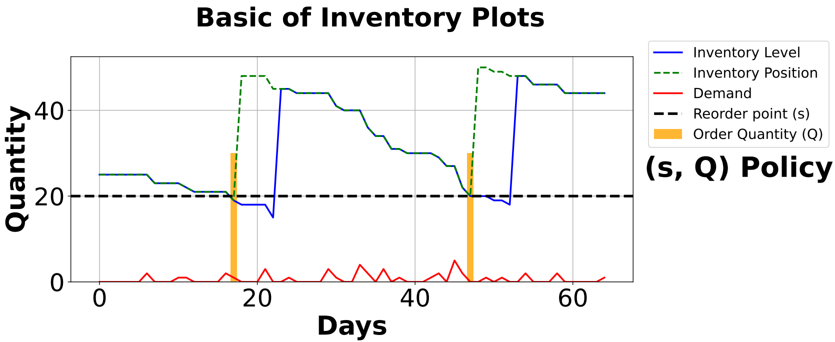
Spare Part Inventory Control and Management - 2
Stochastic Optimization and Simulation Approaches

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

30 September 2024

Outline



- Interpreting inventory plots.
- 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 SL and cost (often trade-offs).
- The evaluation can be deterministic or stochastic.

Homework

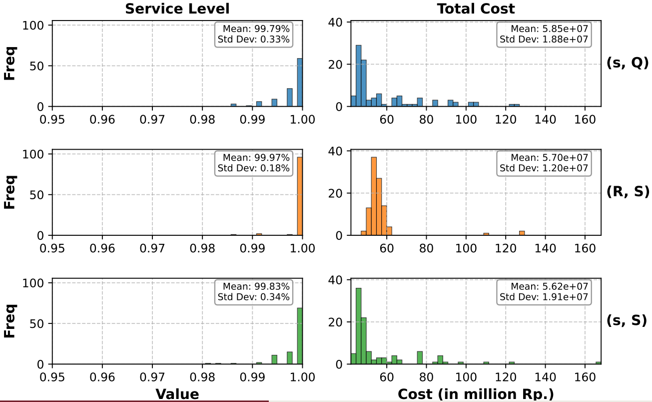
- Discuss **Activity #3** and present to the class.
- **Stochastic demand and cost data**:
  - Collect (or simulate) demand data for 1 (one) spare part/product relevant to your organization
    - make sure to anonymize the data
    - collect at least 10 data points
  - Collect (or estimate) the costs 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.

Activity #3: Simulation Results (1)

- Does the results change your recommendation? Why or why not?
  - **Single Run Evaluation**:

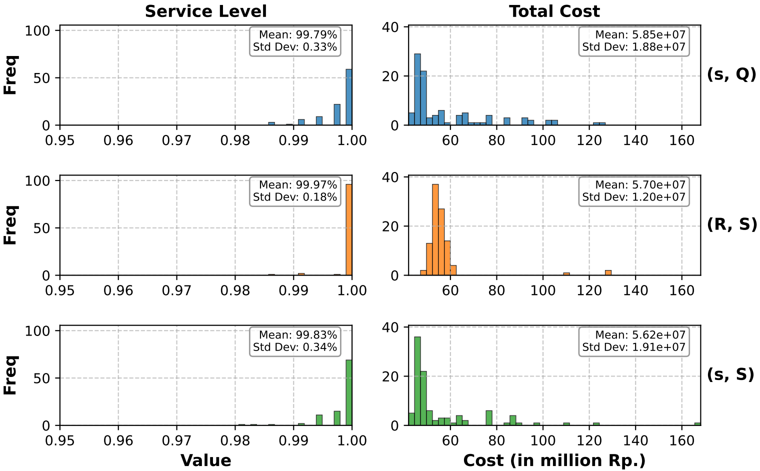
Policy	Service Level	C_{total}	$C_{holding}$	C_{order}	$C_{stockout}$
(s=20, Q=30)	100.00%	44.01	43.66	0.35	0.00
(R=30, S=50)	100.00%	56.33	55.73	0.60	0.00
(s=20, S=50)	100.00%	47.78	47.44	0.35	0.00

  - **Multi Run Evaluation**:



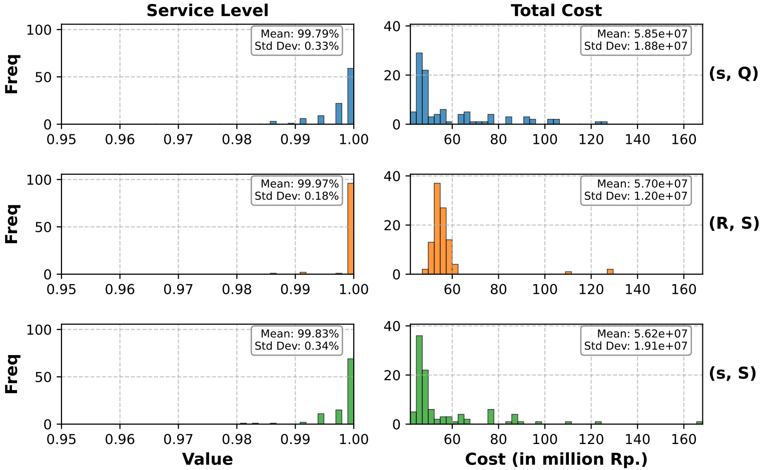
Activity #3: Simulation Results (2)

- How would you present the results to your manager?



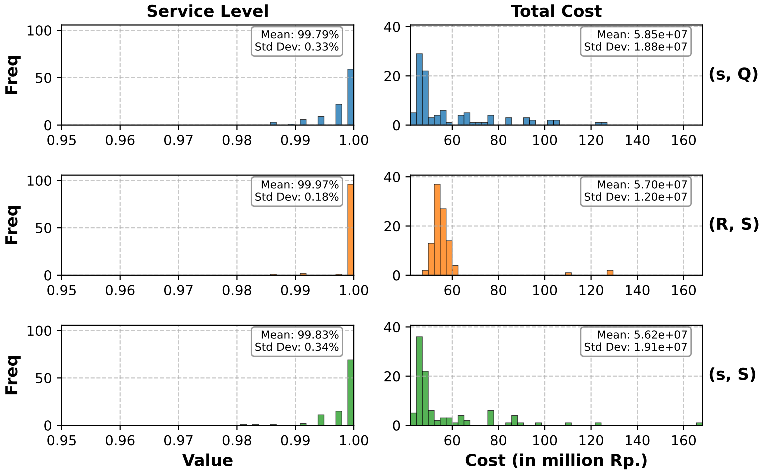
Activity #3: Simulation Results (3)

- Can you collect multiple demand data in your organization to carry this out? What are the challenges?



Activity #3: Simulation Results (4)

- What other problems in your organization can benefit from stochastic (simulation) evaluation?



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.

How do we choose the best (s, Q) or (R, S) parameters?

- **Mathematical optimization**: build a model, load the data, and solve.
- **Analytical methods**: use formulas to find the best parameters.
- **Expert judgment**: use experience and intuition to set the parameters.

Activity #4: Expert Judgment

- Open these two Google spreadsheets (**sQ_policy** and **RS_policy**):

https://bit.ly/sQ_policy   https://bit.ly/RS_policy

- Discuss and find the best (s, Q) and (R, S) parameters (**6 minutes**)
- Submit your group answers in the Google Form provided: https://forms.gle/pT4Jfy3kMPVNzdxBA
- We'll evaluate your answers and calculate the metrics for each group using **the same cost data** but **a different set of demand data**.
- **Share your observations** from this activity!

Analytical Methods (1)

- An alternative to expert judgment is to use analytical methods.
- For example, the (s, Q) policy can be optimized using the EOQ formula.
- Under the EOQ model, the optimal order quantity Q^* is given by:

$$Q^* = \sqrt{\frac{2 \cdot D \cdot C_{\text{order}}}{C_{\text{holding}}}} \tag{1}$$

  where
  - D is the annual demand,
  - C_{order} is the ordering cost (per order), and
  - C_{holding} is the holding cost (per unit per year).
- The optimal reorder point s^* with safety stock S_{safety} is given by:

$$s^* = D \cdot L + S_{\text{safety}} \tag{2}$$

  where
  - L is the lead time (in years), and
  - S_{safety} is the safety stock, commonly set to 0.65 times the standard deviation of demand during lead time ($D \cdot L$)

Analytical Methods (2)

- We have:
  - $C_{holding}$: Rp. 5.000/unit/day = Rp. 1.825.000/unit/year
  - C_{order}: Rp. 50.000/order
  - Planning horizon: 365 days (1 year)
  - Demand: 224 units/year
- We can calculate the optimal (s, Q) parameters as follows:

$$Q^* = \sqrt{\frac{2 \cdot 224 \cdot 50.000}{1.825.000}} = 3.5 \rightarrow 4 \text{ units}$$

- Assuming $L = 20$ days and $S_{safety} = 0$ units, we have

$$s^* = 224 \cdot \frac{20}{365} + 0 = 12.3 \rightarrow 13 \text{ units}$$

Analytical Methods (3)

- If you try this so-called **optimal** parameters (s^*, Q^*) for our problem, **the cost is excessively high**.

Table: EOQ Policy Evaluation Results (in millions of Rupiah)

Policy	Service Level	C_{total}	$C_{holding}$	C_{order}	$C_{stockout}$
(s=13, Q=4)	90.7%	364.05	22.05	2.00	340.00

- Your judgment is **waaay better** than the EOQ model.
- **Why?**

Analytical Methods (4)

- There's also a formula to select **the optimal (R, S) parameters**.
- We will skip this, but you can find it in your textbook (**page 36-40**).
- What does **your intuition** say about the optimal (R, S) parameters?

Mathematical Optimization (1)

- The EOQ model is a simplification of the real world.
- We can build a more complex model using **mathematical optimization**.
- For example, we can use the **stochastic optimization** approach.
- In this approach, we optimize the inventory policy by considering the **stochastic nature of demand**.

Mathematical Optimization (2)

- A simple (nonlinear) stochastic model is as follows:

$$\min_{s,Q} \; C_{\text{order}} \cdot n_{\text{orders}} + C_{\text{holding}} \cdot IL_{\text{total}} + C_{\text{stockout}} \cdot \text{Prob(Stockouts)}$$
$$\text{s.t. } \text{Prob(Stockouts)} \leq 1 - \text{SL}$$

where:

- $n_{\text{orders}} = \frac{\sum_{i=1}^{n} D_i}{Q}$ is the number of orders in a planning horizon,
- $IL_{\text{total}} = \sum_{i=1}^{n} IL_n^{\text{end}}$ is the total inventory level (on-hand),
- $\text{Prob(Stockouts)} = \frac{\sum_{i=1}^{n} \mathbb{I}(IP_n^{\text{end}} < 0)}{n}$ is the probability of stockouts.
- n is the number of days in the planning horizon,
- D_i is the demand in day i,
- IL_n^{end} is the inventory level (on-hand) at the end of day n, and
- IP_n^{end} is the inventory position at the end of day n.

Mathematical Optimization (3)

- If we have $K = 100$ sets of demand data, we can use the sum (or average) objective:

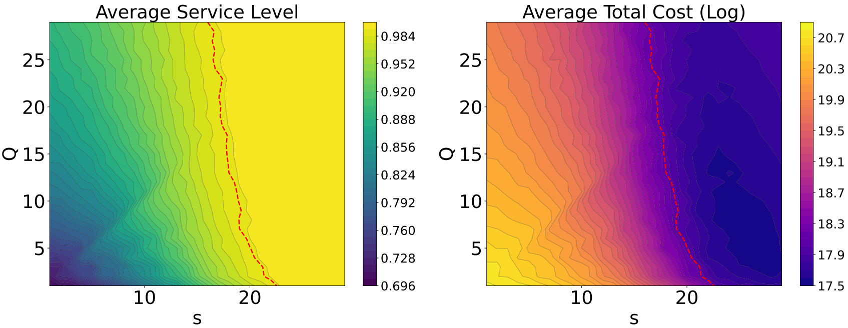
$$\min_{s,Q} \sum_{k=1}^{K} \left(C_{\text{order}} \cdot n^k_{\text{orders}} + C_{\text{holding}} \cdot IL^k_{\text{total}} + C_{\text{stockout}} \cdot \text{Prob}_k(\text{Stockouts}) \right)$$

  where:
  - n^k_{orders} is the number of orders for demand data set k,
  - IL^k_{total} is the total inventory level (on-hand) for demand data set k,
  - $\text{Prob}_k(\text{Stockouts})$ is the probability of stockouts for demand data set k.
- The constraint can also be based on the average service level:

$$\frac{1}{K} \sum_{k=1}^{K} \text{Prob}_k(\text{Stockouts}) \leq 1 - \text{SL}$$

Mathematical Optimization (4)

- Solving this model requires a **nonlinear optimization solver**.
- If we plot the objective values with 100 demand data, we get this contour plot (to the right of the red line is solutions with SL $\geq$ 99%)

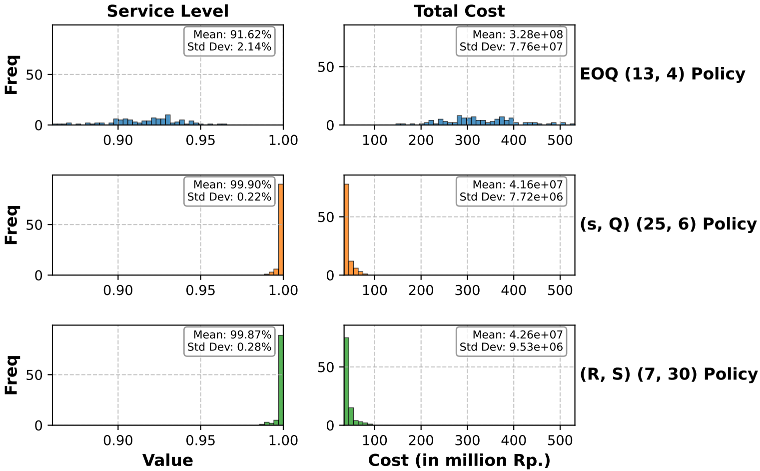


- Evaluating ($s = 25, Q = 6$) policy, we have the best metric!

Policy	Service Level	C_{total}	$C_{holding}$	C_{order}	$C_{stockout}$
(s=25, Q=6)	100%	37.85	36.15	1.70	0.00

Metrics Comparison: EOQ vs Stochastic Optimization

Policy	Service Level	C_{total}	$C_{holding}$	C_{order}	$C_{stockout}$
(s=13, Q=4)	91.6 ± 2.1%	328.3 ± 78.0	20.2 ± 1.6	2.1 ± 0.1	306.0 ± 78.5
(s=25, Q=6)	99.9 ± 0.2%	41.6 ± 7.7	36.2 ± 1.7	1.7 ± 0.1	3.7 ± 8.2
(R=7, S=30)	99.9 ± 0.3%	42.6 ± 9.5	35.6 ± 1.8	2.2 ± 0.0	4.8 ± 10.2



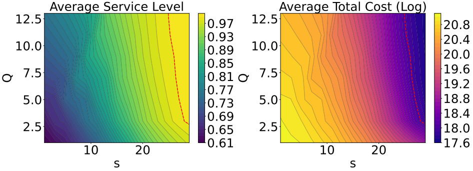
Activity #5: Nonstationary Demands

- Each two groups will be given a different model to solve.
  - Group 1 and 2: Model A (nonstationary demand, long lead time)
  - Group 3 and 4: Model B (nonstationary demand, short lead time, high order cost)
  - Group 5 and 6: Model C (nonstationary demand, short lead time, low stockout cost)

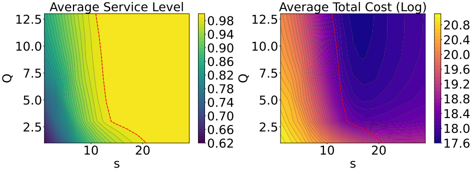
`bit.ly/spareparts-inv-5A`   `bit.ly/spareparts-inv-5B`   `bit.ly/spareparts-inv-5C`

- You will have 10 minutes to pick two sets of (s, Q) parameters.
- Share your results with the class.

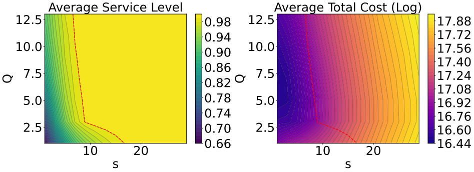
- A: nonstationary demand, long lead time



- B: nonstationary demand, short lead time, high order cost



- C: nonstationary demand, short lead time, low stockout cost



Critical and Non-Critical Spare Parts

- Often, spare parts are classified into **critical** and **non-critical** parts.
- Critical parts are those that are **essential for operations**.
- Non-critical parts can be **substituted or replaced** with other parts.
- Strategies for critical & non-critical parts can be **different**.
- One can use **ABC analysis** on spare parts stockout costs and values.

General Inventory Strategies for Spare Parts Management

- **Centralized vs. decentralized inventory control**: centralize the control of spare parts inventory to reduce costs.
- **Vendor-managed inventory (VMI)**: inventories are managed directly by the vendor, not the buyer.
- **Consignment inventory**: the vendor owns the inventory until used.
- **Just-in-time (JIT) inventory**: inventory is delivered when needed.
- **Collaborative planning, forecasting, and replenishment (CPFR)**: the vendor and the buyer collaborate in planning, forecasting, and replenishment.

Conclusion and Takeaways

- Differentiating factors for spare parts (vs. general) inventory control
- Key factors to consider in evaluating inventory policies
- Main information needed for inventory policy optimization
- **What could be useful for you (from the last two sessions)?**
- **What remaining/new questions you have?**

Thank you!
Questions?

Ask me offline (mansur.arief@stanford.edu**)**
or in LinkedIn (https://linkedin.com/in/mansurarief**)**