Spare Part Inventory Control and Management
Stochastic Optimization and Simulation Approaches

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Outline

Spare parts inventory control is unique.

- Demand and supply are stochastic.
  - The demand is intermittent and unpredictable.
  - The number of items is usually large.
  - Most items are slow-moving.
- The costs are high.
  - Stockout cost is high.
  - Holding cost is also high.
- The stakeholders are different (internal and external).
  - The customers are internal (production line, maintenance, etc.)
  - The suppliers are external (OEM, third-party vendors, etc.)
- The lead time is usually long.
- The data is often incomplete.

Activity #1: Share your experience

- **Form a group of 2-3 people and discuss the following:**
- Share your experience as a **customer** needing spare parts for your equipment!
    - What are the challenges you often face?
    - What do you expect from the spare parts management team?
- Any experience in **managing spare parts** inventory?
    - What are the challenges you face?
    - What are the key performance indicators (KPIs) you use?
- **Choose 1 person to share your group's discussion with the class.**

Refresher #1: Inventory Control Framework

- Inventory control is about managing the trade-off between **costs** and **service levels**.
- Often takes the form of **simple rules or policies**.
- Approaches to define the inventory policy:
    - **Mathematical programming**: use **historical data** and solutions from **optimazation** models.
    - **Analytical model** or simulation: use **statistics and analytical** solutions to estimate the **optimal policy**.
    - **Heuristic/expert policy**: use **expert knowledge** and wisdom from the field.

Refresher #2: Inventory Policies

- The inventory policy is a set of rules that determine **when** and **how much** to order.
- The policy should be **simple**, **easy to understand**, and **easy to implement**.
- Examples:
    - Order x units every other week
    - Order y units when the inventory runs out
    - Check the inventory every day and order x units if the inventory is below y units.
   - ...

Refresher #3: Common Inventory Policies

- **(Continuous) Reorder Point (s, Q) Policy**: Order Q units when the inventory level reaches s units.
- **Periodic Review (R, S) Policy**: Review the inventory every R time and replenish inventory to S units.
- **Hybrid Policies**: Combination of the above policies
  - **(Continuous) Base Stock (s, S) Policy**: Replenish the inventory to S units whenever the inventory level drops to s units.

- Can you identify all the ??? in the legend?

Basic of Inventory Plots
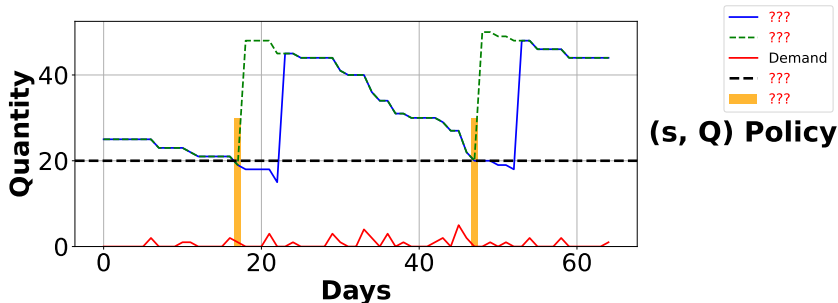
(s, Q) Policy
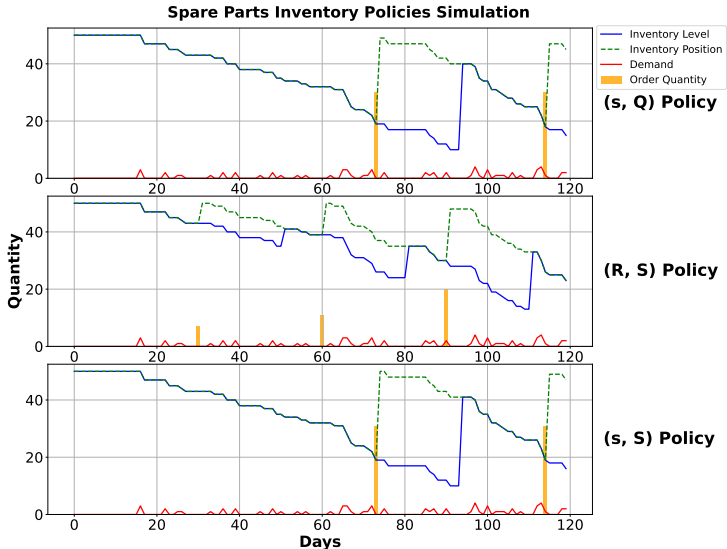
Basic of Inventory Plots
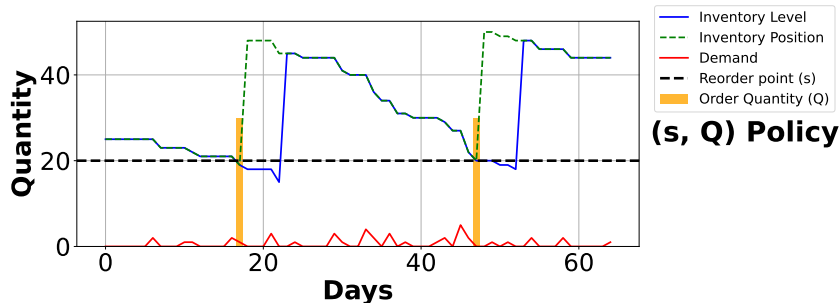
(s, Q) Policy

- What is the **order lead time** in this plot?
- During which period is a **stockout** likely to happen?
- If you want to **prevent stockouts**, what would you do?

Metrics for Inventory Policies

- An inventory policy is often evaluated based on the following metrics:
  - **Service level**: the probability of not running out of stock.
  - **Stockout cost**: the cost of not having the item in stock.
  - **Holding cost**: the cost of holding the item in stock.
  - **Order cost**: the cost of placing an order.
  - **Total cost**: the sum of stockout cost, holding cost, and order cost.

- For spare parts, the demand is often intermittent and unpredictable.
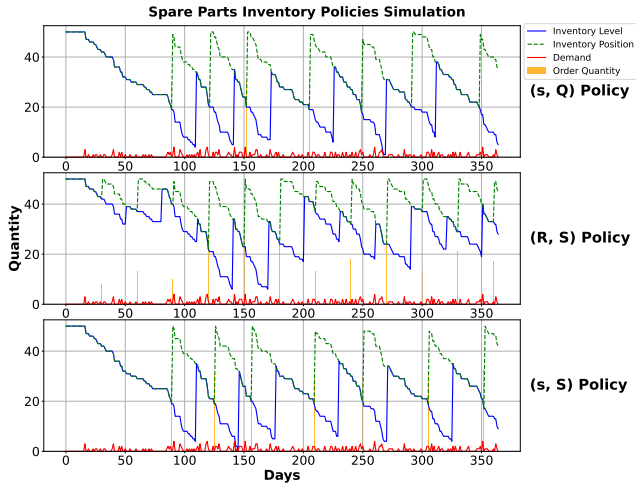

Spare Parts Inventory Policies Simulation

Evaluating Inventory Policies for Spare Parts (2)

- For spare parts, the demand is often intermittent and unpredictable.
- The lead time is usually long, the planning horizon is often long.

Spare Parts Inventory Policies Simulation

Service Level and Cost Calculation (1)

- **Service level** (SL): the probability of not running out of stock.

$$SL = 1 - \underbrace{\frac{\text{Number of stockouts}}{\text{Total number of periods}}}_{\text{a.k.a. stockout probability}}$$

- **Number of stockouts**: the number of times the inventory level could not meet the demand.
- SL is often set to a target value (e.g., 95%).
- If there are multiple simulation runs, SL is the **average** of all runs.

Service Level and Cost Calculation (2)

- **Stockout cost** ($C_{stockout}$): the cost of not having the item in stock.

$$C_{stockout} = \text{Stockout cost/unit} \times \text{Number of stockouts}$$

- **Holding cost** ($C_{holding}$): the cost of holding the item in stock.

$$C_{holding} = \text{Holding cost/unit/period} \times \text{Total inventory level}$$

Total inventory level $= \sum_{t=1}^{T} \text{Inventory level at the end of time } t$

- **Order cost** (C_{order}): the cost of placing an order.

$$C_{order} = \text{Order cost/order} \times \text{Number of orders}$$

Service Level and Cost Calculation (3)

- **Total Cost** (C_{total}): the sum of stockout cost, holding cost, and order cost.

$$C_{\text{total}} = C_{\text{stockout}} + C_{\text{holding}} + C_{\text{order}}$$

- Both the service level and the total cost are functions of the inventory policy.
  - **When to order** is related to the service level, stockout cost, order cost, among others
  - **How much to order** is related to the holding cost, among others

Activity #2: Discuss the Metrics

- **Form a group of 2-3 people and discuss the following:**
- **Service Level**:
    - How do you measure the service level in your department?
    - What is the target service level you'd set for spare parts that are critical for your operation?
- **Costs**:
    - Which cost components are more important in your department?
    - Which cost components are more difficult to estimate? Which are easier?
- **Other Metrics**: Are there other metrics you'd use?
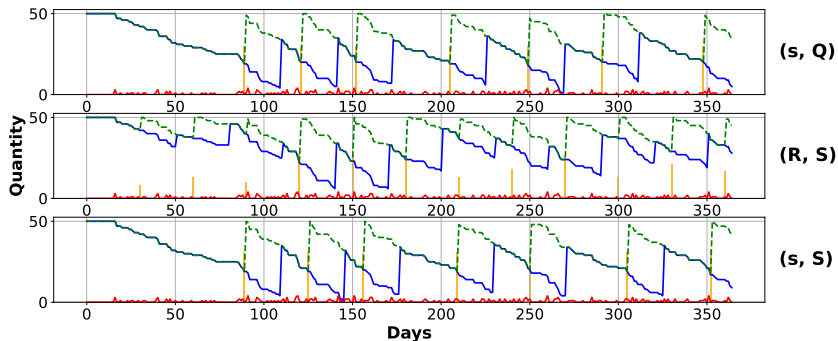
Single-run Evaluation (1)

- **Parameters**:
  - Initial inventory level: 50 units
  - Stockout cost: Rp. 10.000.000/unit
  - Holding cost: Rp. 5.000/unit/day
  - Order cost: Rp. 50.000/order
  - Planning horizon: 365 days

- **Inventory Policies**:
  - (s, Q) policy: $s = 20$, $Q = 30$
  - (R, S) policy: $R = 30$, $S = 50$
  - (s, S) policy: $s = 20$, $S = 50$

Single-run Evaluation (2)

Policy	Service Level	C_{total}	$C_{holding}$	C_{order}	$C_{stockout}$
(s=20, Q=30)	100.00%	44.01	43.66	0.35	0.00
(R=30, S=50)	100.00%	56.33	55.73	0.60	0.00
(s=20, S=50)	100.00%	47.78	47.44	0.35	0.00

- Is there a policy that you'd recommend? Why?

Single-run Evaluation (3)

- With different demand samples, **the results may vary**.

Table: Demand samples from UP3 XYZ (in millions of Rupiah)

Policy	Service Level	C_{total}	$C_{holding}$	C_{order}	$C_{stockout}$
(s, Q)	98.63%	111.72	41.31	0.40	70.00
(R, S)	100.00%	50.92	50.33	0.60	0.00
(s, S)	99.45%	65.83	45.48	0.35	20.00

Table: Demand samples from UP3 ZYX (in millions of Rupiah)

Policy	Service Level	C_{total}	$C_{holding}$	C_{order}	$C_{stockout}$
(s, Q)	100.00%	44.49	44.14	0.35	0.00
(R, S)	100.00%	56.97	56.37	0.60	0.00
(s, S)	99.73%	61.39	51.05	0.35	10.00
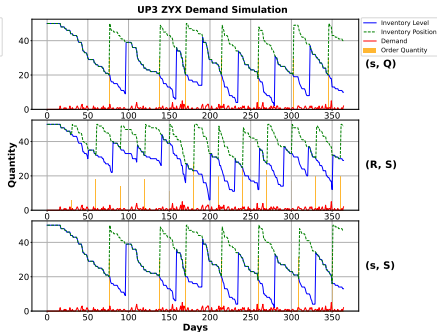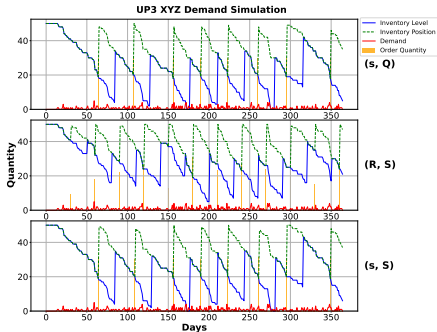
- What may cause demand differences for the same spare part?
  - Different locations?
  - Different years?

Stochastic spare parts demand

- Recall the metrics:
    - **Service level**: the probability of not running out of stock.
    - **Costs**: consists of stockout, inventory holding, and ordering costs
- These metrics are functions of both the **inventory policy** and the **stochastic demand**.
- For **stochastic demand**, metrics from a single sample is not enough
- The metrics **should estimated using multiple samples** (e.g., 100 samples)
- **Goal**: find the policy that **minimizes the total cost** while **maintaining an acceptable service level**.

Multi-runs (a.k.a Simulation) Evaluation

- Let's calculate the metrics using $k = 100$ demand data.

Table: Service Level and Total Cost

Policy	SL (%)	C_{total} (in millions of Rupiah)
(R, Q)	$99.79\% \pm 0.33\%$	58.49 ± 18.84
(T, S)	$99.97\% \pm 0.18\%$	56.97 ± 11.97
(s, S)	$99.83\% \pm 0.34\%$	56.20 ± 19.14

Table: Total Cost Breakdown (in millions of Rupiah)

Policy	$C_{holding}$	C_{order}	$C_{stockout}$
(R, Q)	45.55 ± 1.99	0.34 ± 0.03	12.60 ± 19.78
(T, S)	54.07 ± 2.80	0.60 ± 0.00	2.30 ± 12.64
(s, S)	46.27 ± 1.90	0.33 ± 0.03	9.60 ± 19.39

- What is your conclusion now?

Summarizing Simulation Results

- When using more samples, the results give a more complete picture.
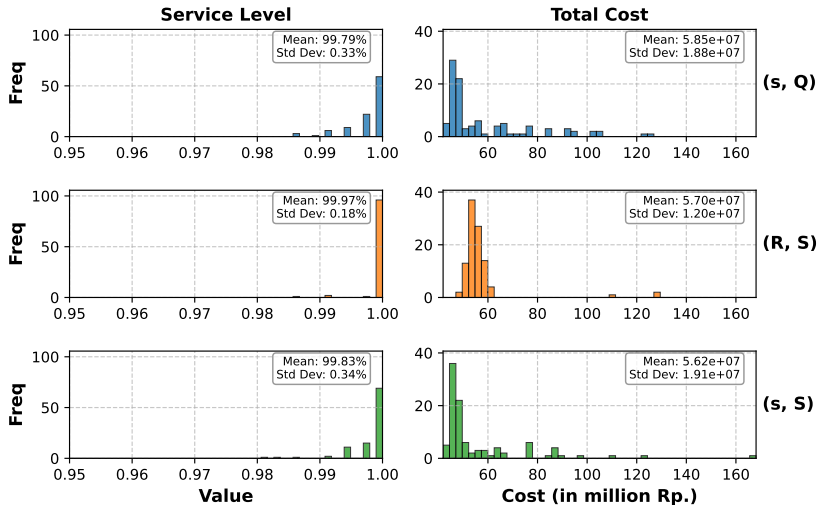
- Does the simulation results change your recommendation (vs. the single-run evaluation)? Why or why not?
- How would you present the results to your manager?
- Can you collect multiple demand data in your organization to carry this out? What are the challenges?
- What other problems in your organization can benefit from stochastic (simulation) evaluation?

Summary

- Inventory control for spare parts is unique (vs. other common items).
- Inventory policies mostly use simple rules (e.g., (s, Q), (R, S), (s, S)).
- The policies are evaluated based on service level and cost (often trade-offs).
- The evaluation can be done using deterministic or stochastic approaches.

What's next?

- How to choose the optimal s, Q, R, and S values?
- How to deal with many spare part items?
  - Most items (often around 80%) are slow-moving and low-value (low stockout cost).
  - Only a small portion are critical (high stockout cost).

Thank you!
Questions?