INFORMS Student Competition

Agustín Chiu, Martín Costabal, Macarena Navarro, Joaquín Ossandón, Sebastián Vásquez

Pontificia Universidad Católica de Chile

April 27th, 2020 – Virtually in Denver, CO

John R. Birge, Committee Chair

Levin Distinguished Service Professor of Operations Management

University of Chicago, Booth School of Business

Willem-Jan Van Hoeve, Committee Chair

Carnegie Bosch Professor of Operations Research

Carnegie Mellon University, Tepper School of Business

Dinámicas de grupo

- Comienzo: Fines de diciembre. Fin: 27 de Enero.
- Heterogeneidad.
- Dos equipos: Simulación y métodos para la toma de decisiones.
- Reuniones grupales semanales.
- Últimas semanas de Enero: ¡Ardió Roma!

Aprendizajes

- Armar un buen equipo: Habilidades, responsabilidad, motivación.
- Tener tolerancia al fracaso y superación.
- Confiar en las habilidades del equipo.
- Investigar, pedir ayuda y trabajar mucho.

Advisors

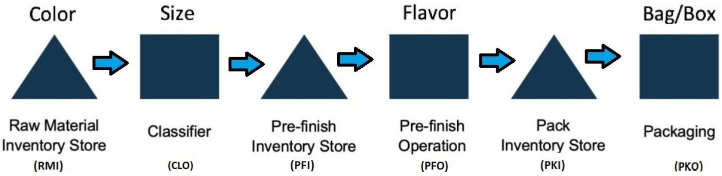
  

Contents

Contents

Context

- Five manufacturing locations: Columbus, Detroit, Green Bay, Omaha, and Springfield.
- Independent work, overall demand.
- Demand of SKUs (color, size, flavor, type of package).
- Transportation between locations, before manufacturing process.

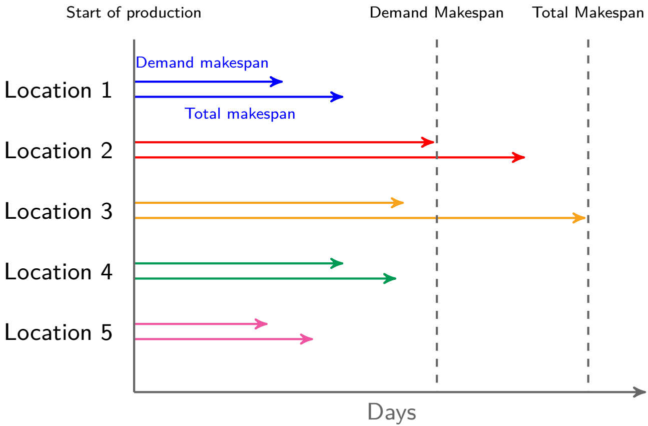


Manufacturing process. Source: ISC, 2019

JBM's problem

Task and objective

- Design a list of work orders to cover overall demand.
- Trade off between demand coverage, overall cost, and makespans.

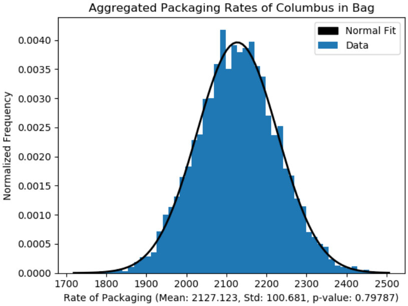


Key assumptions

- **Transportation**
  - One truck and one trip per location.
  - Cost depends linearly on the quantity transported.
  - No transfers after production starts.
- **Production**
  - No bin contamination allowed.
  - Bins can be re–filled and partially emptied.

Data

- D'Agostinos & Pearson's Normal distribution fit for process rates (95% level of confidence).
- Aggregated process rates per process and location (t–test and F–test).
- Maximum coefficient of variation $(\frac{s}{\bar{x}})$: 22.8%.



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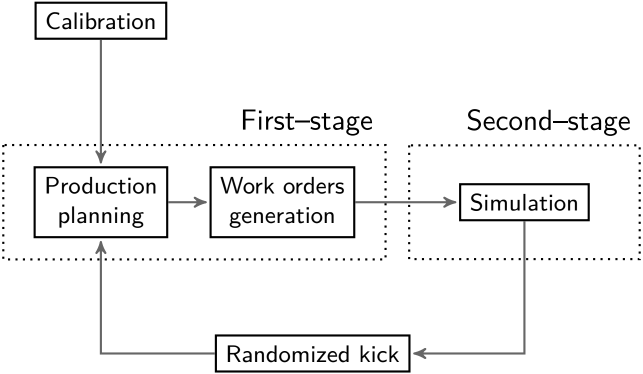
Solution approach



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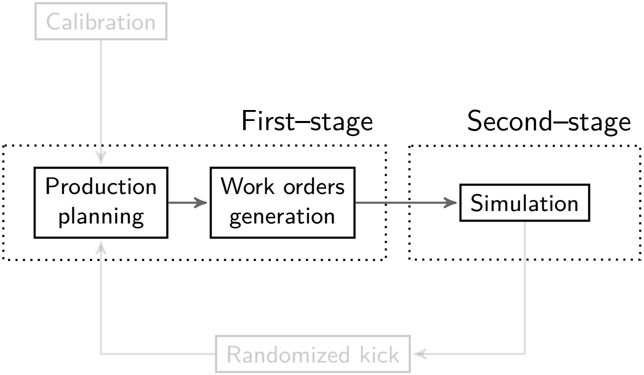

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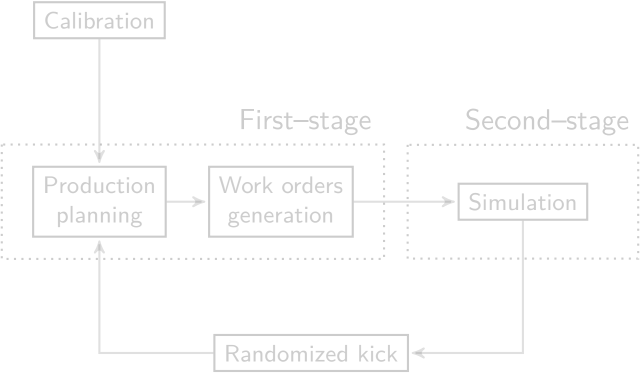
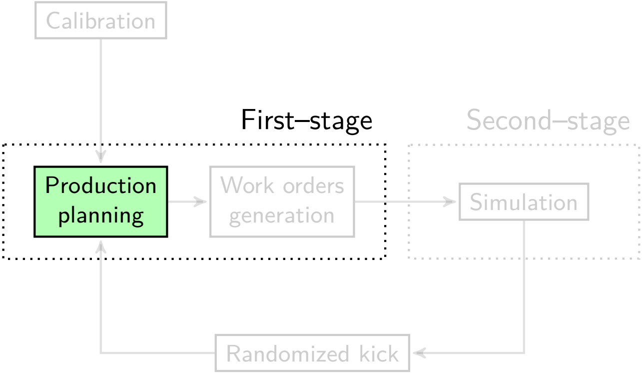
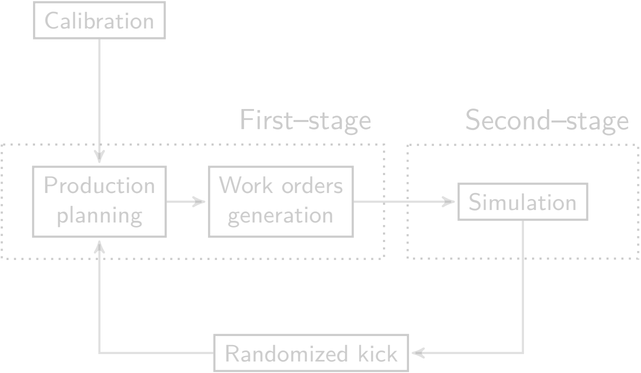


Production planning

First–stage problem

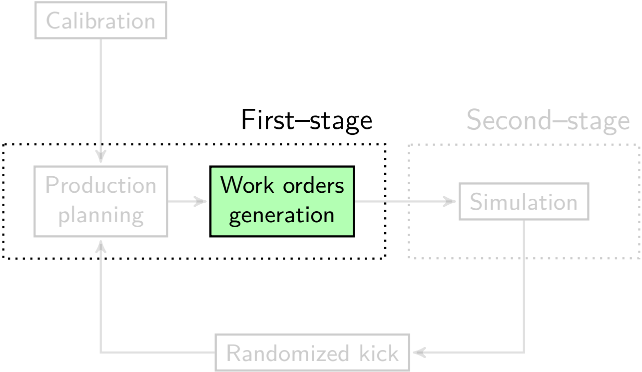


- Purpose: Assign initial RMI and local demands.
- MIP.
- Initial production time approximation.

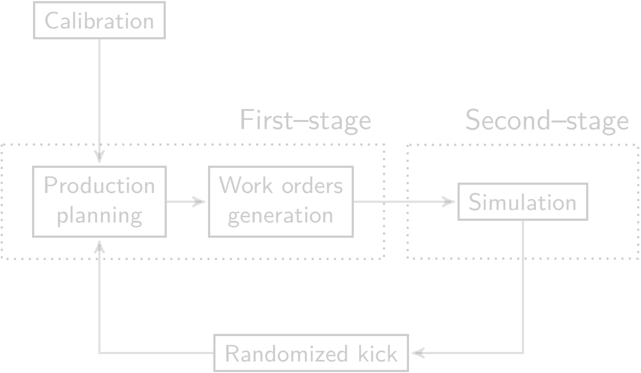

Calibration
First–stage
Second–stage
Production planning
Work orders generation
Simulation
Randomized kick

Work orders generation

First–stage problem



- Purpose: Design work orders per location.
- Iterative procedure.
- Color ranking.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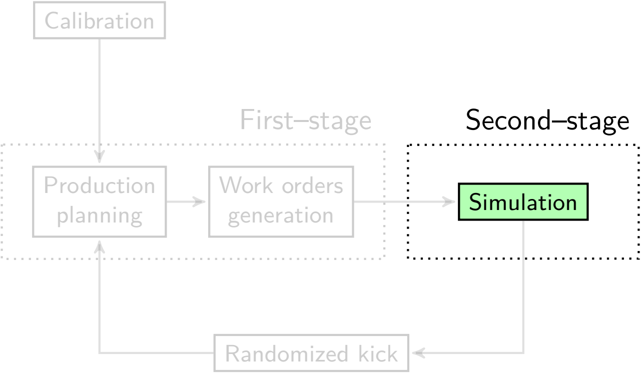
Simulation

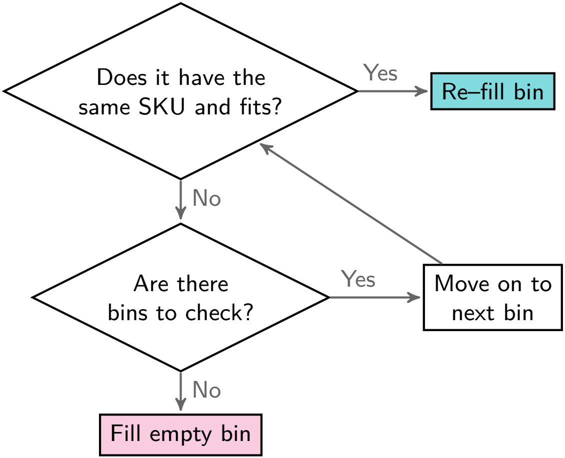
Second–stage problem



- Purpose: Compute real makespans.
- Discrete Event Simulation.
- "Push" Policy.

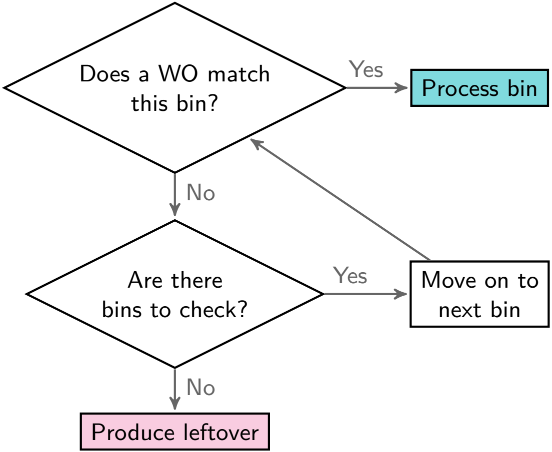
Simulation: Bin filling

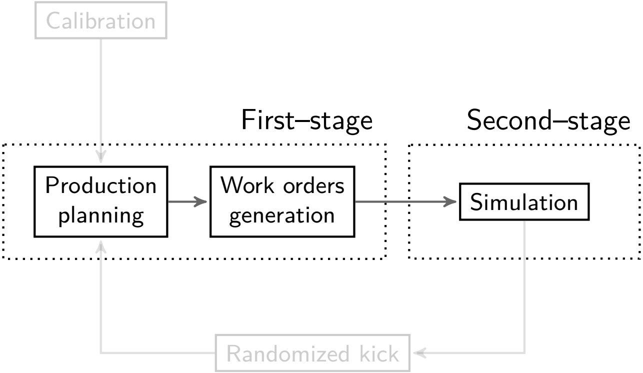
Second–stage problem



Simulation: Bin emptying

Second–stage problem

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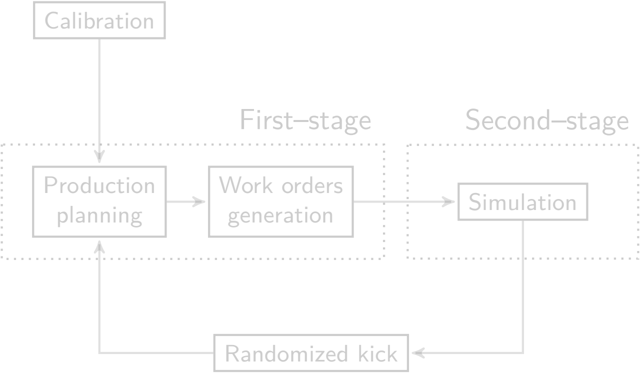
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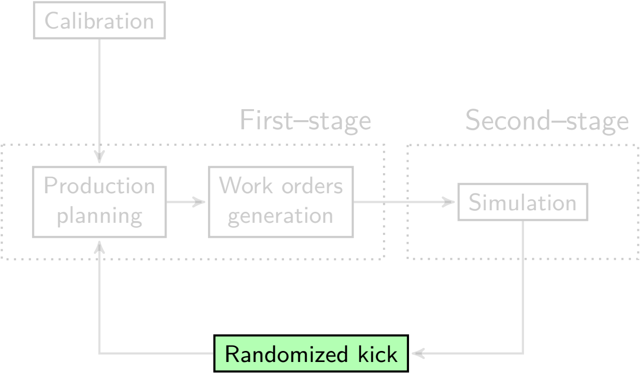
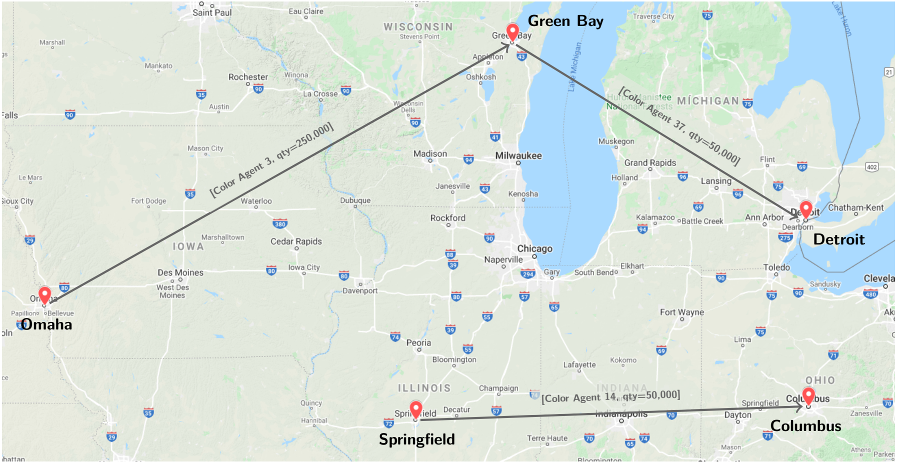


- Purpose: Explore MIP's domain to obtain better feasible solutions.
- Randomized cut generation procedure.

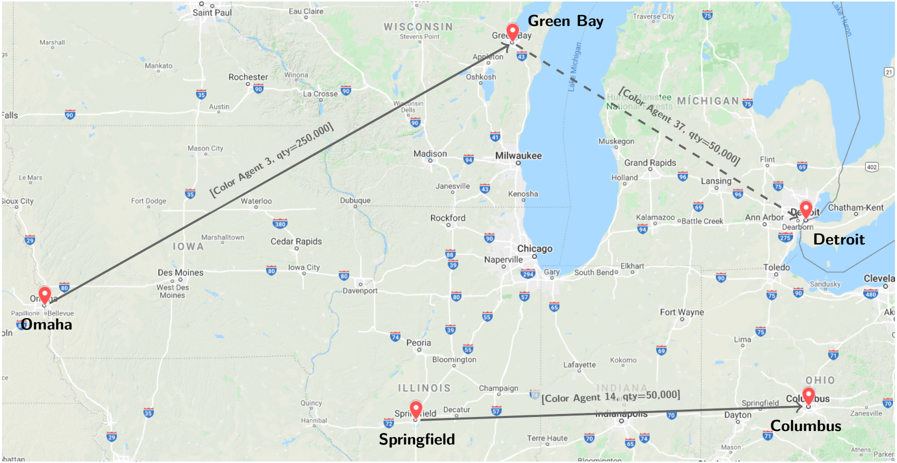
Randomized kick

Initial feasible raw material transfer



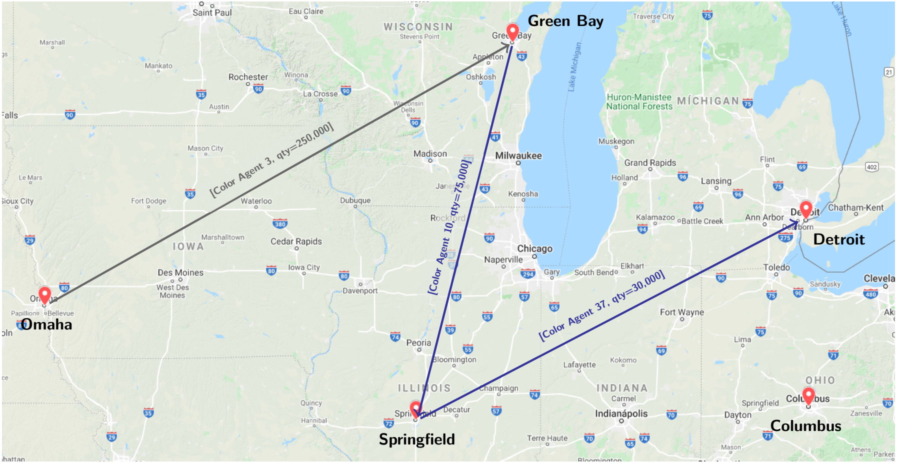
Randomized kick

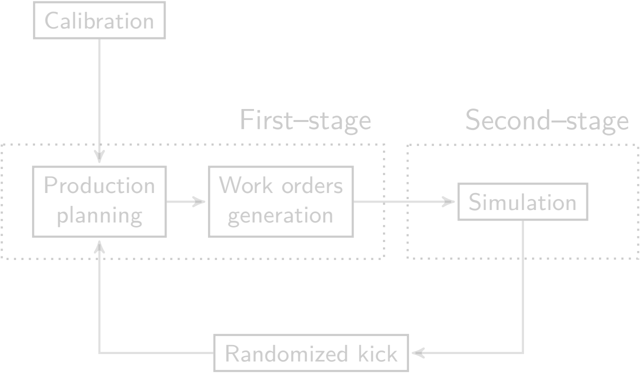
Green Bay–Detroit transfer forbidden



Randomized kick

Raw material transfer re–optimization

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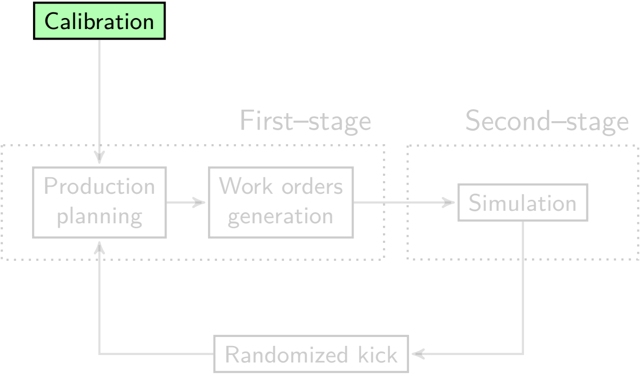
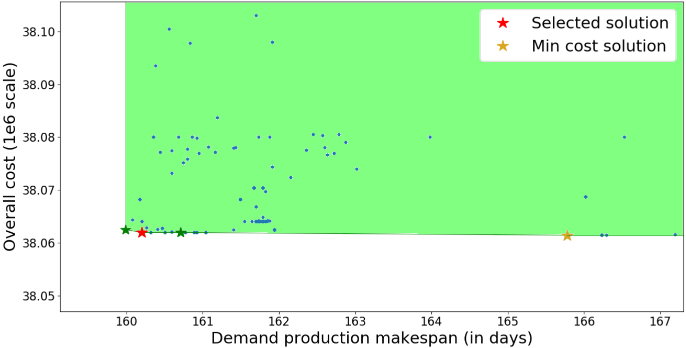
Calibration



- Purpose: Tune production time parameters.

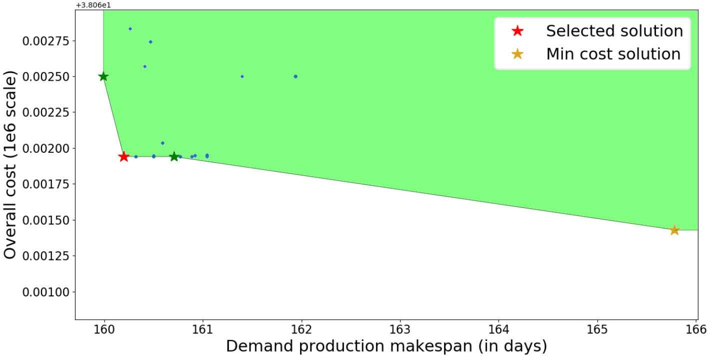
Contents

Solution selection



- Trade off between overall cost and demand makespan.
- Based on average rates.

Solution selection



- Trade off between overall cost and demand makespan.
- Based on average rates.

Solution selection

- **Selected solution ★**
  - Demand makespan: 160 days.
  - Total makespan: 164 days.
  - Overall cost: $38,061,940.
  - Transfers: Springfield, Columbus and Detroit to Omaha.

- **Cheapest solution covering demand ★**
  - Overall cost: $38,061,430.

- **Solution's validation**
  - Simulated demand makespan: 162 days.
  - Simulated total makespan: 166 days.
  - Optimality Gap (w.r.t. simulation relaxation): 3%

Further analysis

- **Detected bottlenecks after simulation**
  - Detroit defines total makespan. Columbus follows.
  - Bottleneck in PFO: 97% of utilization rate.

- **Total makespan reduction**

+ 1 PFO machine in Detroit:

(-4) days.

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+ 1 PFO machine in Columbus:

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+ 1 PKO–Bag machine in Detroit and Columbus:

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+ 1 PFO machine in Columbus:

(-6) days.

+ 1 PKO–Bag machine in Detroit and Columbus:

(-9) days.

+ 1 PKO–Box in Detroit and Columbus + double CLO rate in each location:

(-65) days.

Further analysis

- One extra transportation truck:
  (-\$18,300) cost.
  (-2) days.

- MIP can solve (to optimality) instances with up to 70 color agents or 6 location within 600 seconds.

Contents

Insights for Manufacturing Executive JB Team

Investing in additional machines for process bottlenecks reduces makespan

1 extra PFO machine in Detroit reduces total makespan by 4 days.

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Insights for Manufacturing Executive JB Team

- Investing in additional machines for process bottlenecks reduces makespan
  - 1 extra PFO machine in Detroit reduces total makespan by 4 days.
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- Investing in RMI bins for Omaha can reduce costs and total makespan: Highest throughput, lowest unit production cost, and one of the lowest total makespan.

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  - 97% of utilization rate for process bottleneck machines in Detroit.

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- Color ranking can be helpful when overall demand cannot be covered.

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- Following the "Push" policy can reduce leftover material production and increase utilization rates.
  - 97% of utilization rate for process bottleneck machines in Detroit.
- Color ranking can be helpful when overall demand cannot be covered.
- The valid lower bound can be used to implement a pruning strategy.

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Initial solution approaches

- MIP to model the complete process.
- IP to model the complete process, based on Flow Shop Scheduling Problem and Capacity Indexed Vehicle Routing Problem.

RMI initial inventory statistics

Location	Remaining capacity	Empty RMI bins
Columbus	7.33%	2
Detroit	9.54%	2
Green Bay	64.24%	1
Omaha	22.43%	3
Springfield	9.37%	2

Processing rates statistics (pounds/hour)

Average processing rates. Std. Dev. between parenthesis

Process	Detroit	Columbus	Green Bay	Springfield	Omaha
CLO	3,420 (0)	2,280 (0)	2,050 (0)	1,260 (0)	4,440 (0)
PFO	1,349 (150)	759 (100)	850 (120)	1,139 (99)	1,199 (80)
PKO–Bag	2,999 (528)	2,400 (373)	1,795 (304)	1,194 (272)	3,590 (551)
PKO–Box	3,081 (502)	2,468 (385)	1,846 (302)	1,228 (255)	3,693 (537)

Production planning step

MIP

$$\min \quad \lambda_1 \cdot (\tau_{RMI} + \tau_{OB}) + \lambda_2 \cdot CT + (1 - \lambda_1 - \lambda_2) \left(\sum_{c \in C,\ f \in F,\ p \in P} \alpha^p_{cf} \right) \tag{1}$$

$$\text{s. t.} \quad x^p_{bc} \leq \kappa^p_{RMI} \cdot z^p_{bc} \qquad p \in P,\ c \in C,\ b \in B^p_{RMI} \tag{2}$$

$$\sum_{b \in B^p_{RMI}} x^p_{bc} = \sum_{b \in B^p_{RMI}} O^p_{bc} + \sum_{a \in P \setminus \{p\}} (y^c_{ap} - y^c_{pa}) \qquad p \in P,\ c \in C \tag{3}$$

$$y^c_{ab} \leq 500,000 \cdot \bar{y}^c_{ab} \qquad c \in C,\ a, b \in P : a \neq b \tag{4}$$

$$\sum_{c \in C,\ a \in P \setminus \{p\}} \bar{y}^c_{pa} \leq 1 \qquad p \in P \tag{5}$$

$$\sum_{c \in C} z^p_{bc} \leq 1 \qquad p \in P,\ b \in B^p_{RMI} \tag{6}$$

$$\sum_{p \in P} d^p_{csfr} = D_{csfr} \qquad c \in C,\ s \in S,\ f \in F,\ r \in R \tag{7}$$

$$\sum_{f \in F,\ r \in R} \frac{d^p_{csfr}}{\phi_{cs}} \leq \sum_{b \in B^p_{RMI}} x^p_{bc} \qquad c \in C,\ s \in S,\ p \in P \tag{8}$$

$$\sum_{r \in R} \left(\frac{d_{csfr}}{\phi_{cs}} - \frac{d_{cs'fr}}{\phi_{cs'}} \right) \leq \alpha^p_{cf} \qquad p \in P,\ c \in C,\ f \in F,\ s, s' \in S : s \neq s' \tag{9}$$

$$\tau_{RMI} \geq T^p \left(\sum_{b \in B^p_{RMI},\ c \in C} x^p_{bc} \right) \qquad p \in P \tag{10}$$

$$\tau_{OB} \geq T^p \left(\sum_{c \in C,\ s \in S,\ f \in F,\ r \in R} d^p_{csfr} \right) \qquad p \in P \tag{11}$$

$$CT = CT_{\text{bag}} + CT_{\text{box}} + CT_{\text{transport}} \tag{12}$$

$$CT_{\text{bag}} = \sum_{p \in P} C^p_{\text{bag}} \cdot \sum_{c \in C,\ s \in S,\ f \in F} \frac{d^p_{csf(\text{bag})}}{100} + \sum_{p \in P} \frac{\sum_{b \in B^p_{RMI},\ c \in C} O^p_{bc} - \sum_{c \in C,\ s \in S,\ f \in F,\ r \in R} d^p_{csfr}}{100} \tag{13}$$

$$CT_{\text{box}} = \sum_{p \in P} C^p_{\text{box}} \cdot \sum_{c \in C,\ s \in S,\ f \in F} \frac{d^p_{csf(\text{box})}}{100} \tag{14}$$

$$CT_{\text{transport}} = \sum_{a,p \in P: a \neq p,\ c \in C} \frac{3.5}{50,000} \cdot y^c_{ap} \cdot \text{dist}_{ap} \tag{15}$$

$$x, y, d, \tau_{RMI}, \tau_{OB}, \alpha, CT_{\text{bag}}, CT_{\text{box}}, CT_{\text{transport}} \geq 0 \tag{16}$$

$$\bar{y} \in \{0,1\}^{C \times P \times P}. \tag{17}$$

Production planning step

Calibration

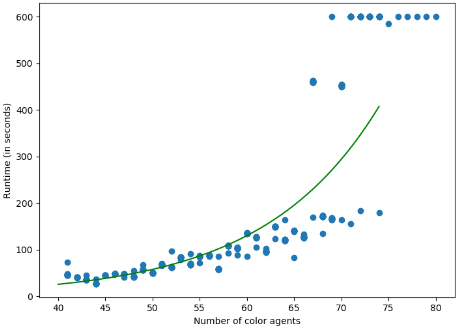
- To better estimate $T^p(x)$, we applied a procedure based on moving average and linear regression to calibrate t^p.

$$T^p(x) = t^p \cdot x$$

Production planning step

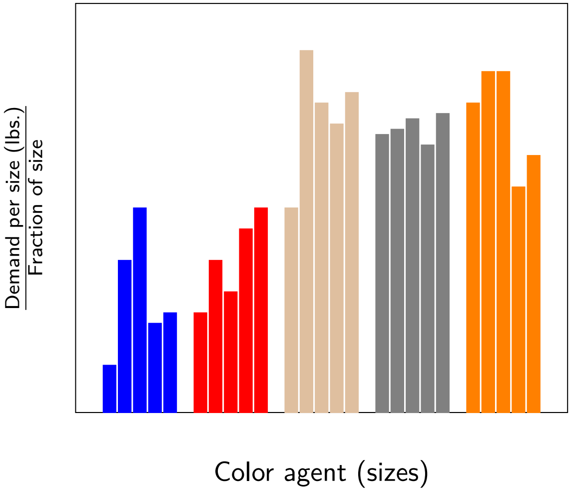
Scalability analysis

- The MIP solver is stable for instances of up to 70 color agents or 6 locations. For bigger instances, a heuristic approach is recommendable.



Scalability of MIP solver

Color ranking



Ranking:

(i) Gray
(ii) Orange
(iii) Pink
(iv) Red
(v) Blue

Work order complexity

- Metric for work order evaluation:

$$\theta(w) = \mathsf{LO} + \ln \Delta \mathsf{F},$$

where w is a work order, LO is the quantity of leftover material produced when processing w and ΔF the number of different colors contained in w.

Simulation step

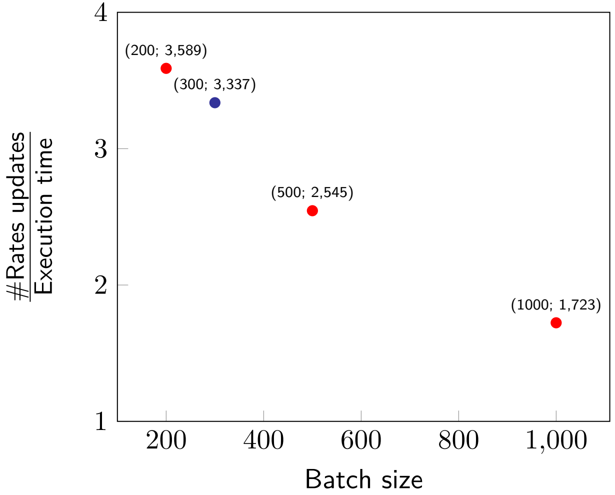
Batch size analysis

Batch size (lbs.)	Execution time (sec.)	#Rate updates	Ratio
200	333.32	1,196,175	3,589
300	240.83	803,602	3,337
500	192.05	488,791	2,545
1000	146.69	253,173	1,726

- Release batch size: 300 lbs:
  - Consistent average processing rates.
  - Reasonable average execution times.

Simulation step

Batch size selection



Selected solution

Overall results

Efficient solutions found. Std. Dev. between parenthesis

Solution	Demand–total production makespan with average rates (in days)	Average demand–total production makespan with sampled rates (in days)	Overall cost
1	159.99 – 164.38	161.71 – 165.57 (0.003)	$38,062,500
2	**160.20 – 164.43**	**162.11 – 165.95 (0.004)**	**$38,061,940**
3	160.71 – 165.15	162.14 – 166.75 (0.003)	$38,061,939
4	165.78 – 167.64	167.23 – 169.14 (0.003)	$38,061,430

Selected solution

Locations analysis

Manufacturing site	**Total production (lbs)**	**Total number of days to complete production**
Green Bay	2,360,152	62.79
Omaha	11,323,298	143.52
Springfield	3,723,516	149.28
Columbus	8,575,866	**162.09**
Detroit	10,355,579	**165.95**

Manufacturing site	**Total production cost ($)**	**Assigned demand**
Green Bay	2,407,355	5.86%
Omaha	11,300,981	24.02%
Springfield	4,091,931	16.89%
Columbus	9,331,959	25.62%
Detroit	10,875,048	27.61%

Selected solution

Machine utilization

Location	CLO Utilization	PFO Utilization	PKO Utilization	Bottleneck
Green Bay	76.30%	93.02%	99.23% (Bag) 0.00% (Box)	PKO–Bag
Omaha	74.13%	91.65%	99.65% (Bag) 3.45% (Box)	PKO–Bag
Springfield	82.42%	91.77%	11.24% (Bag) 67.74% (Box)	PFO
Columbus	96.65%	97.80%	51.80% (Bag_1) 29.52% (Bag_2) 17.58% (Box)	PFO
Detroit	76.02%	97.02%	96.30% (Bag) 2.57% (Box)	PFO

Selected solution

Transportation amounts/costs

- Only three trucks are used and all of them transfer raw material to Omaha.
- Omaha has the lowest unit production cost.

	Omaha
Green Bay	-
Springfield	Color Agent 29 (264,000 lbs/$11,642.4)
Columbus	Color Agent 7 (320,000 lbs/$17,472)
Detroit	Color Agent 17 (500,000 lbs/$25,550)

Process bottlenecks analysis

Detroit and Columbus extra machines

Extra machines	**Total production time reduction in Detroit (in days)**	**Total production time reduction in Columbus (in days)**	**Total production makespan reduction (in days)**
1 PFO machine	-6.00	-5.01	-6.00
1 PFO machine + 1 PKO–Bag machine	-39.36	-5.01	-9.09
2 PFO machines + 1 PKO–Bag machine	-39.45	-5.01	-9.12

Lower bound on simulated makespan