Spare Part Inventory Control and Management
Stochastic Optimization and Simulation Approaches

By: Mansur M. Arief (SIMT ITS)

Kelas S2 PJJ PLN, Program Studi Magister Teknik Industri
Departemen Teknik dan Sistem Industri (DTSI)
Institut Teknologi Sepuluh Nopember (ITS) Surabaya

23 September 2024

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

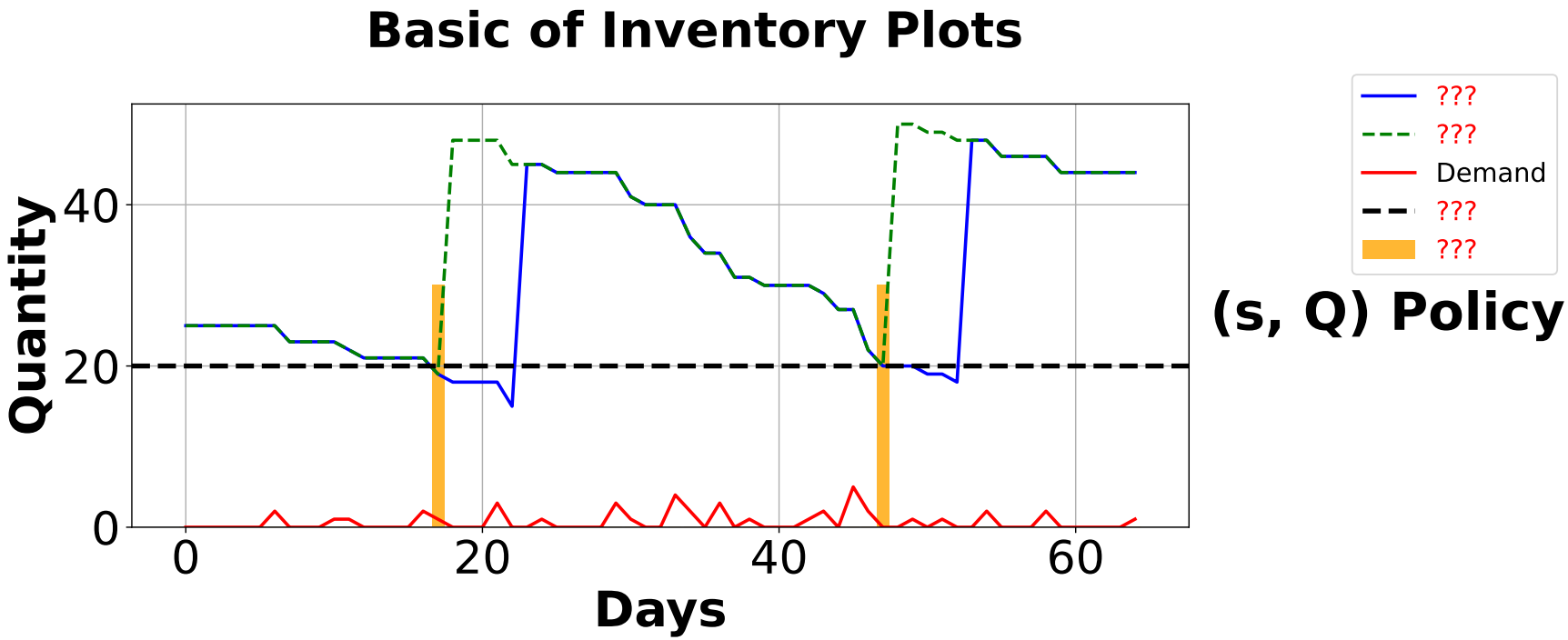
- The inventory policy is a set of rules that determine **when** and **how much** to order.
- The policy should be **simple**, **easy to understand**, and **easy to implement**.
- Examples:
  - Order x units every other week
  - Order y units when the inventory runs out
  - Check the inventory every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

Refresher #3: Common Inventory Policies

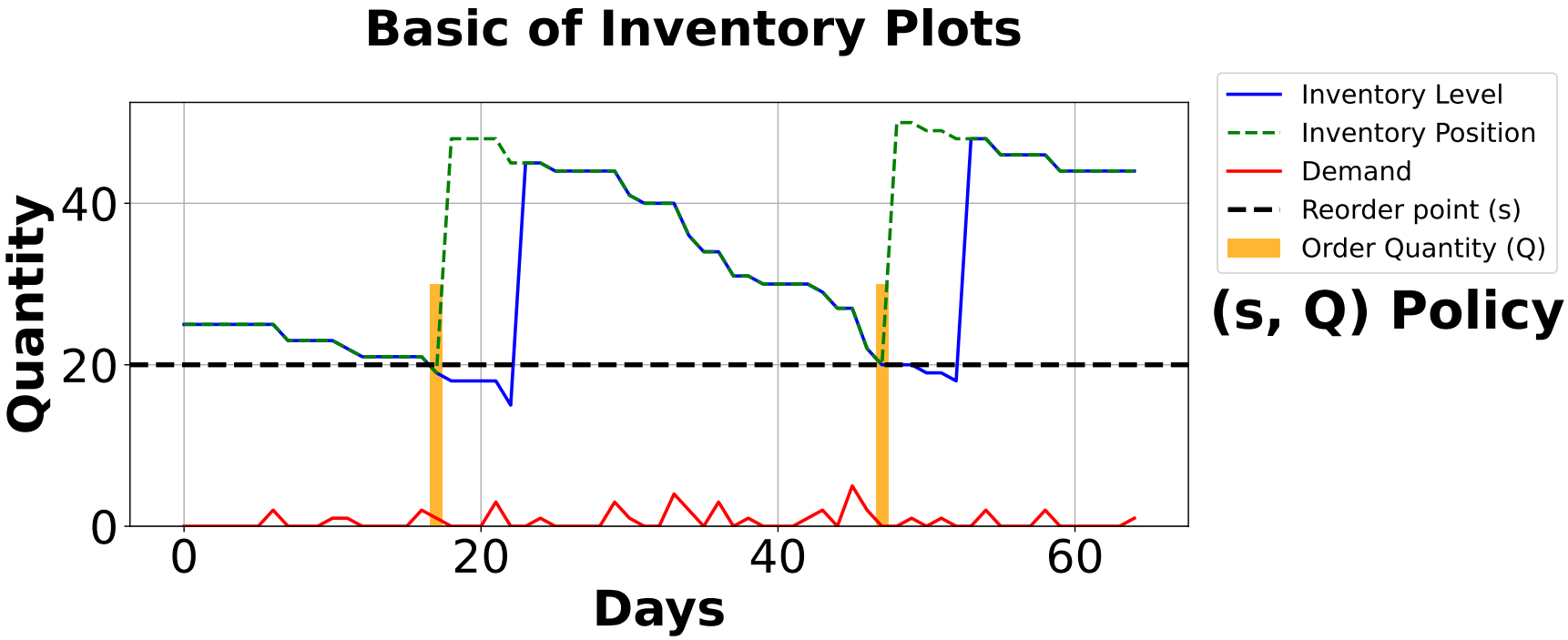
- **(Continuous) Reorder Point (s, Q) Policy**: Order Q units when the inventory level reaches s units.
- **Periodic Review (R, S) Policy**: Review the inventory every R time and replenish inventory to S units.
- **Hybrid Policies**: Combination of the above policies
  - **(Continuous) Base Stock (s,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

Refresher #4: Understanding Inventory Plot (1)

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



Refresher #4: Understanding Inventory Plot (2)



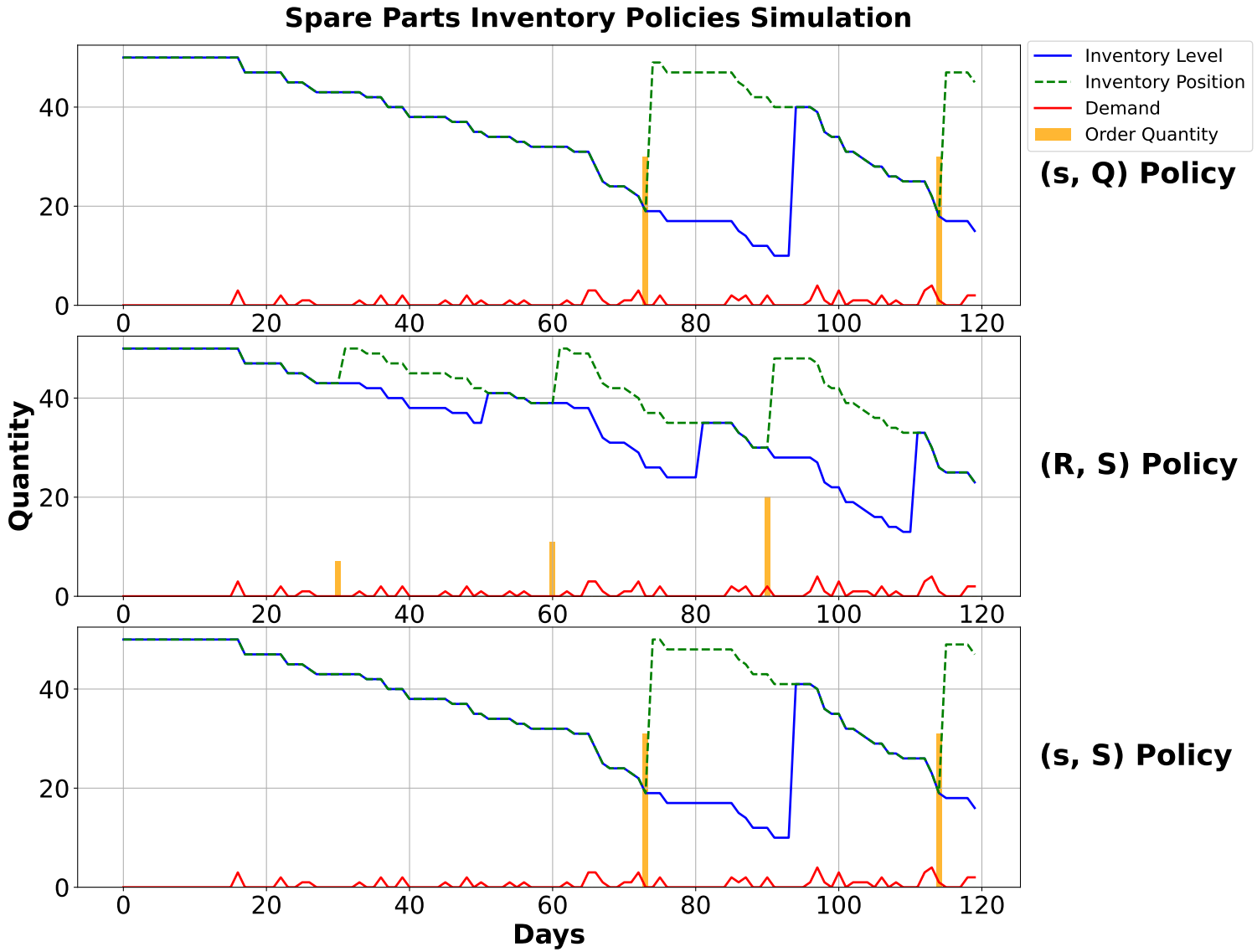
- What is the **order lead time** in this plot?
- During which period is a **stockout** likely to happen?
- If you want to **prevent stockouts**, what would you do?

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.

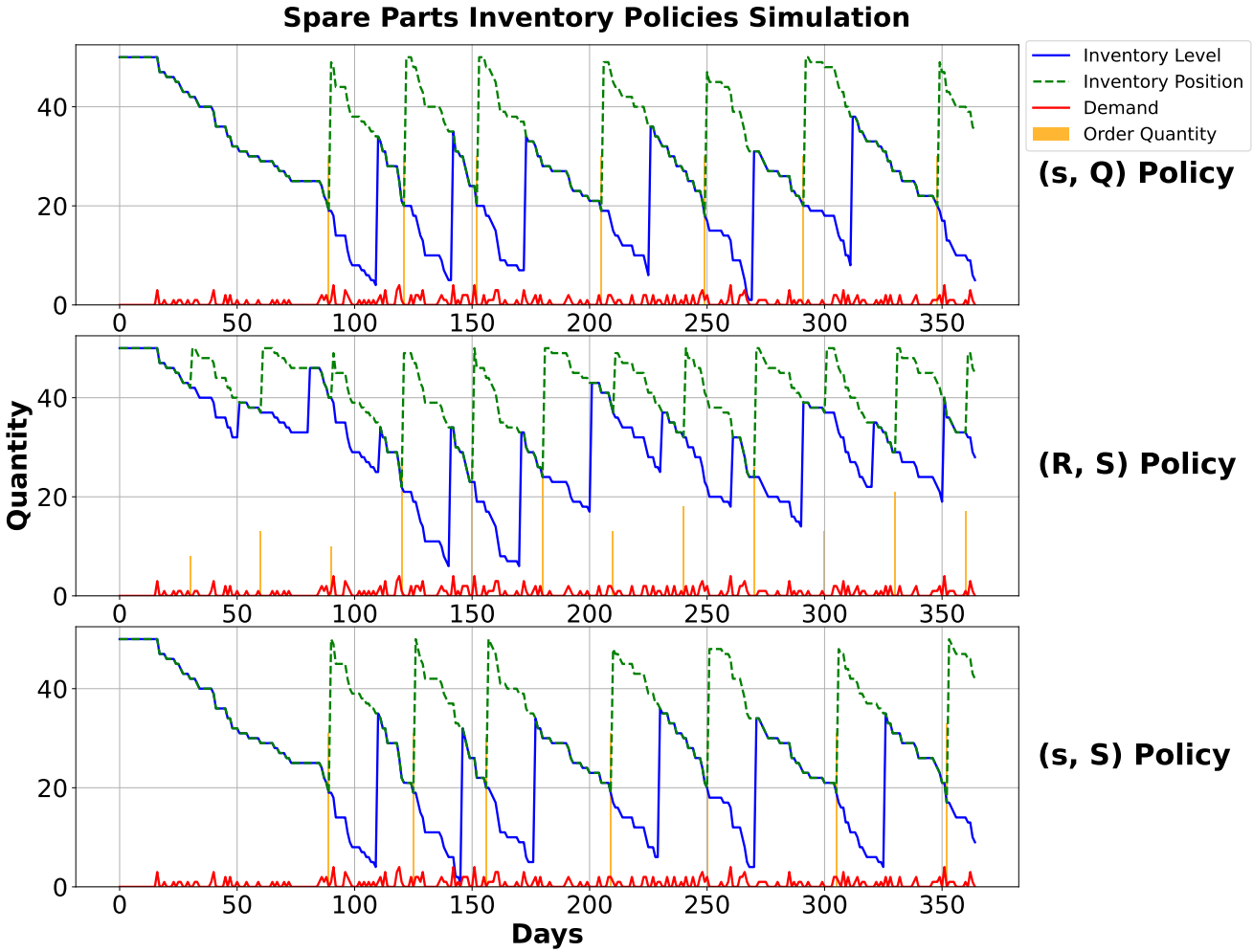
Evaluating Inventory Policies for Spare Parts (1)

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



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.



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.

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

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

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

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

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

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

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

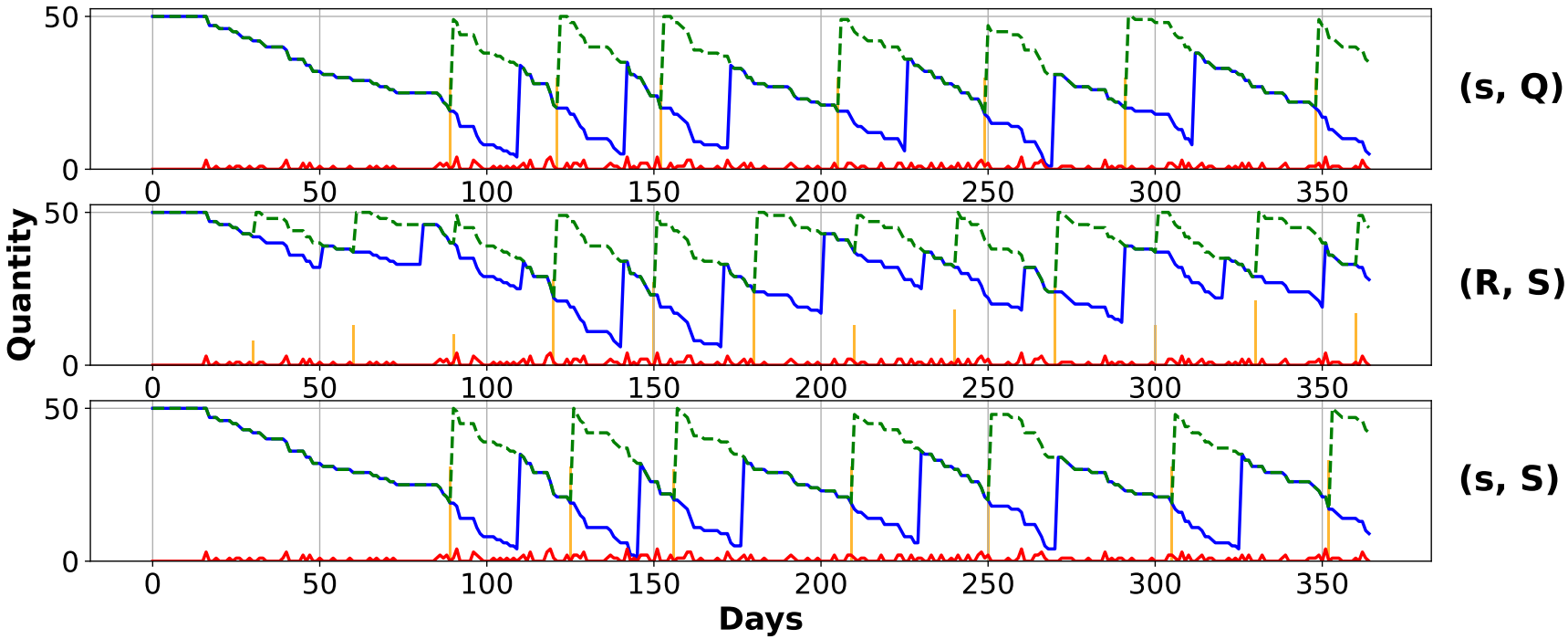
- **Form a group of 2-3 people and discuss the following:**
- **Service Level**:
  - How do you measure the service level in your department?
  - What is the target service level you'd set for spare parts that are critical for your operation?
- **Costs**:
  - Which cost components are more important 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**.

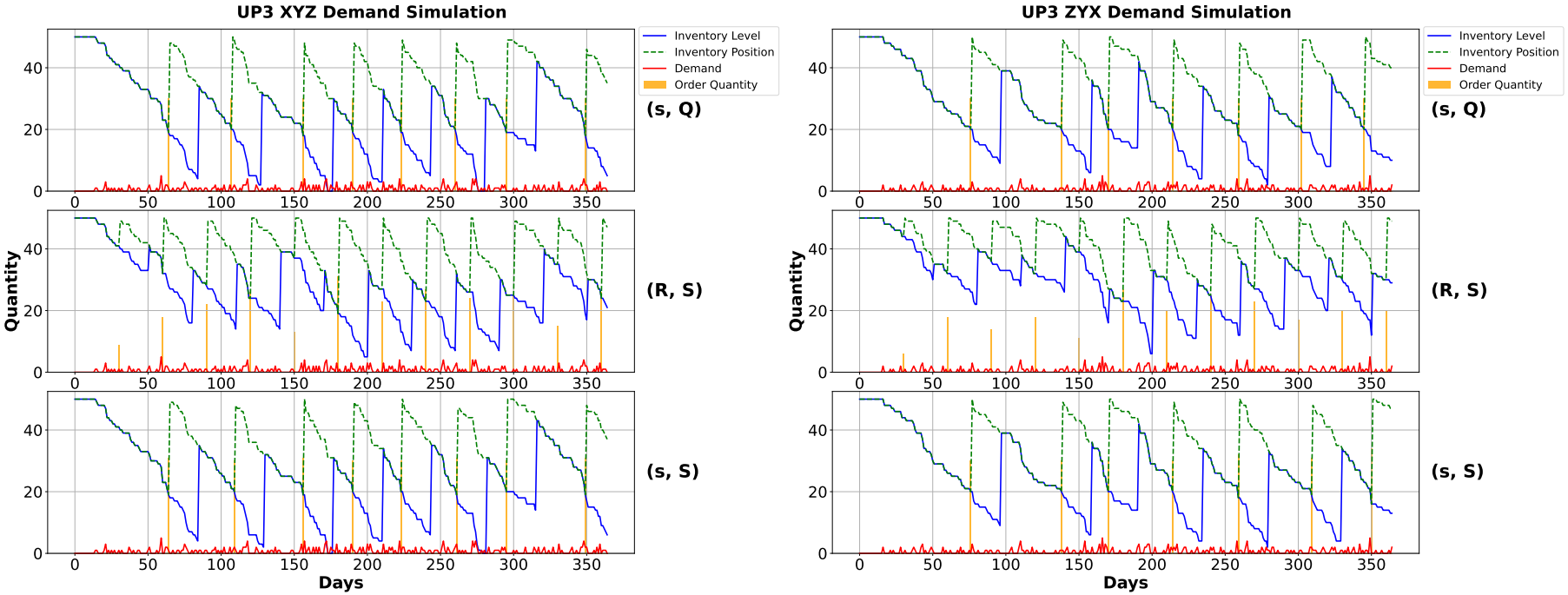
Table: Demand samples from UP3 XYZ (in millions of Rupiah)

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

Single-run Evaluation (4)



- 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)
(s, Q)	99.79% ± 0.33%	58.49 ± 18.84
(R, S)	99.97% ± 0.18%	56.97 ± 11.97
(s, S)	99.83% ± 0.34%	56.20 ± 19.14

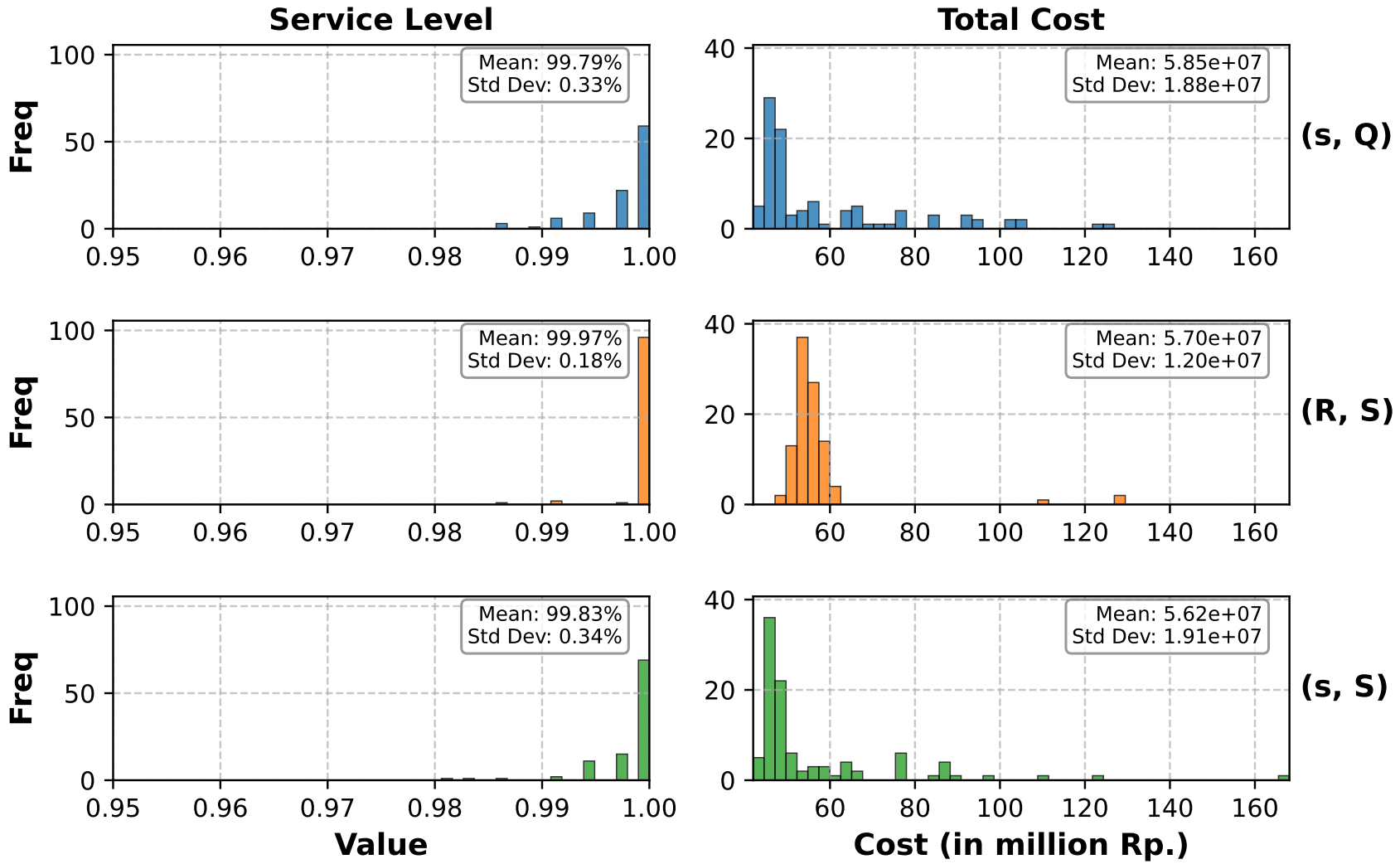
Table: Total Cost Breakdown (in millions of Rupiah)

Policy	$C_{holding}$	C_{order}	$C_{stockout}$
(s, Q)	45.55 ± 1.99	0.34 ± 0.03	12.60 ± 19.78
(R, 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.



Activitiy #3: Simulation Results

- 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).

Homework for Next Week

- Discuss **Activity #3** and present to the class next week.
- **Stochastic demand and cost data**:
  - Collect (or simulate) demand data for 1 (one) spare part/product relevant to your organization
    - make sure to anonymize the data
    - collect at least 10 data points
  - Collect (or estimate) the costs associated with stockouts, holding, and ordering for the same spare part/product
    - make sure to anonymize the data
  - Discuss these data with your team and present to the class next week.

Thank you!

Questions?