Isfahan University of Technology

Amirkabir University of Technology
(Tehran Polytechnic)

Zinc-Smelter Logistics Network Design under Interruption Risks

Pooya Hoseinpour

Assistant Professor, Industrial Engineering and Management Systems,

Amirkabir University of Technology (Tehran Polytechnic), Iran

Isfahan University of Technology

Dec 2020

Outline

- Zinc-smelting industry
- Zinc-mining logistics
- Interruptions in zinc-smelters
- Problem modeling
- Solution algorithm
- Managerial insights
- Conclusion and extensions

Zinc-smelting industry

- One of the industries that is extremely capital-intensive!

Zinc-smelting industry

- One of the industries that is extremely capital-intensive!
- Zinc-smelting is the process of converting zinc concentrates (ores that contain zinc) into zinc ingots.

Zinc-smelting industry

- One of the industries that is extremely capital-intensive!
- Zinc-smelting is the process of converting zinc concentrates (ores that contain zinc) into zinc ingots.

Smelting Process

Zinc-smelting industry
zinc-smelting process

- There are basically two common methods for producing zinc ingots:

  pyrometallurgical and **hydrometallurgical**.

Zinc-smelting industry
zinc-smelting process

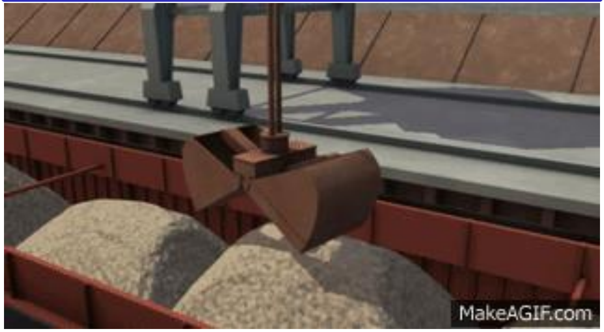
- There are basically two common methods for producing zinc ingots:

  pyrometallurgical and **hydrometallurgical**.
- Four main steps:
  - Roasting
  - Leaching and purification
  - Electrolysis
  - Smelting and casting

Zinc-smelting industry

zinc-smelting process

Transporting zinc concentrates to the temporary storage



Zinc-smelting industry

zinc-smelting process

Transporting zinc concentrates to the temporary storage

Transporting the mixed concentrates to the roasters

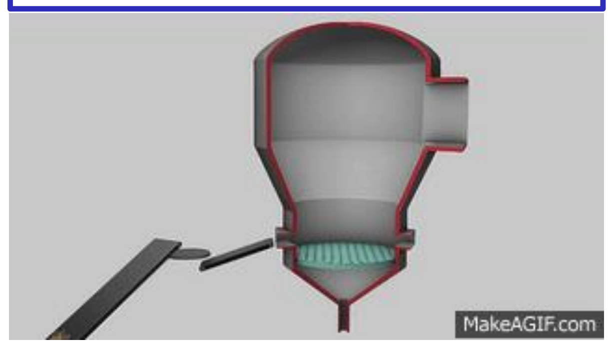
Zinc-smelting industry

zinc-smelting process

Transporting zinc concentrates to the temporary storage

Transporting the mixed concentrates to the roasters

Roasting plant: convert zinc sulfide to impure zinc oxide



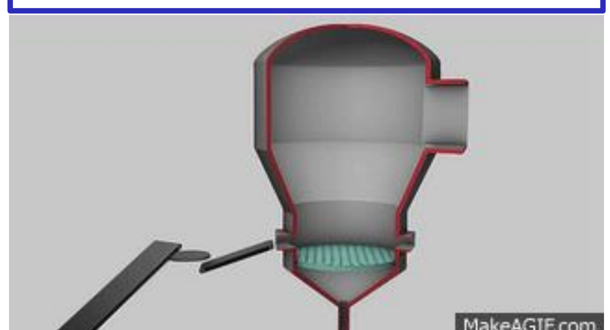
Zinc-smelting industry

zinc-smelting process

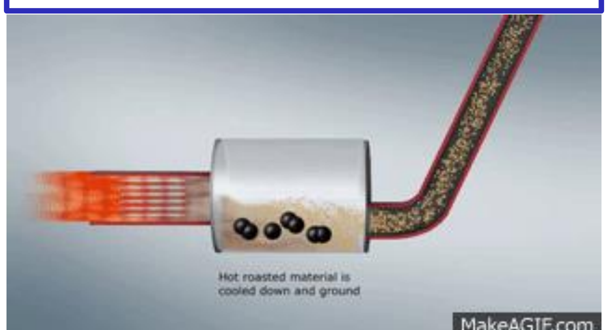
Transporting zinc concentrates to the temporary storage

Transporting the mixed concentrates to the roasters

Roasting plant: convert zinc sulfide to impure zinc oxide



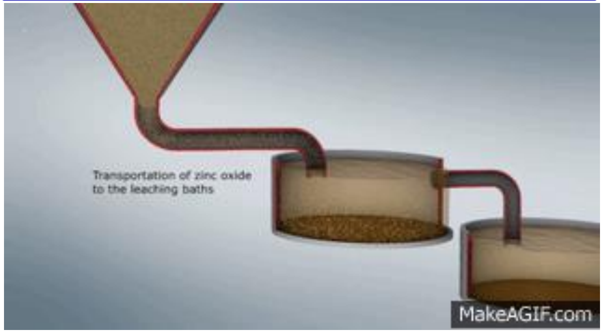
Transporting zinc oxide to the leaching plant



Zinc-smelting industry

zinc-smelting process

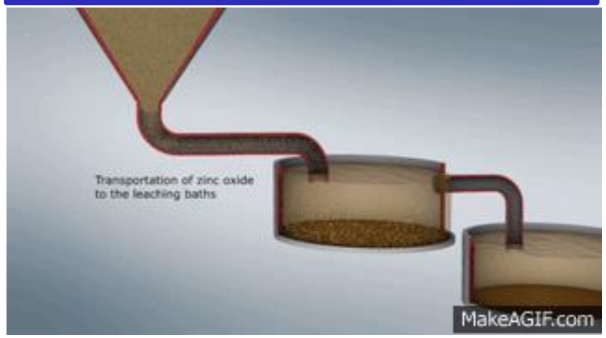
Leaching process: impurities are precipitated



Zinc-smelting industry

zinc-smelting process

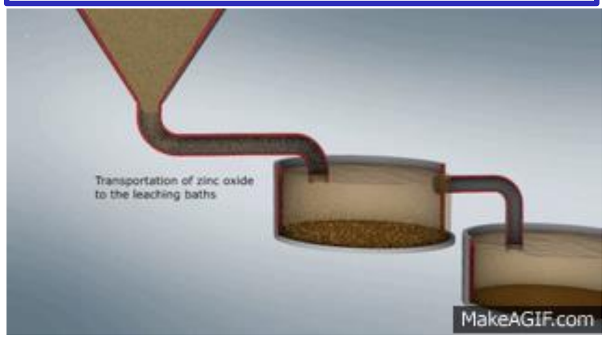
Leaching process: impurities are precipitated → Transporting roasted materials to the Electrolysis plants



Zinc-smelting industry

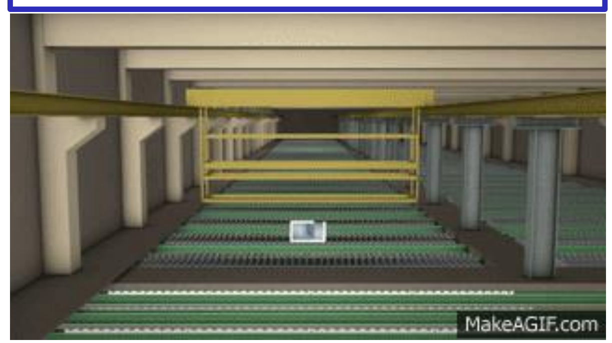
zinc-smelting process

Leaching process: impurities are precipitated



Transporting roasted materials to the Electrolysis plants

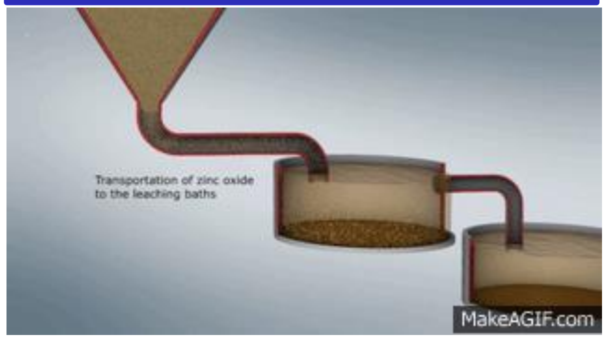
Electrolysis process: zinc is deposited in Aluminum sheets



Zinc-smelting industry

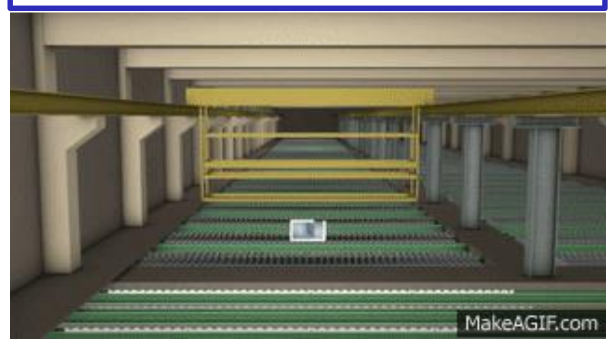
zinc-smelting process

Leaching process: impurities are precipitated

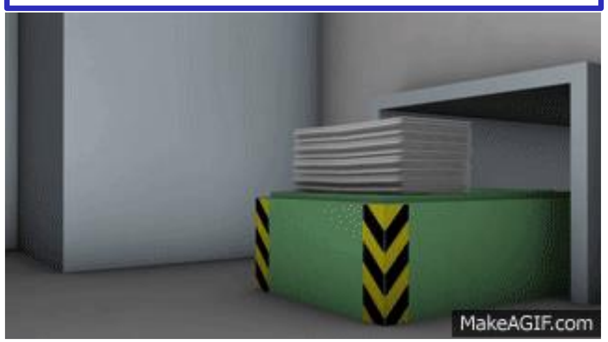


Transporting roasted materials to the Electrolysis plants

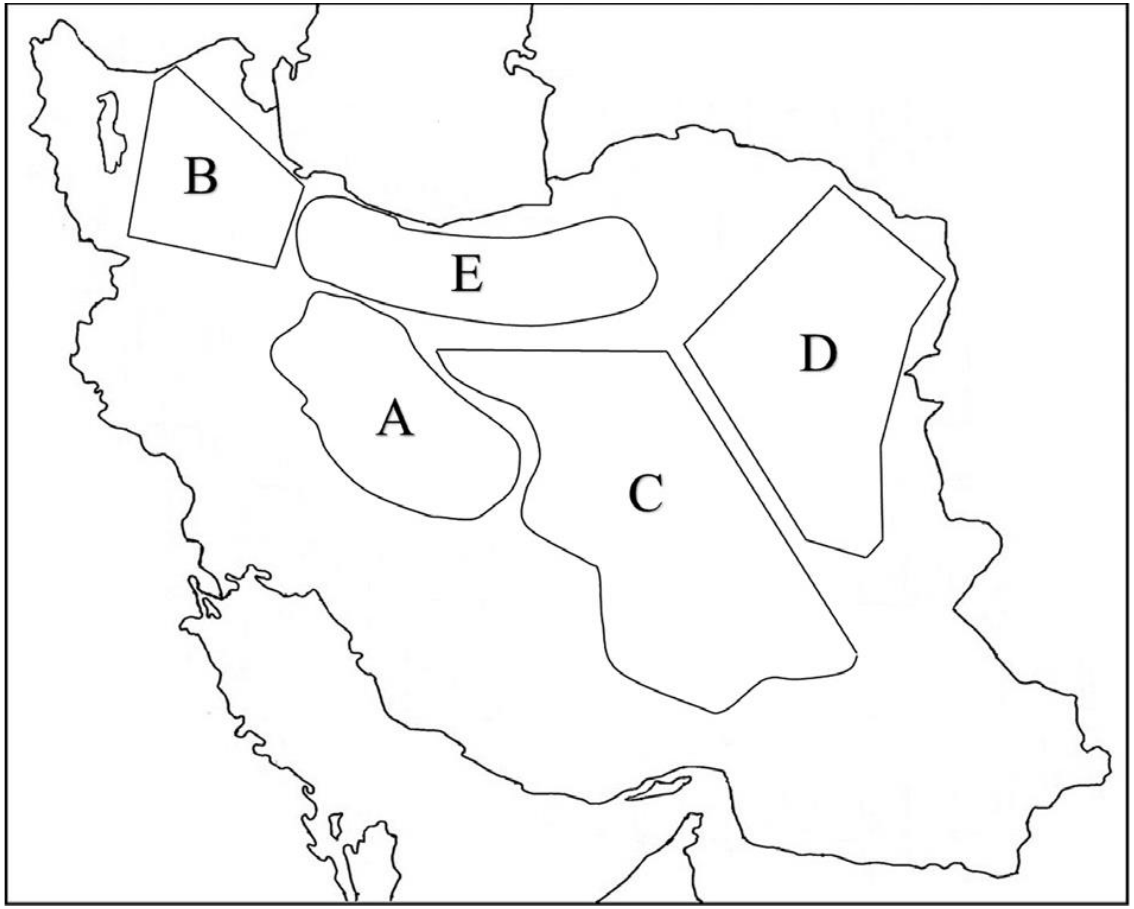
Electrolysis process: zinc is deposited in Aluminum sheets



Melting and casting process; done in induction furnaces



Zinc-mining logistics



Iran Zinc Mines Development Company plans to increase zinc production, i.e., zinc ingots, by making investments to establish new smelters.

Areas of zinc mineralization can be classified into five regions.

Two potential places are selected from each region as candidate locations for new smelters.

Zinc-mining logistics

- Zinc-mining logistics is concerned with the optimal **number**, **location**, and **service capacity** of smelters, as well as, **allocation** of zinc mines.

Zinc-mining logistics

- Zinc-mining logistics is concerned with the optimal **number**, **location**, and **service capacity** of smelters, as well as, **allocation** of zinc mines.
- Cost-effectively delivering the zinc ingots to the market is the main goal of mining ventures.

Zinc-mining logistics

- Zinc-mining logistics is concerned with the optimal **number**, **location**, and **service capacity** of smelters, as well as, **allocation** of zinc mines.
- Cost-effectively delivering the zinc ingots to the market is the main goal of mining ventures.
- Cost includes: smelters' establishing fixed cost, production (service) cost, transportation cost, and storage (congestion) cost.

Interruptions in zinc-smelters

Smelting process of each smelter can be stopped frequently due to different kinds of interruptions in any plants:

Interruptions in zinc-smelters

Smelting process of each smelter can be stopped frequently due to different kinds of interruptions in any plants:

power outage

Interruptions in zinc-smelters

Smelting process of each smelter can be stopped frequently due to different kinds of interruptions in any plants:

power outage

lack of materials

(e.g. fuel, sulfuric acid and water for leaching process)

Interruptions in zinc-smelters

Smelting process of each smelter can be stopped frequently due to different kinds of interruptions in any plants:

power outage

lack of materials

(e.g. fuel, sulfuric acid and water for leaching process)

unscheduled machine breakdowns

(e.g. improper maintenance or use, and warning signals)

Interruptions in zinc-smelters

Smelting process of each smelter can be stopped frequently due to different kinds of interruptions in any plants:

power outage

lack of materials

(e.g. fuel, sulfuric acid and water for leaching process)

unscheduled machine breakdowns

(e.g. improper maintenance or use, and warning signals)

personnel/operating errors

Interruptions in zinc-smelters

Smelting process of each smelter can be stopped frequently due to different kinds of interruptions in any plants:

Facility Location Problem with Stochastic Demands and Congestion (Service system design problem) with service interruptions

(e.g. fuel, sulfuric acid and water for leaching process)

unscheduled machine breakdowns

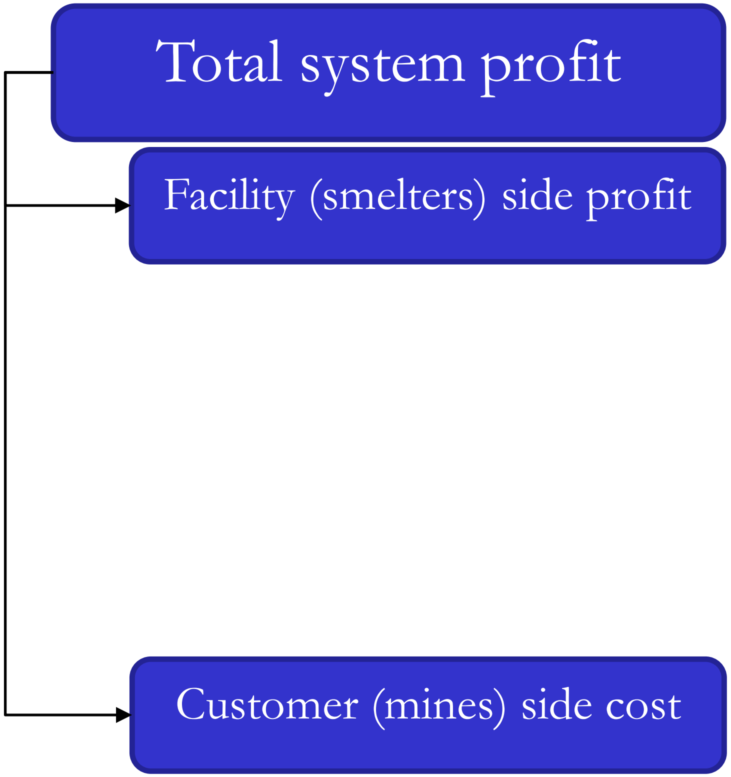
(e.g. improper maintenance or use, and warning signals)

personnel/operating errors

Problem modeling

Total system profit

Problem modeling



Problem modeling

- Total system profit
  - Facility (smelters) side profit
    - Service providing revenue
    - Production (service) cost
    - Facility stablishing cost
  - Customer (mines) side cost

Problem modeling

- Total system profit
  - Facility (smelters) side profit
    - Service providing revenue
    - Production (service) cost
    - Facility stablishing cost
  - Customer (mines) side cost
    - Transportation cost
    - Congestion cost

Problem modeling

- **Total system profit**
  - **Facility (smelters) side profit**
    - Service providing revenue: $SPR = \sum_{i \in I} \sum_{j \in J} p_i \lambda_j y_{ij}$
    - Production (service) cost: $SPC = \sum_{i \in I} s_i \mu_i x_i$
    - Facility stablishing cost: $SFC = \sum_{i \in I} f_i x_i$
  - **Customer (mines) side cost**
    - Transportation cost: $STC = \sum_{i \in I} \sum_{j \in J} t_{ij} \lambda_j y_{ij}$
    - Congestion cost: $SWT = \sum_{i \in I} \sum_{j \in J} w_i \overline{W}_i y_{ij}$

Problem modeling

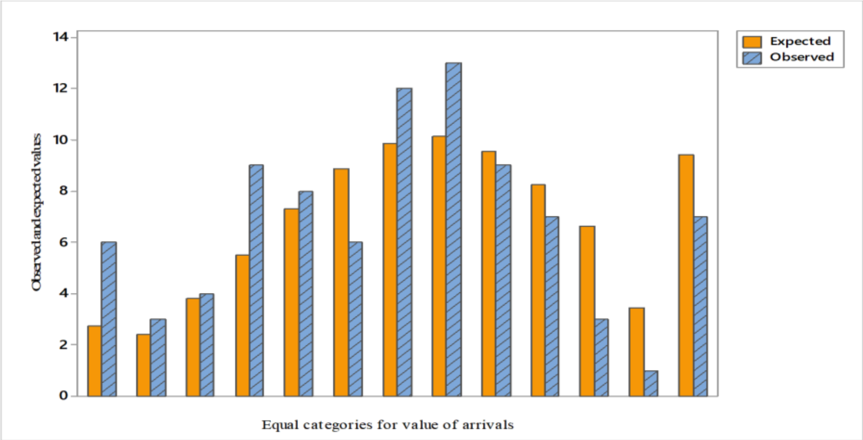
- Total system profit: $$\max\ \left(SPR - SPC - SFC\right) - \left(STC + SWC\right)$$
  - Facility (smelters) side profit
    - Service providing revenue: $$SPR = \sum_{i\in I}\sum_{j\in J} p_i \lambda_j y_{ij}$$
    - Production (service) cost: $$SPC = \sum_{i\in I} s_i \mu_i x_i$$
    - Facility stablishing cost: $$SFC = \sum_{i\in I} f_i x_i$$
  - Customer (mines) side cost
    - Transportation cost: $$STC = \sum_{i\in I}\sum_{j\in J} t_{ij} \lambda_j y_{ij}$$
    - Congestion cost: $$SWT = \sum_{i\in I}\sum_{j\in J} w_i \overline{W}_i y_{ij}$$

Problem modeling

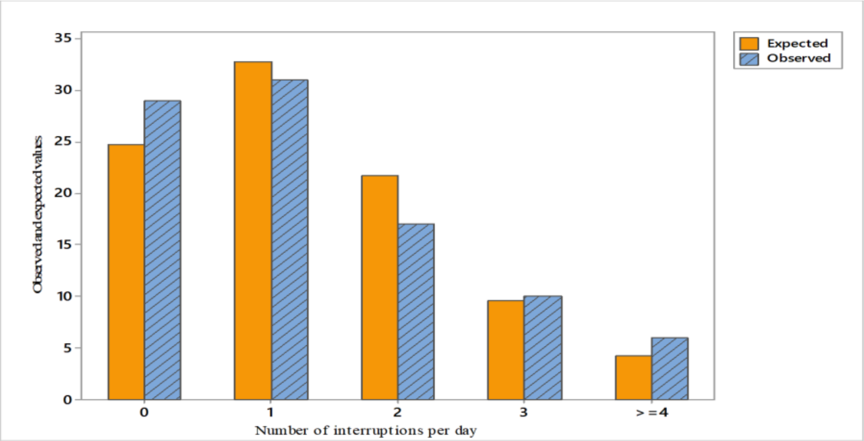
- **Total system profit** $\max\ (SPR - SPC - SFC) - (STC + SWC)$
  - **Facility (smelters) side profit**
    - Service providing revenue $SPR = \sum_{i \in I} \sum_{j \in J} p_i \lambda_j y_{ij}$
    - Production (service) cost $SPC = \sum_{i \in I} s_i \mu_i x_i$
    - Facility stablishing cost $SFC = \sum_{i \in I} f_i x_i$
  - **Customer (mines) side cost**
    - Transportation cost $STC = \sum_{i \in I} \sum_{j \in J} t_{ij} \lambda_j y_{ij}$
    - Congestion cost $SWT = \sum_{i \in I} \sum_{j \in J} w_i \overline{W}_i y_{ij}$

$\sum_{i \in I} y_{ij} \le 1$	$j \in J$
$y_{ij} \le x_i$	$i \in I,\ j \in J$
Stability condition	$i \in I$
$x_i,\ y_{ij} \in \{0,1\}$	$i \in I,\ j \in J$
$\mu_i \ge 0$	$i \in I$

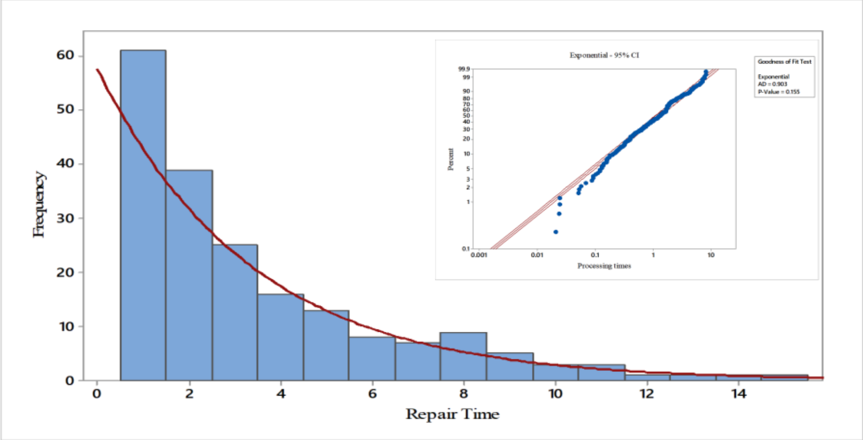
Problem modeling



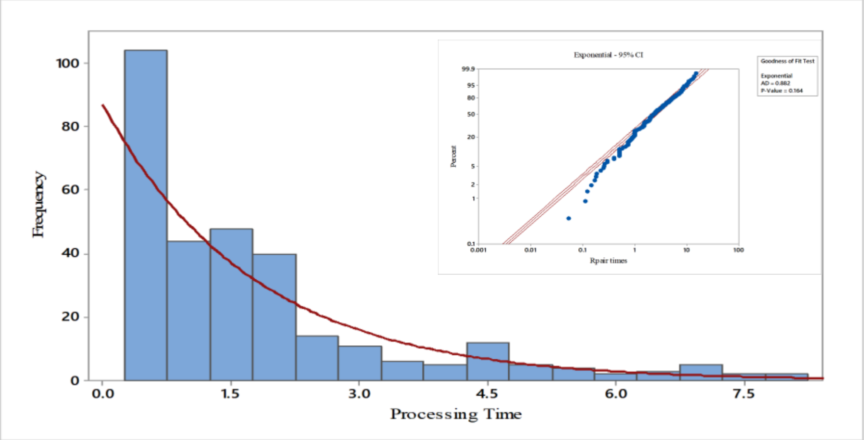
a) H: arrivals follow a Poisson process, number of arrivals per time has a Poisson distribution; pv= 0.293.



b) H: Interruptions follow a Poisson process, number of interruptions per time has a Poisson distribution; pv= 0.459.



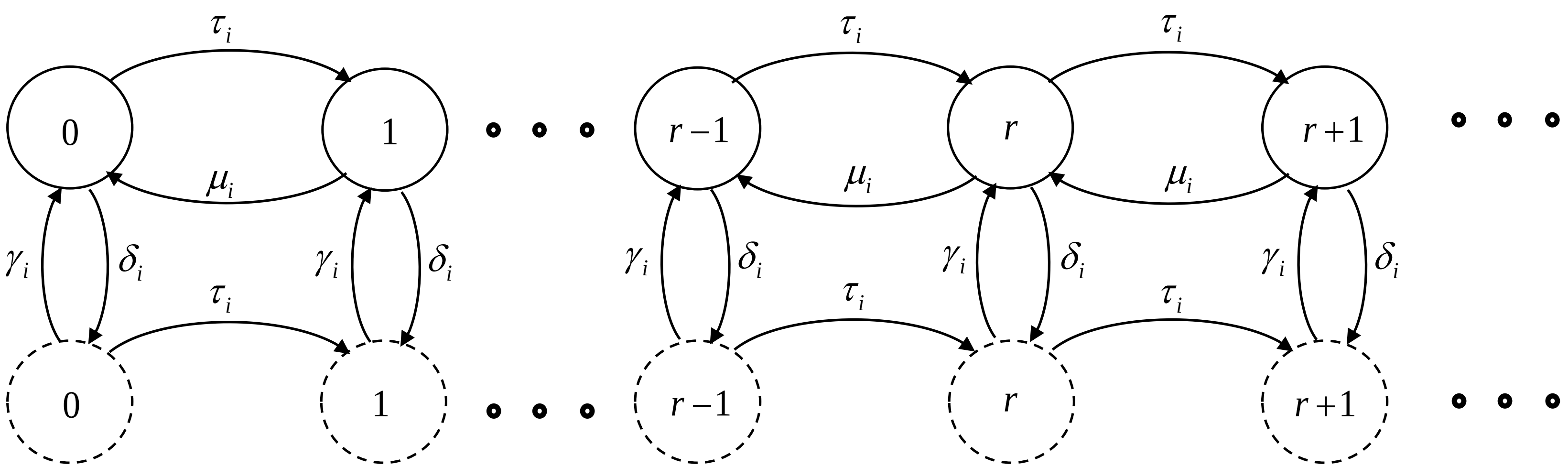
c) H: Processing times are exponentially distributed; pv= 0.155.



d) H: Repair times are exponentially distributed; pv= 0.164.

Problem modeling

$$\tau_i = \sum_{j \in J_i} \lambda_{ij}$$



Interruption rate

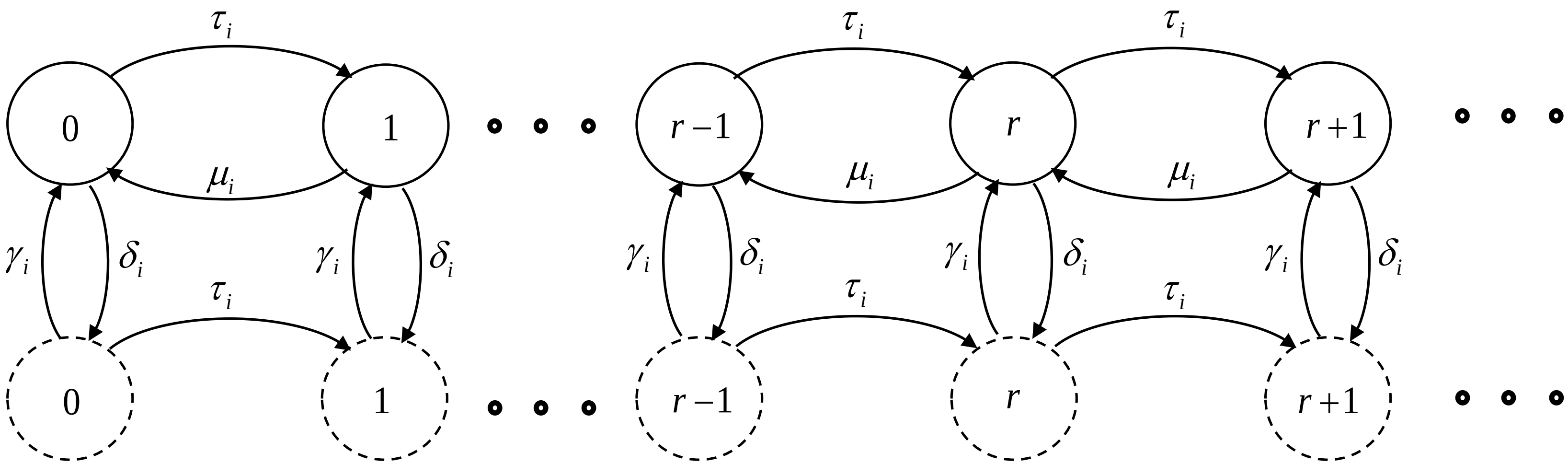
δ_i

Recovery rate

γ_i

Problem modeling

$$\tau_i = \sum_{j \in J_i} \lambda_{ij}$$



$$G_i(z) = \frac{\left(\left(\mu_i - \tau_i\right)\gamma_i - \tau_i\delta_i\right)\left(\delta_i + \tau_i(1-z) + \gamma_i\right)}{\left(\delta_i + \gamma_i\right)\left(\left(\tau_i(1-z) + \gamma_i\right)\left(\mu_i - \tau_i z\right) - \tau_i\delta_i z\right)} \qquad |z| \le 1 \qquad \gamma_i\mu_i > \left(\delta_i + \gamma_i\right)\tau_i$$

$$\overline{W_i} = \frac{\left(\delta_i + \gamma_i\right)^2 + \mu_i\delta_i}{\left(\delta_i + \gamma_i\right)\left(\gamma_i\left(\mu_i - \tau_i\right) - \tau_i\delta_i\right)}$$

Interruption rate

δ_i

Recovery rate

γ_i

Problem modeling

$$\max_{x,\mu,y} \quad v(\boldsymbol{x},\boldsymbol{\mu},\boldsymbol{y}) = \sum_{i\in I}\sum_{j\in J} p_i \lambda_{ij} y_{ij} - \sum_{i\in I} f_i x_i - \sum_{i\in I} s_i \mu_i x_i - \sum_{i\in I}\sum_{j\in J} t_{ij}\lambda_{ij} V_{ij} - \sum_{i\in I} \frac{w_i\left(\sum_{j\in J}\lambda_{ij}y_{ij}\right)\left((\delta_i+\gamma_i)^2+\delta_i\mu_i\right)}{(\delta_i+\gamma_i)\left(\gamma_i\mu_i-(\delta_i+\gamma_i)\left(\sum_{j\in J}\lambda_{ij}y_{ij}\right)\right)}$$

s.t.

$$\sum_{i\in I} y_{ij} \le 1 \qquad j\in J$$

$$y_{ij} \le x_i \qquad i\in I,\ j\in J$$

$$\sum_{j\in J} \lambda_j y_{ij} < \frac{\gamma_i}{\delta_i+\gamma_i}\mu_i \qquad i\in I$$

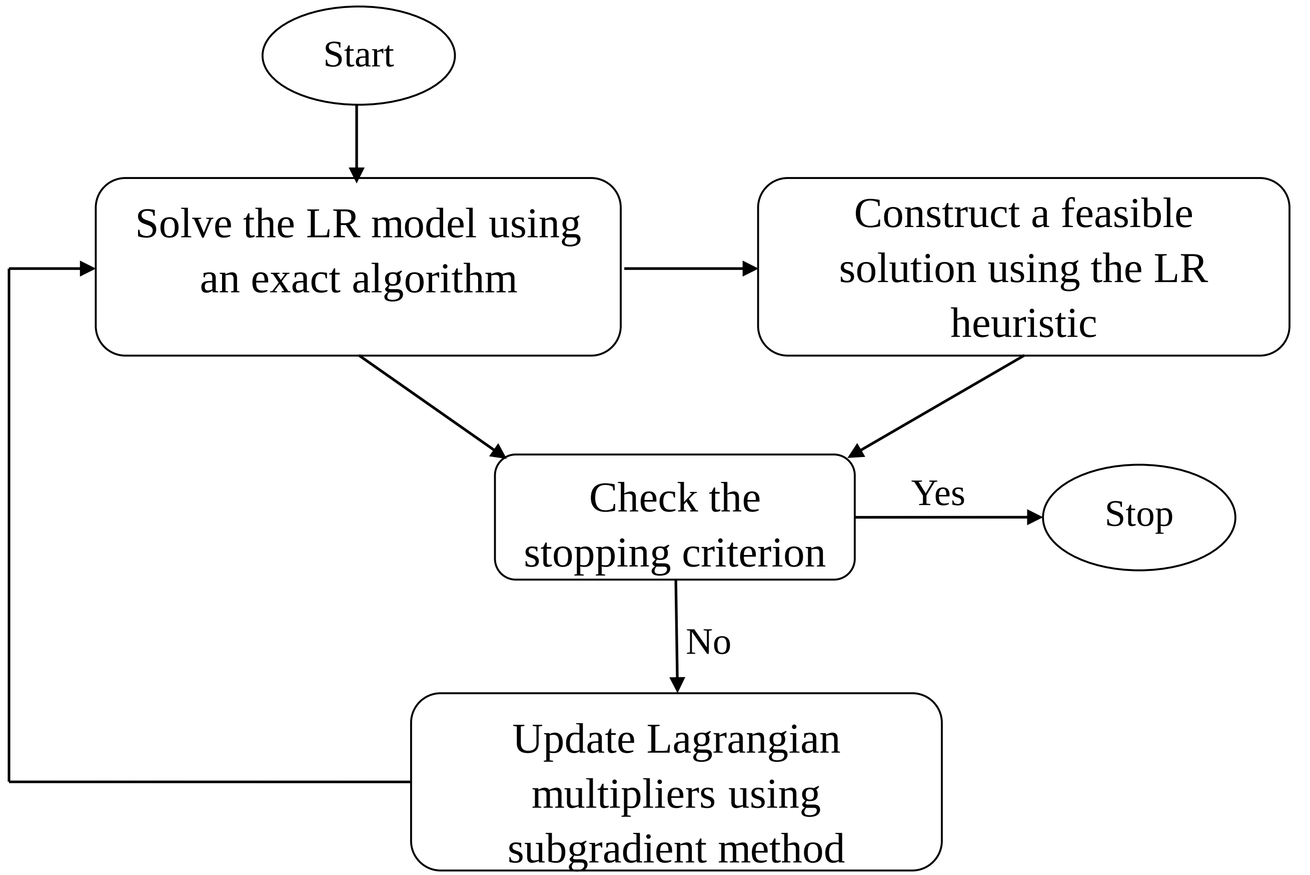
$$\mu_i \ge 0 \qquad i\in I$$

$$y_{ij} \in \{0,1\} \qquad i\in I,\ j\in J$$

$$x_i \in \{0,1\} \qquad i\in I$$

Solution algorithm

Lagrangian Relaxation



Solution algorithm

$$\max_{x,\mu,y} \quad v(\boldsymbol{x},\boldsymbol{\mu},\boldsymbol{y}) = \sum_{i\in I}\sum_{j\in J} p_i\lambda_{ij}y_{ij} - \sum_{i\in I} f_i x_i - \sum_{i\in I} s_i\mu_i x_i - \sum_{i\in I}\sum_{j\in J} t_{ij}\lambda_{ij}V_{ij}$$

$$-\sum_{i\in I}\frac{w_i\left(\sum_{j\in J}\lambda_{ij}y_{ij}\right)\left((\delta_i+\gamma_i)^2+\delta_i\mu_i\right)}{(\delta_i+\gamma_i)\left(\gamma_i\mu_i-(\delta_i+\gamma_i)\left(\sum_{j\in J}\lambda_{ij}y_{ij}\right)\right)}$$

s.t.

$$\sum_{i\in I} y_{ij} \le 1 \qquad j\in J$$

$$y_{ij} \le x_i \qquad i\in I,\ j\in J$$

$$\sum_{j\in J}\lambda_j y_{ij} < \frac{\gamma_i}{\delta_i+\gamma_i}\mu_i \qquad i\in I$$

$$\mu_i \ge 0 \qquad i\in I$$

$$y_{ij} \in \{0,1\} \qquad i\in I,\ j\in J$$

$$x_i \in \{0,1\} \qquad i\in I$$

Solution algorithm

$$\max_{x,\mu,y} \quad v(\boldsymbol{x}, \boldsymbol{\mu}, \boldsymbol{y}) = \sum_{i\in I}\sum_{j\in J} p_i \lambda_{ij} y_{ij} - \sum_{i\in I} f_i x_i - \sum_{i\in I} s_i \mu_i x_i - \sum_{i\in I}\sum_{j\in J} t_{ij} \lambda_{ij} V_{ij}$$

$$- \sum_{i\in I} \frac{w_i \left(\sum_{j\in J} \lambda_{ij} y_{ij}\right)\left((\delta_i + \gamma_i)^2 + \delta_i \mu_i\right)}{(\delta_i + \gamma_i)\left(\gamma_i \mu_i - (\delta_i + \gamma_i)\left(\sum_{j\in J} \lambda_{ij} y_{ij}\right)\right)}$$

s.t.

$$\sum_{i\in I} y_{ij} \le 1 \qquad j \in J$$

$$y_{ij} \le x_i \qquad i \in I,\ j \in J$$

$$\sum_{j\in J} \lambda_j y_{ij} < \frac{\gamma_i}{\delta_i + \gamma_i} \mu_i \qquad i \in I$$

$$\mu_i \ge 0 \qquad i \in I$$

$$y_{ij} \in \{0,1\} \qquad i \in I,\ j \in J$$

$$x_i \in \{0,1\} \qquad i \in I$$

$$\min_{\mu_i} \quad g(\mu_i) = s_i \mu_i + w_i \frac{\tau_i \left((\delta_i + \gamma_i)^2 + \mu_i \delta_i\right)}{(\delta_i + \gamma_i)\left(\gamma_i (\mu_i - \tau_i) - \tau_i \delta_i\right)}$$

s.t.

$$\mu_i > \tau_i \left(\frac{\delta_i + \gamma_i}{\gamma_i}\right),$$

Solution algorithm

$$\max_{x,\mu,y} \quad v(\boldsymbol{x},\boldsymbol{\mu},\boldsymbol{y}) = \sum_{i\in I}\sum_{j\in J} p_i \lambda_{ij} y_{ij} - \sum_{i\in I} f_i x_i - \sum_{i\in I} s_i \mu_i x_i - \sum_{i\in I}\sum_{j\in J} t_{ij}\lambda_{ij} V_{ij}$$

$$- \sum_{i\in I} \frac{w_i\left(\sum_{j\in J}\lambda_{ij}y_{ij}\right)\left((\delta_i+\gamma_i)^2+\delta_i\mu_i\right)}{(\delta_i+\gamma_i)\left(\gamma_i\mu_i-(\delta_i+\gamma_i)\left(\sum_{j\in J}\lambda_{ij}y_{ij}\right)\right)}$$

s.t.

$$\sum_{i\in I} y_{ij} \le 1 \qquad j\in J$$

$$y_{ij} \le x_i \qquad i\in I,\ j\in J$$

$$\sum_{j\in J} \lambda_j y_{ij} < \frac{\gamma_i}{\delta_i+\gamma_i}\mu_i \qquad i\in I$$

$$\mu_i \ge 0 \qquad i\in I$$

$$y_{ij}\in\{0,1\} \qquad i\in I,\ j\in J$$

$$x_i\in\{0,1\} \qquad i\in I$$

$$\min_{\mu_i} \quad g(\mu_i) = s_i\mu_i + w_i \frac{\tau_i\left((\delta_i+\gamma_i)^2+\mu_i\delta_i\right)}{(\delta_i+\gamma_i)\left(\gamma_i(\mu_i-\tau_i)-\tau_i\delta_i\right)}$$

s.t.

$$\mu_i > \tau_i\left(\frac{\delta_i+\gamma_i}{\gamma_i}\right),$$

$$\mu_i^* = \sqrt{\frac{w_i(\delta_i+\gamma_i)}{s_i\gamma_i}\tau_i + \frac{\delta_i w_i}{s_i\gamma_i^2}\tau_i^{\ 2}} + \frac{\delta_i+\gamma_i}{\gamma_i}\tau_i.$$

Solution algorithm

$$\max_{x,\mu,y} \quad v(\boldsymbol{x},\boldsymbol{\mu},\boldsymbol{y}) = \sum_{i\in I}\sum_{j\in J} p_i\lambda_{ij}y_{ij} - \sum_{i\in I} f_i x_i - \sum_{i\in I} s_i\mu_i x_i - \sum_{i\in I}\sum_{j\in J} t_{ij}\lambda_{ij}V_{ij}$$

$$-\sum_{i\in I}\frac{w_i\left(\sum_{j\in J}\lambda_{ij}y_{ij}\right)\left((\delta_i+\gamma_i)^2+\delta_i\mu_i\right)}{(\delta_i+\gamma_i)\left(\gamma_i\mu_i-(\delta_i+\gamma_i)\left(\sum_{j\in J}\lambda_{ij}y_{ij}\right)\right)}$$

s.t.

$$\sum_{i\in I} y_{ij} \le 1 \qquad j\in J$$

$$y_{ij} \le x_i \qquad i\in I,\ j\in J$$

$$\sum_{j\in J}\lambda_j y_{ij} < \frac{\gamma_i}{\delta_i+\gamma_i}\mu_i \qquad i\in I$$

$$\mu_i \ge 0 \qquad i\in I$$

$$y_{ij}\in\{0,1\} \qquad i\in I,\ j\in J$$

$$x_i\in\{0,1\} \qquad i\in I$$

$$\mu_i^* = \sqrt{\frac{w_i(\delta_i+\gamma_i)}{s_i\gamma_i}\tau_i + \frac{\delta_i w_i}{s_i\gamma_i^2}\tau_i^{\,2}} + \frac{\delta_i+\gamma_i}{\gamma_i}\tau_i.$$

Solution algorithm

$$\max_{x,y} \quad z(\boldsymbol{x},\boldsymbol{\mu}^*,\boldsymbol{y}) = \sum_{i\in I}\sum_{j\in J} A_{ij} y_{ij} - \sum_{i\in I}\sqrt{\sum_{j\in J} B_{ij} y_{ij} + \left(\sum_{j\in J} C_{ij} y_{ij}\right)^2} - \sum_{i\in I} f_i x_i$$

s.t.

$$A_{ij} = p_i\lambda_{ij} - t_{ij}\lambda_{ij} - \frac{s_i\lambda_{ij}(\delta_i+\gamma_i)^2 + w_i\delta_i\lambda_{ij}}{\gamma_i(\delta_i+\gamma_i)}$$

$$B_{ij} = \frac{4s_i w_i(\delta_i+\gamma_i)\lambda_{ij}}{\gamma_i}$$

$$C_{ij} = \frac{2\lambda_{ij}}{\gamma_i}\sqrt{s_i\delta_i w_i},$$

$$\sum_{i\in I} y_{ij} \le 1 \qquad j \in J$$

$$y_{ij} \le x_i \qquad i\in I,\ j\in J$$

$$y_{ij} \in \{0,1\} \qquad i\in I,\ j\in J$$

$$x_i \in \{0,1\} \qquad i\in I$$

Solution algorithm

$$\max_{x,y} \quad z\left(\boldsymbol{x},\boldsymbol{\mu}^*,\boldsymbol{y}\right)=\sum_{i\in I}\sum_{j\in J}A_{ij}y_{ij}-\sum_{i\in I}\sqrt{\sum_{j\in J}B_{ij}y_{ij}+\left(\sum_{j\in J}C_{ij}y_{ij}\right)^2}-\sum_{i\in I}f_i x_i$$

s.t.

$$A_{ij}=p_i\lambda_{ij}-t_{ij}\lambda_{ij}-\frac{s_i\lambda_{ij}\left(\delta_i+\gamma_i\right)^2+w_i\delta_i\lambda_{ij}}{\gamma_i\left(\delta_i+\gamma_i\right)}$$

$$B_{ij}=\frac{4s_iw_i\left(\delta_i+\gamma_i\right)\lambda_{ij}}{\gamma_i}$$

$$C_{ij}=\frac{2\lambda_{ij}}{\gamma_i}\sqrt{s_i\delta_iw_i},$$

$$\sum_{i\in I}y_{ij}\le 1 \qquad j\in J$$

$$y_{ij}\le x_i \qquad i\in I,\ j\in J$$

$$y_{ij}\in\{0,1\} \qquad i\in I,\ j\in J$$

$$x_i\in\{0,1\} \qquad i\in I$$

Solution algorithm

$$\max_{x,y} \sum_{i\in I}\sum_{j\in J} A_{ij}y_{ij} - \sum_{i\in I}\sqrt{\sum_{j\in J} B_{ij}y_{ij} + \left(\sum_{j\in J} C_{ij}y_{ij}\right)^2} - \sum_{i\in I} f_i x_i + \sum_{j\in J} u_j\left(1-\sum_{i\in I} y_{ij}\right)$$

$s.t.$

$$y_{ij} \le x_i \qquad i\in I,\ j\in J$$

$$y_{ij} \in \{0,1\} \qquad i\in I,\ j\in J$$

$$x_i \in \{0,1\} \qquad i\in I$$

$$A_{ij} = p_i\lambda_{ij} - t_{ij}\lambda_{ij} - \frac{s_i\lambda_{ij}(\delta_i+\gamma_i)^2 + w_i\delta_i\lambda_{ij}}{\gamma_i(\delta_i+\gamma_i)}$$

$$B_{ij} = \frac{4s_i w_i(\delta_i+\gamma_i)\lambda_{ij}}{\gamma_i}$$

$$C_{ij} = \frac{2\lambda_{ij}}{\gamma_i}\sqrt{s_i\delta_i w_i},$$

Solution algorithm

$$\max_{x,y} \sum_{i\in I}\sum_{j\in J} A_{ij} y_{ij} - \sum_{i\in I}\sqrt{\sum_{j\in J} B_{ij} y_{ij} + \left(\sum_{j\in J} C_{ij} y_{ij}\right)^2} - \sum_{i\in I} f_i x_i + \sum_{j\in J} u_j \left(1 - \sum_{i\in I} y_{ij}\right)$$

$s.t.$

$$y_{ij} \le x_i \qquad i\in I,\ j\in J$$

$$y_{ij} \in \{0,1\} \qquad i\in I,\ j\in J$$

$$x_i \in \{0,1\} \qquad i\in I$$

$$A_{ij} = p_i\lambda_{ij} - t_{ij}\lambda_{ij} - \frac{s_i\lambda_{ij}(\delta_i+\gamma_i)^2 + w_i\delta_i\lambda_{ij}}{\gamma_i(\delta_i+\gamma_i)}$$

$$B_{ij} = \frac{4s_i w_i(\delta_i+\gamma_i)\lambda_{ij}}{\gamma_i}$$

$$C_{ij} = \frac{2\lambda_{ij}}{\gamma_i}\sqrt{s_i\delta_i w_i},$$

$$\max_{y_{ij}\in\{0,1\}} \sum_{j\in J} D_{ij}^t y_{ij} - \sqrt{\sum_{j\in J} B_{ij} y_{ij} + \left(\sum_{j\in J} C_{ij} y_{ij}\right)^2} - f_i$$

$$D_{ij}^t = p_i\lambda_j - t_{ij}\lambda_j - \frac{s_i\lambda_j(\delta_i+\gamma_i)^2 + w_i\delta_i\lambda_j}{\gamma_i(\delta_i+\gamma_i)} - u_j^t$$

$$B_{ij} = \frac{4s_i w_i(\delta_i+\gamma_i)\lambda_j}{\gamma_i}$$

$$C_{ij} = \frac{2\lambda_j}{\gamma_i}\sqrt{s_i\delta_i w_i},$$

Managerial insights

- Two potential places in each of the five regions are considered for new smelters.
- 90 demand areas for zinc mineralization are indicated.
- The demand rate of area is estimated based on data reported in the NGDI (National Geoscience Database of Iran).
- The transportation cost for each ton is estimated based on data provided by the RMTO (Road Maintenance & Transportation Organization)

Managerial insights

Case with interruptions

- Expected Total profit:

  27 m$

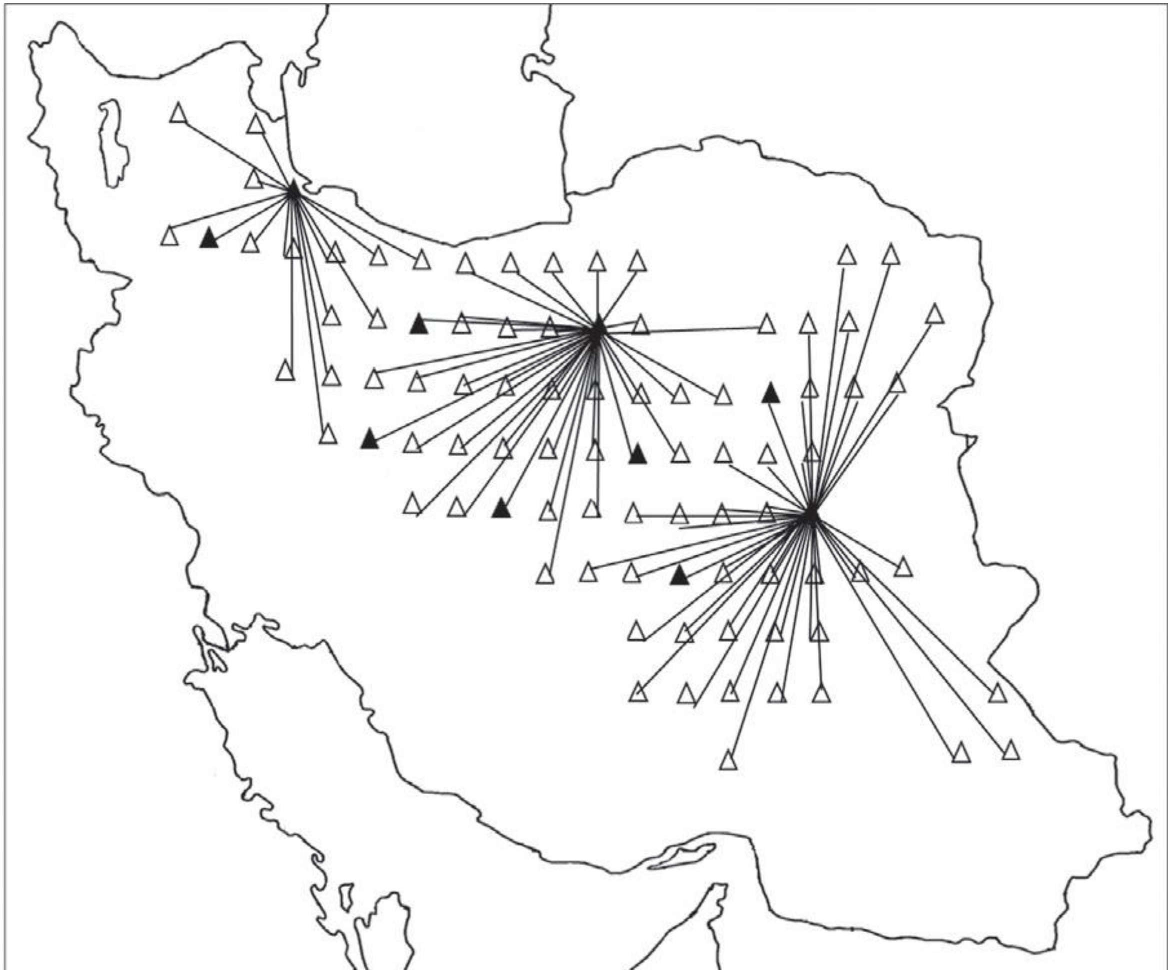
- Number of Smelters:

  2

- Percent of covered deposits:

  94%

Managerial insights



Case without interruptions

- Expected Total profit:

  53 m$

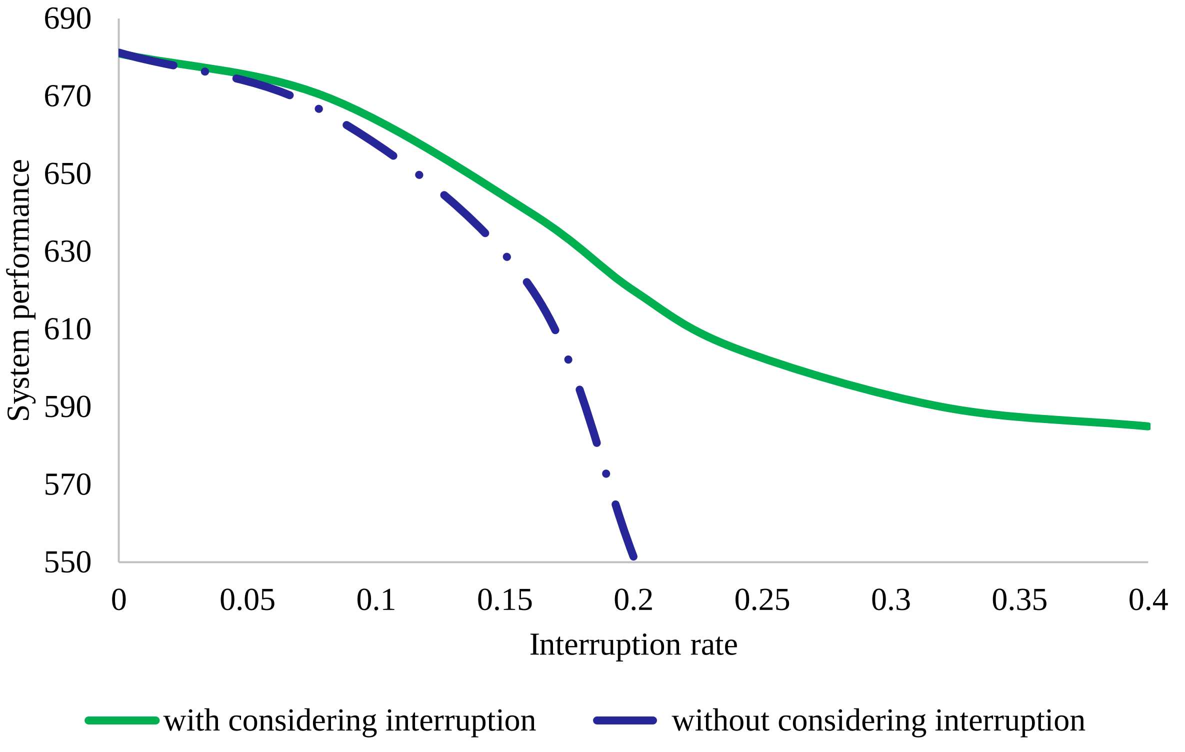
- Number of Smelters:

  3

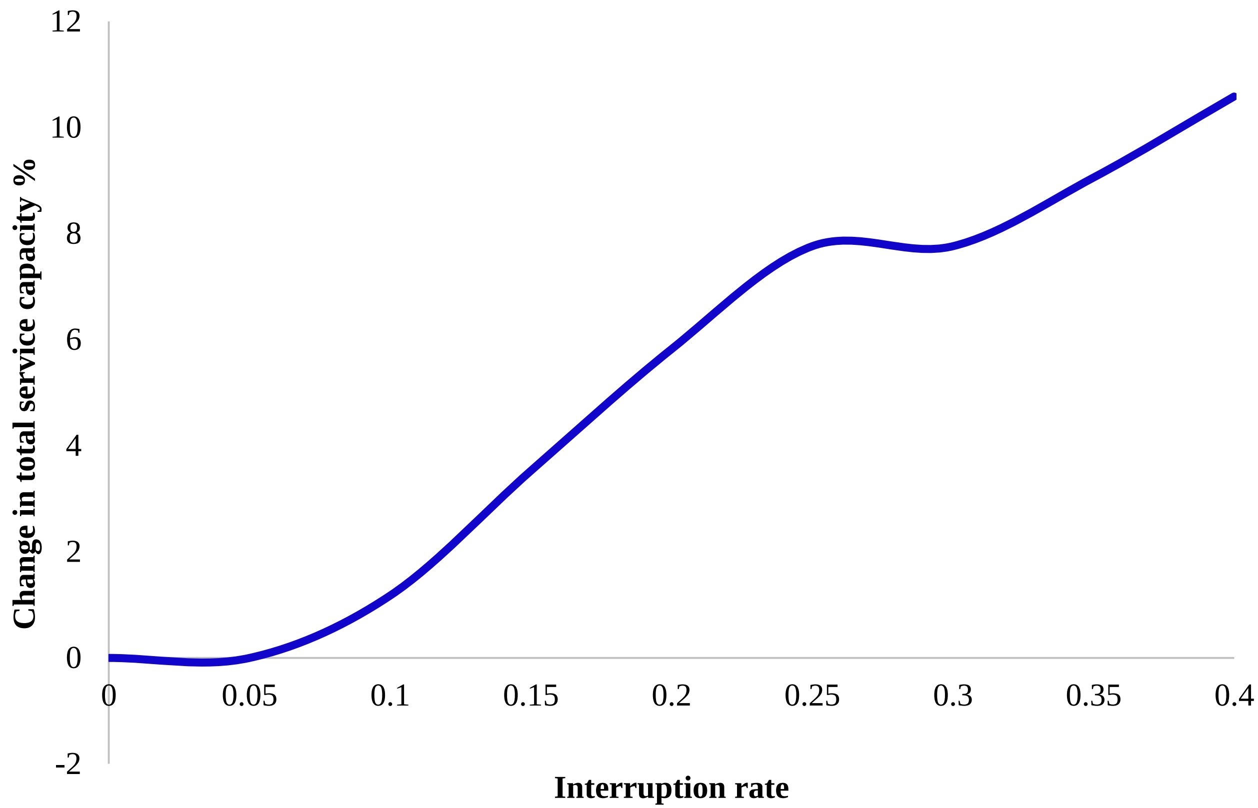
- Percent of covered deposits:

  100%

Managerial insights



Managerial insights



Conclusion and extensions

Conclusion and extensions

- A service system design problem has been considered under interruption risks

Conclusion and extensions

- A service system design problem has been considered under interruption risks
- Effect of considering service interruption risk on designing an service system is demonstrated.

Conclusion and extensions

- A service system design problem has been considered under interruption risks
- Effect of considering service interruption risk on designing an service system is demonstrated.
- Backup service can also be considered as another mitigation strategy along with location-allocation and service capacity ones

Conclusion and extensions

- A service system design problem has been considered under interruption risks
- Effect of considering service interruption risk on designing an service system is demonstrated.
- Backup service can also be considered as another mitigation strategy along with location-allocation and service capacity ones
- Assessment time is considered before recovery phase.

Conclusion and extensions

- A service system design problem has been considered under interruption risks
- Effect of considering service interruption risk on designing an service system is demonstrated.
- Backup service can also be considered as another mitigation strategy along with location-allocation and service capacity ones
- Assessment time is considered before recovery phase.
- The model is extended for other kinds of queue systems in both single server and multiple servers as well as for other kinds of interruptions as well.

Thank you so much for your consideration!