# 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.

# 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.

# 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.)

# 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.

# 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**.

# 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**.

# 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.

# 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**.

# 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.

# Refresher #3: Common Inventory Policies

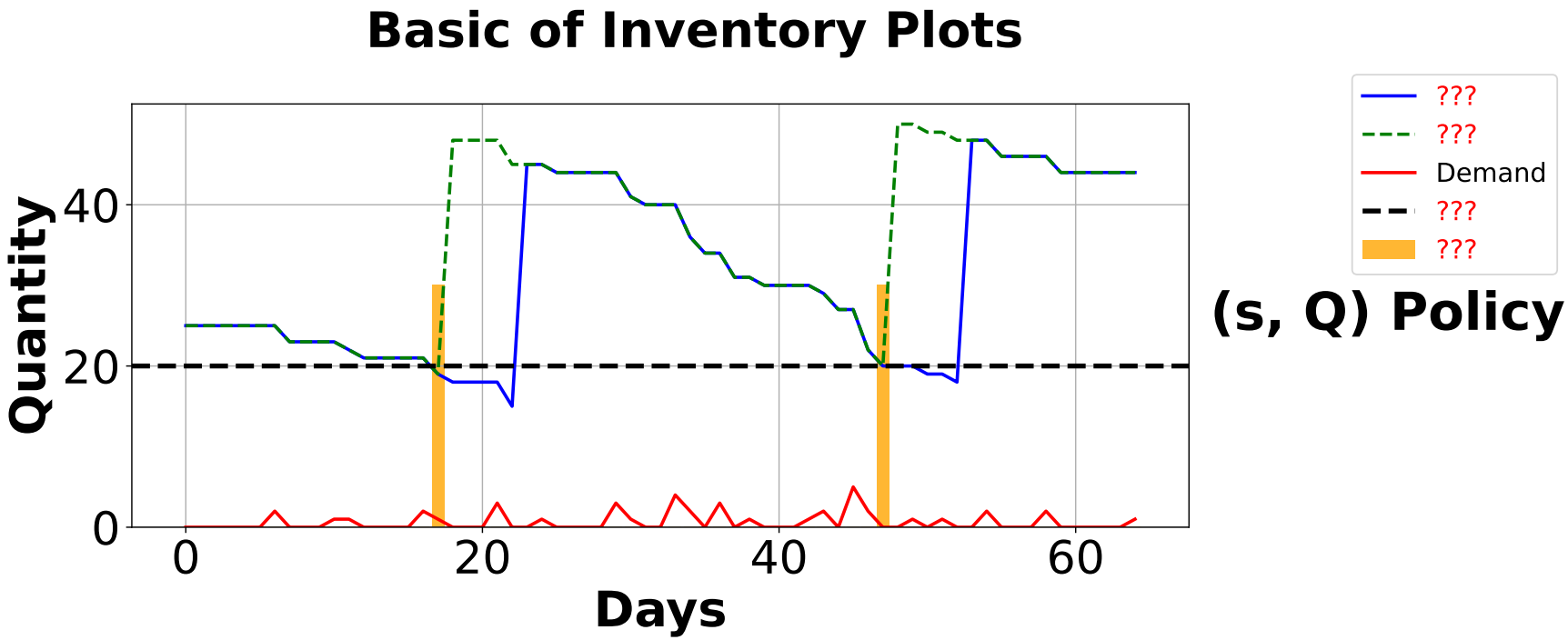
- **(Continuous) Reorder Point (s, Q) Policy**: Order $Q$ units when the inventory level reaches $s$ units.
- **Periodic Review (R, S) Policy**: Review the inventory every $R$ time and replenish inventory to $S$ units.

# Refresher #3: Common Inventory Policies

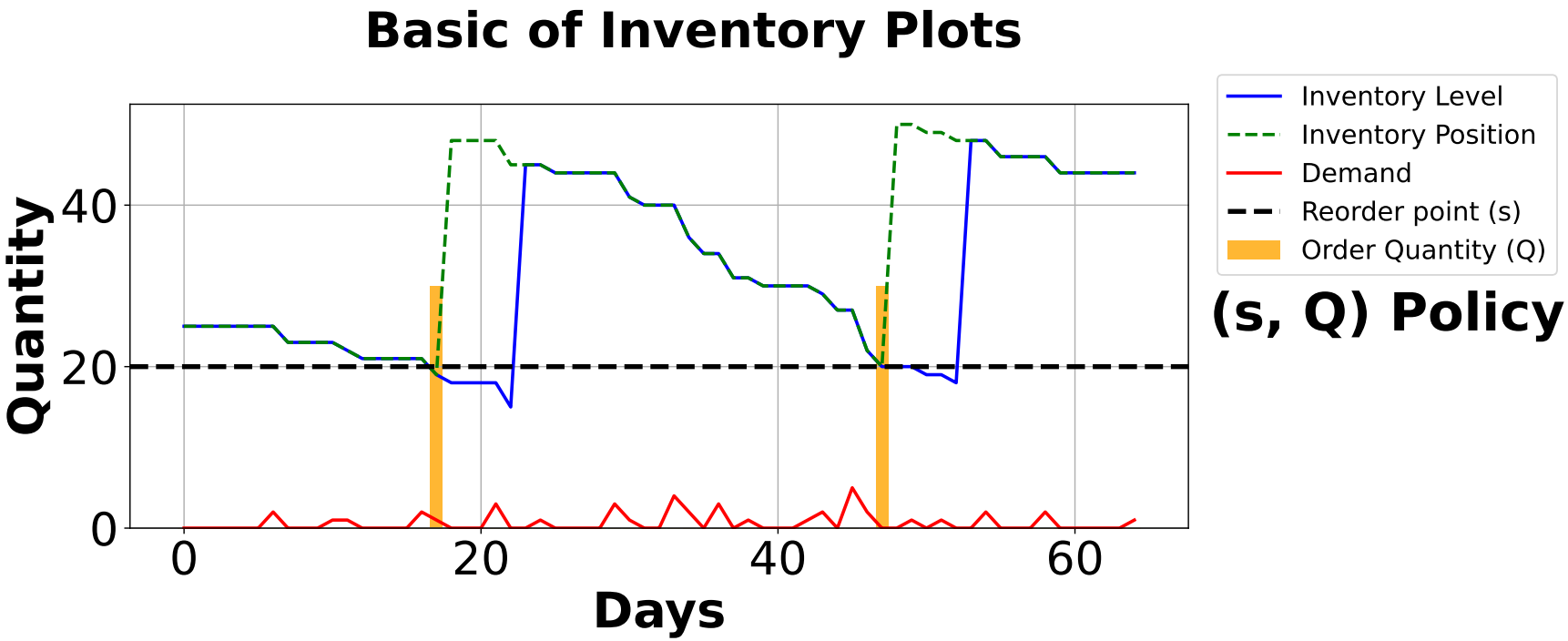
- **(Continuous) Reorder Point (s, Q) Policy**: Order $Q$ units when the inventory level reaches $s$ units.
- **Periodic Review (R, S) Policy**: Review the inventory every $R$ time and replenish inventory to $S$ units.
- **Hybrid Policies**: Combination of the above policies
  - **(Continuous) Base Stock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

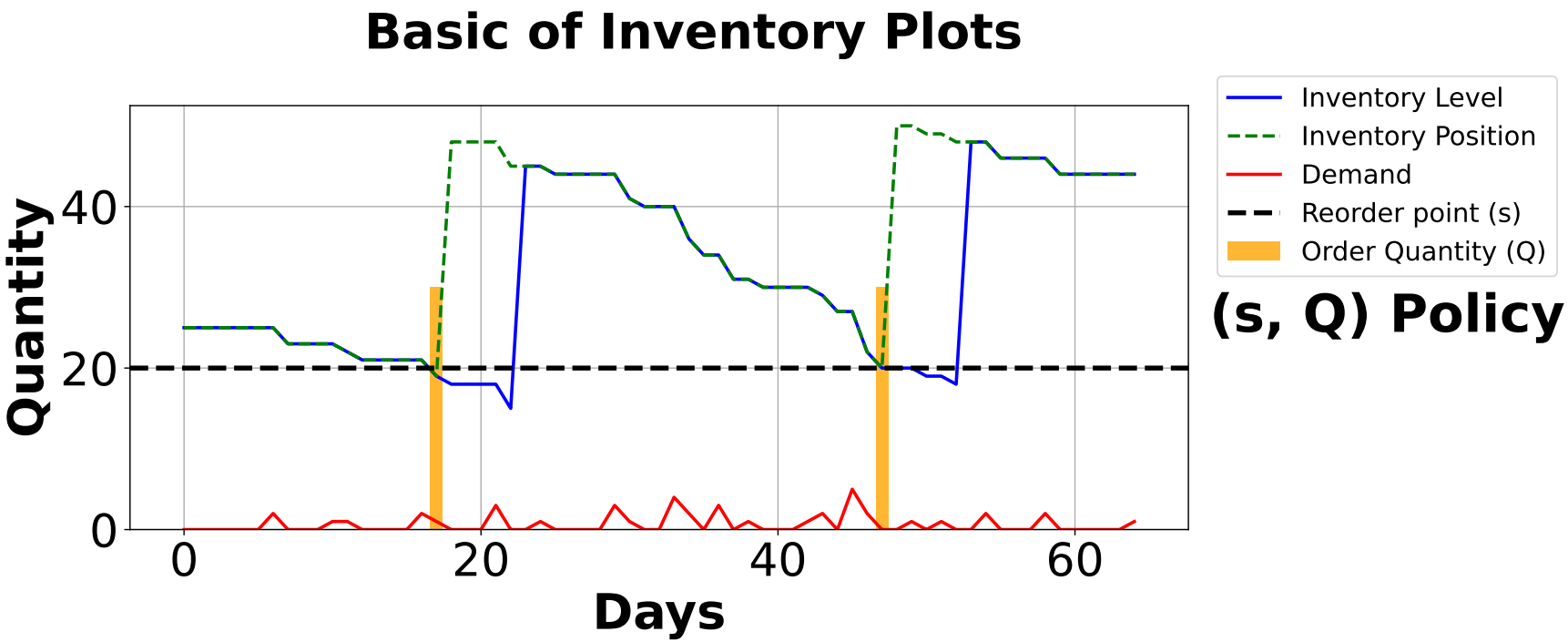


# Refresher #4: Understanding Inventory Plot (2)



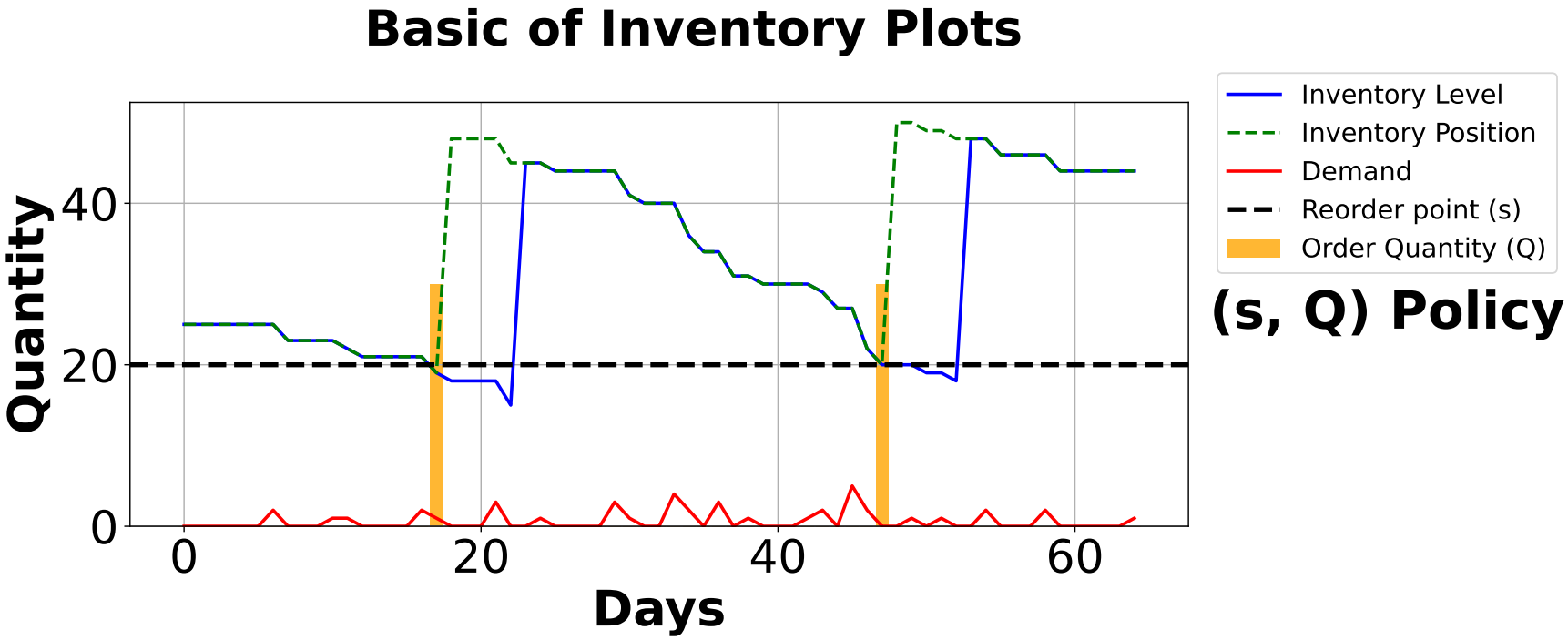

- What is the **order lead time** in this plot?

# Refresher #4: Understanding Inventory Plot (2)




- What is the **order lead time** in this plot?
- During which period is a **stockout** likely to happen?

# Refresher #4: Understanding Inventory Plot (2)



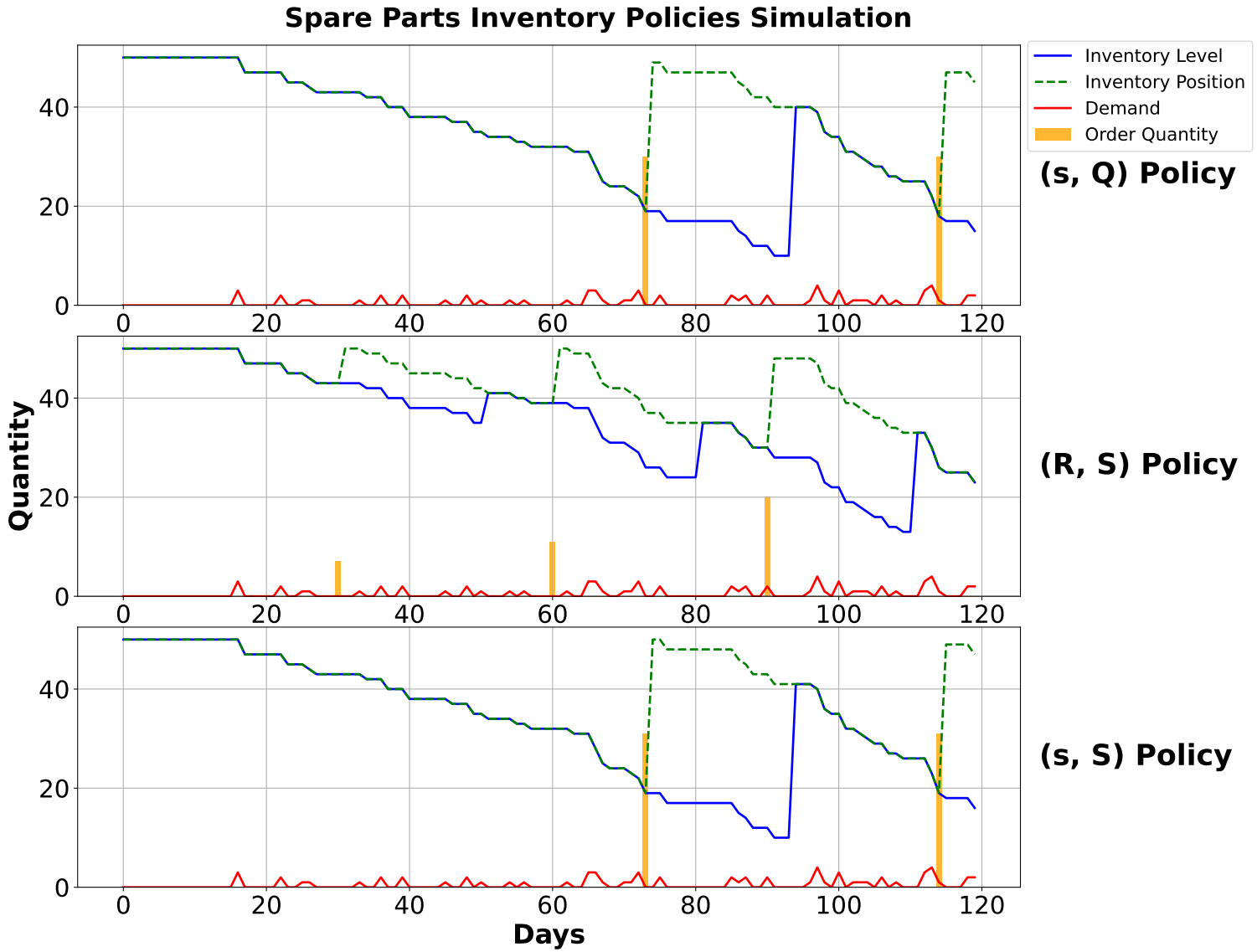

- What is the **order lead time** in this plot?
- During which period is a **stockout** likely to happen?
- If you want to **prevent stockouts**, what would you do?

# 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.

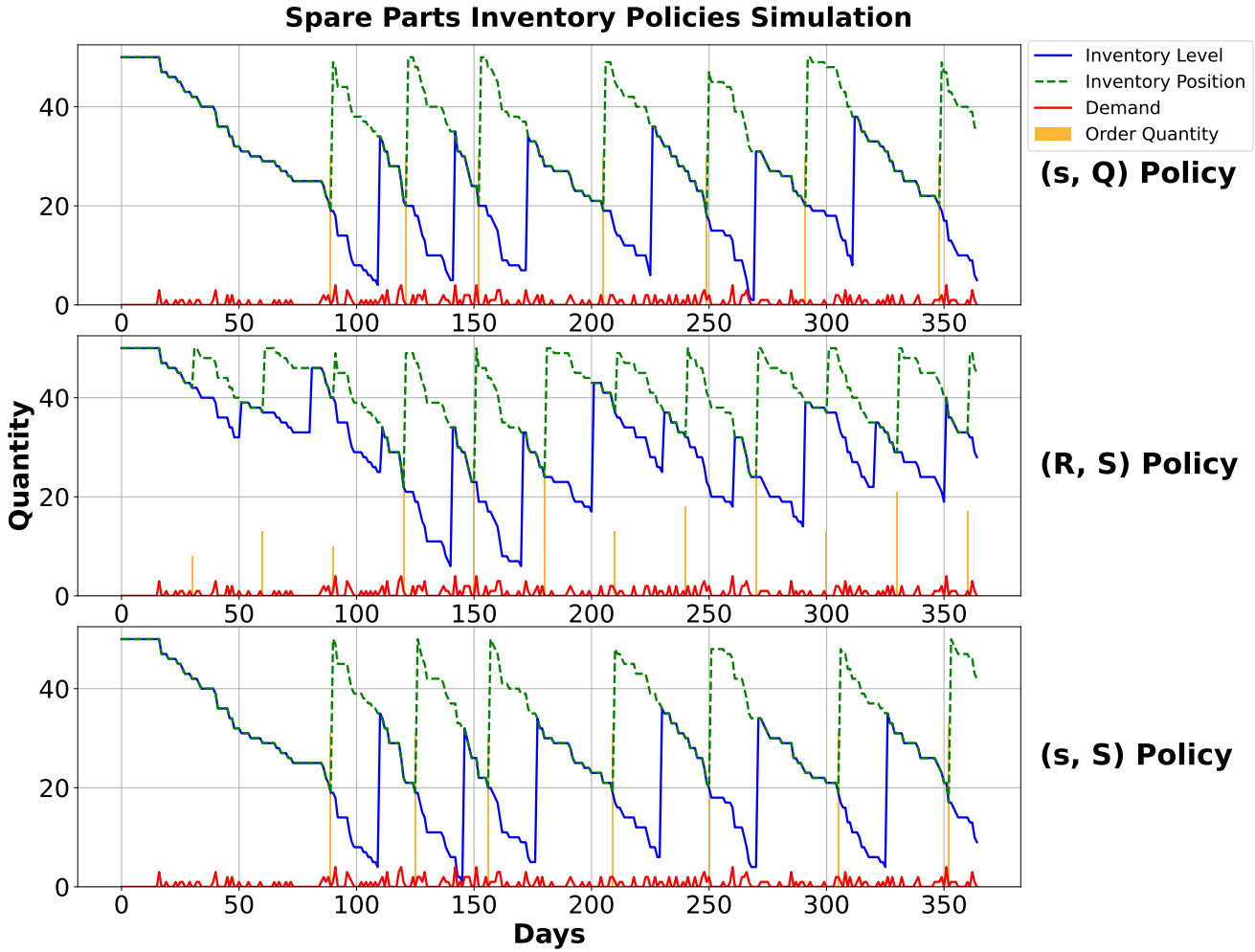
# Evaluating Inventory Policies for Spare Parts (1)

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

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

# Service Level and Cost Calculation (2)

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

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

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

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

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

# Service Level and Cost Calculation (2)

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

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

- **Holding cost** ($C_{\text{holding}}$): 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** ($C_{\text{order}}$): 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** ($C_{\text{total}}$): the sum of stockout cost, holding cost, and order cost.

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

# Service Level and Cost Calculation (3)

- **Total Cost** ($C_{\text{total}}$): 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

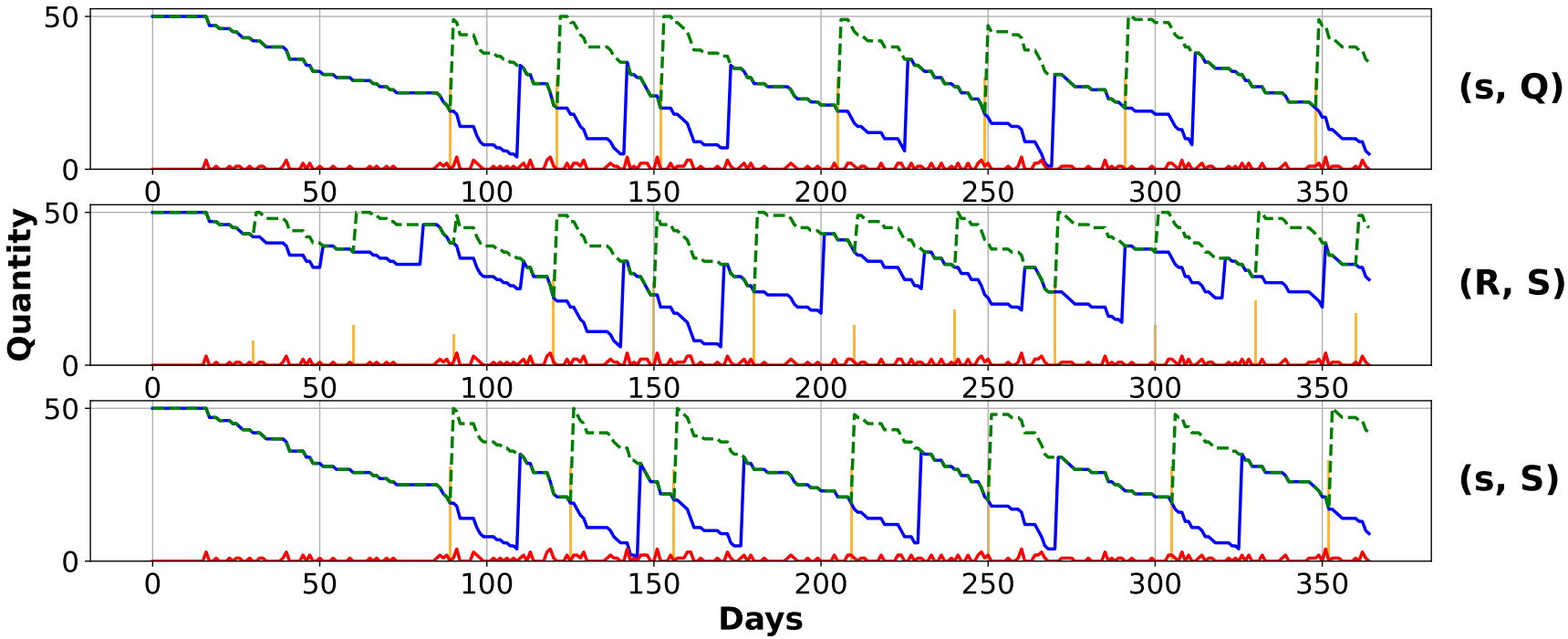
- **Form a group of 2-3 people and discuss the following:**
- **Service Level**:
  - How do you measure the service level in your department?
  - What is the target service level you'd set for spare parts that are critical for your operation?
- **Costs**:
  - Which cost components are more important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

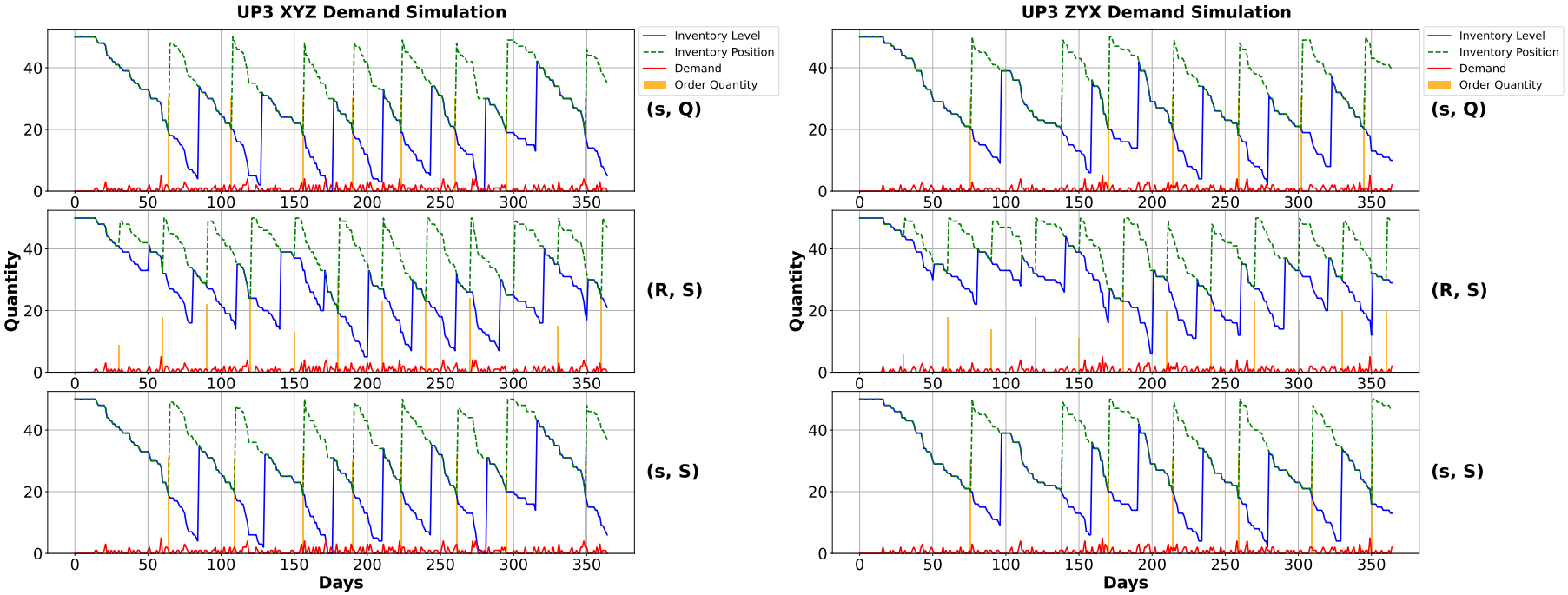
Table: Demand samples from UP3 XYZ (in millions of Rupiah)

| 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

# 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**.

# 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

# 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)

# 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% ± 0.33% | 58.49 ± 18.84 |
| (T, S) | 99.97% ± 0.18% | 56.97 ± 11.97 |
| (s, S) | 99.83% ± 0.34% | 56.20 ± 19.14 |

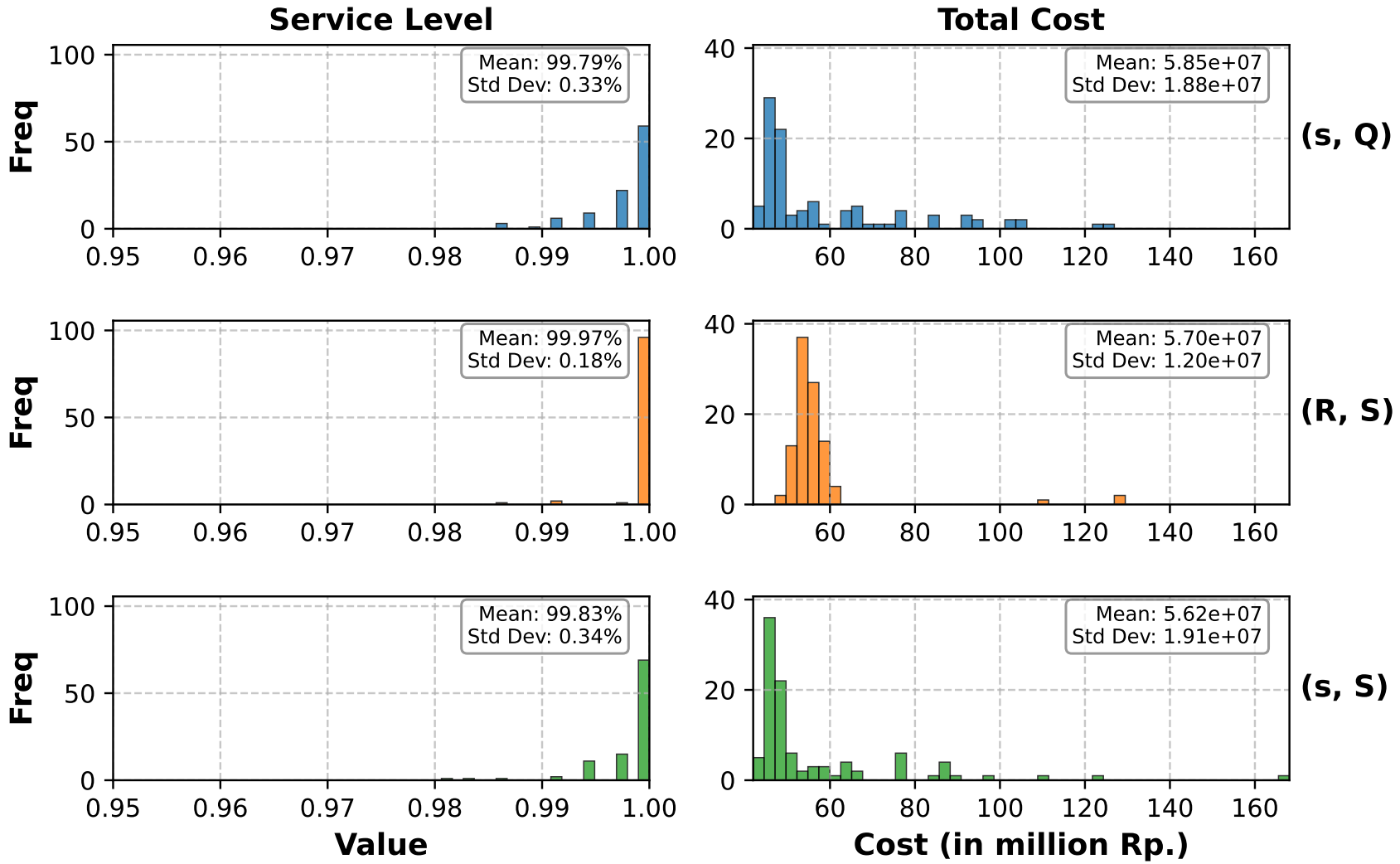
Table: Total Cost Breakdown (in millions of Rupiah)

| Policy | $C_{holding}$ | $C_{order}$ | $C_{stockout}$ |
|---|---|---|---|
| (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.



# 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).

# 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)).

# 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).

# 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?

# 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?