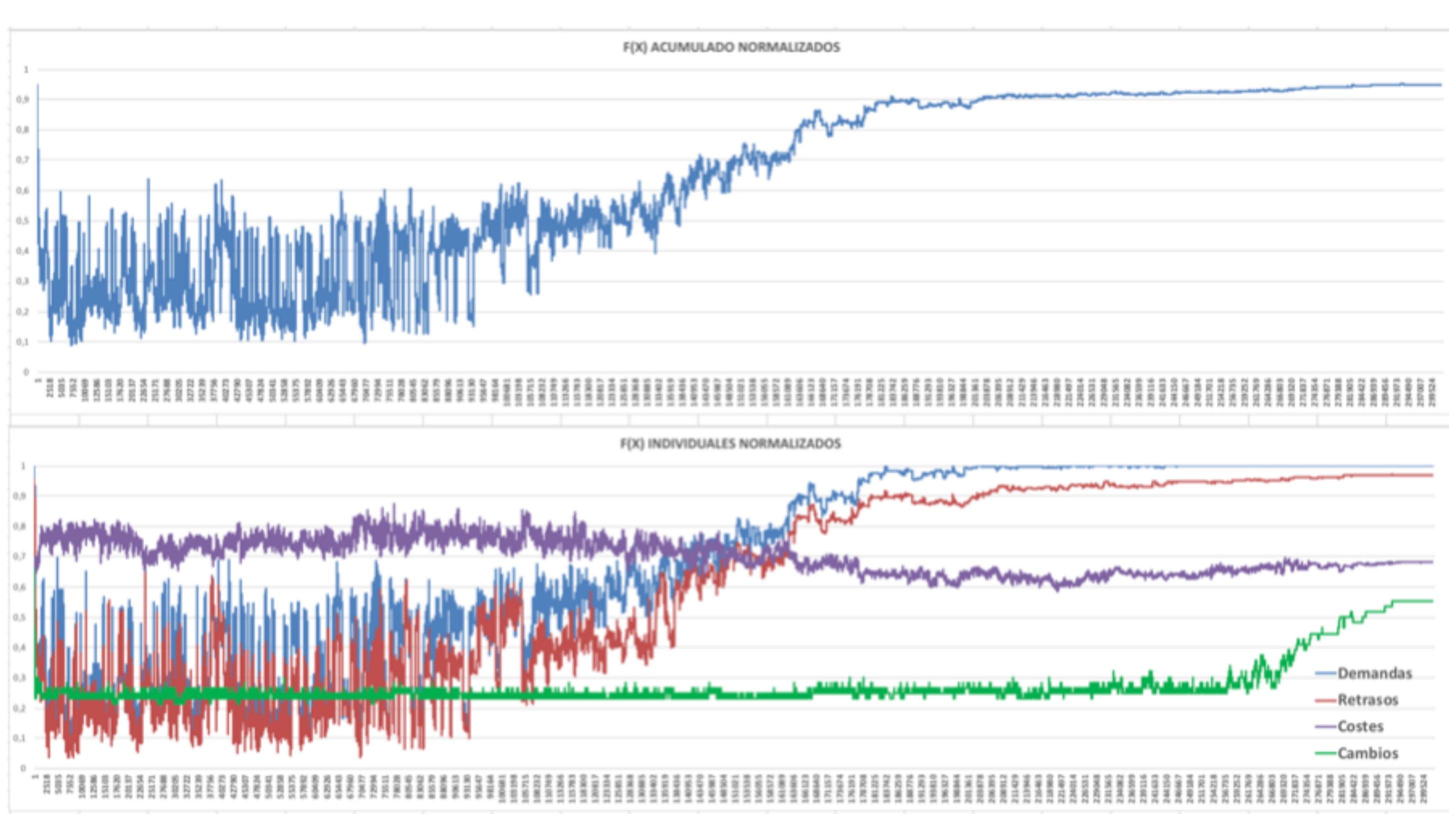


Random selection of the injection period and mold to inject

ILLUSTRATIVE EXAMPLE

Instance description

- *Time period:* Nov 20th – Dec 3rd 2017
- *Number of demanded parts*: **33** (out of 160)
- *Total demand:* **224864**
- Empty stocks.
- First Sunday and the second weekend are festive.
- The first Saturday only the injection machines 2, 4 and 6 are available
- Three days maintenance process in machine 1 from Wednesday to Friday in the first week (40% operation capability).
- A day maintenance in machine 2 on Tuesday in the first week.



Optimal solution

Initial solution

Unmet demand:	540 (0.24%)
Delays (unit * day):	83092
Costs:	21552.37
Number of mold changes:	19
Fitness:	**0.947618**

Iterations: 301499
Execution time: 3 minutes

Optimal solution

Unmet demand:	0
Delays (unit * day):	55351 (in 14 pieces)
Costs:	20630.84
Number of mold changes:	25
Fitness:	**0.949996**