Prioritizing Lockers

Introduction

Network of parcel lockers. These parcel lockers are used by users to ship items.

The standard shipment flow for our parcel lockers is as follows:

1. Seller of a pre-loved item drops off their parcel at a locker;
2. Driver picks up the parcel from the origin locker & brings it to a warehouse;
3. Parcels are sorted in the warehouse;
4. Driver picks up the parcel from the warehouse & drops it off at the destination locker;
5. Buyer of a pre-loved item picks up the parcel from the destination locker.

Every day, we must decide which lockers to visit. This decision involves a trade-off between conflicting business objectives. Visiting more lockers increases delivery speed, but it also **increases delivery costs.**

The management team has asked you to investigate how to optimize the way we prioritize our lockers.

Section I: Prioritization Framework

Let's begin by developing a framework for prioritizing lockers based on the available data.

Throughout this problem, assume that our **service-level agreement** (SLA) is to reliably deliver the parcel to the buyer within **5 days** of the drop off by the seller.

(A) Define a set of measures — which you could calculate using the provided data — that should be included in the prioritization framework. Provide a rationale why these measures are appropriate given the business objectives.

Occupancy Ratio of a Locker: The ratio of used slots to total slots in a locker. **High ratios should be prioritized.** A locker close to being full needs to be emptied to maintain capacity for new parcels.

$$\text{OccupancyRatio}_i = 1 - \frac{\text{AvailableSlots}_i}{\text{TotalSlots}_i}$$

Average Days Since Drop-off: The average number of days parcels have been waiting in a locker since the seller drop-off. A high average suggests parcels are not being moved quickly enough, risking SLA violation.

$$\text{AvgDaysSinceDropOff}_i = \frac{1}{N}\sum_{j=1}^{N}\text{DaysSinceSellerDropOff}_{ij}$$

In-Out Ratio: This is the ratio of the number of parcels incoming to a locker to the number of parcels outgoing from that locker. A higher value indicates that more parcels are being moved from the warehouse to the locker, which aligns with the goal of reducing warehouse storage requirements (assumption).

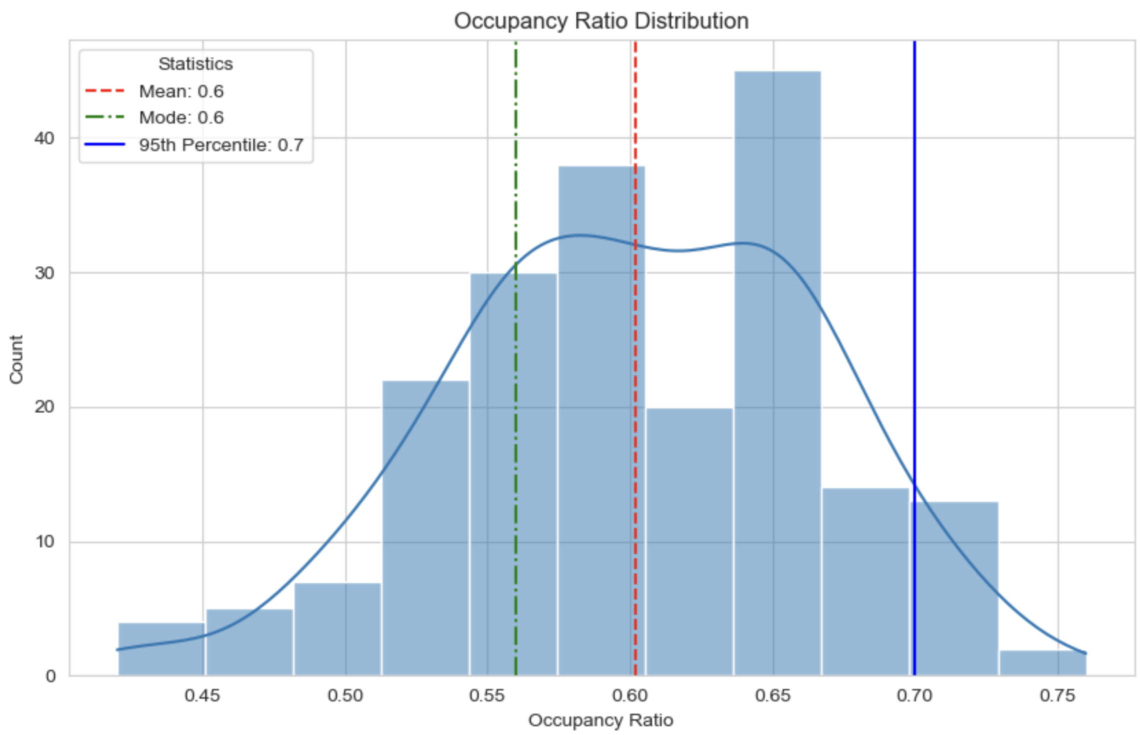
$$\text{InOutRatio}_i = \frac{\text{InFlow}_i}{\text{OutFlow}_i}$$

SLA Violation Count: The number of parcels in a locker that have been waiting for more than 5 days since the seller drop-off, thereby violating the SLA.

$$\text{SLA\_Violation}_i$$

(B) Conduct an exploratory data analysis (EDA) of the provided data files. How does the distribution of the measures you proposed look like at the locker-level? How do these measures relate to each other?

Occupancy Ratio



➔ The average and mode being around **60%** and **56%** suggests that there may be room for improving the utilization of the locker space.

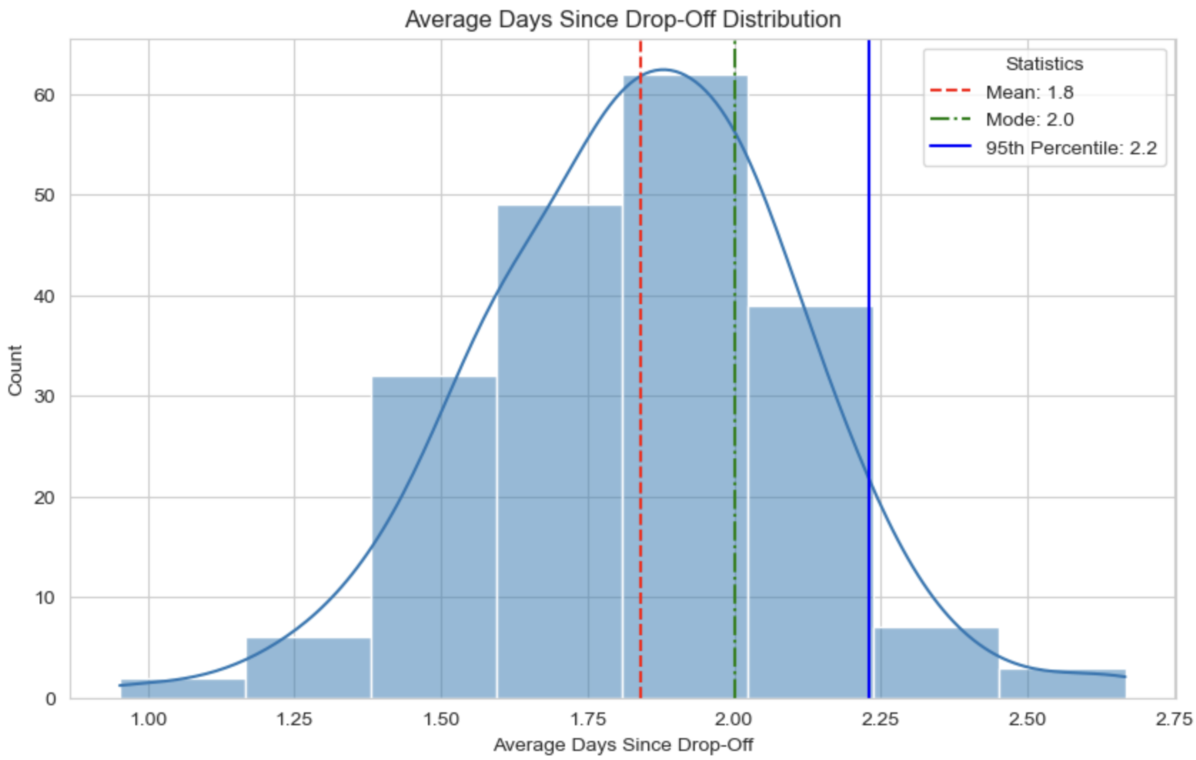
➔ The 95th percentile tells us that some lockers are heavily utilized, and might need to be emptied more often to avoid exceeding capacity (?).

Mean and mode in both distributions - **a well-balanced system** - most lockers are neither too empty nor too full, which is a positive indicator of system efficiency.

There is a good match between locker capacity and demand for space.

One possible improvement is to identify why some lockers are **underutilized** or to take measures to relieve those that are **overfilled**.

Average Days Since Drop-Off

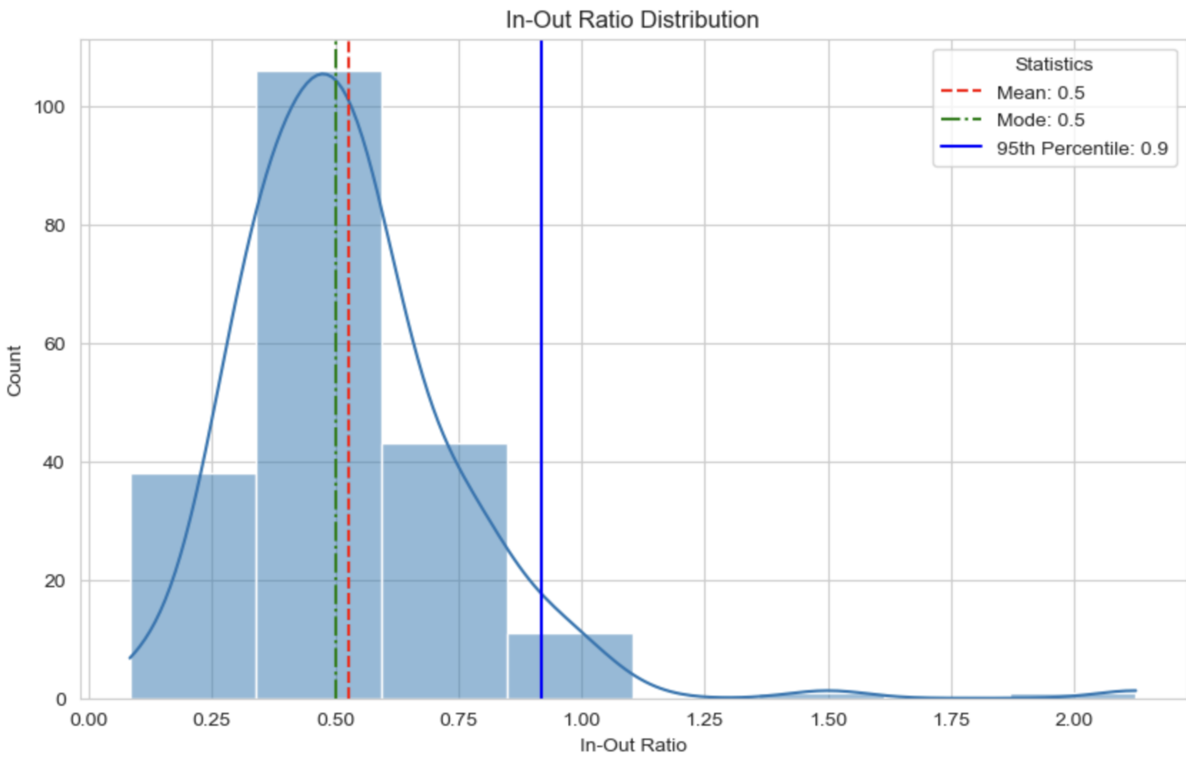


➔ The mean being around 1.84 suggests that most lockers are experiencing a healthy turnover of parcels. This aligns well with the business goal of maximizing locker usage without overwhelming the system.

➔ Some lockers with an *Average Days Since Drop-Off* close to the maximum might require attention. These could be outliers in terms of SLA violations or inefficient usage, which could potentially disrupt the whole system if not managed.

Given the metrics, there's a strong correlation between locker *Occupancy Ratio* and *Average Days Since Drop-Off*, suggesting that the system has a good balance between these two metrics.

In-Out Ratio

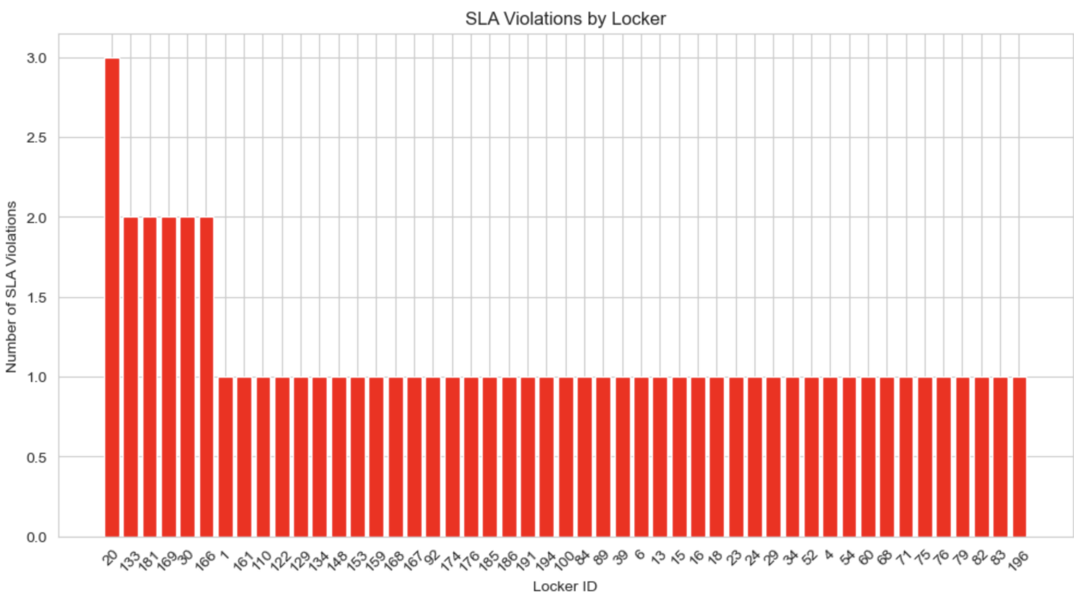


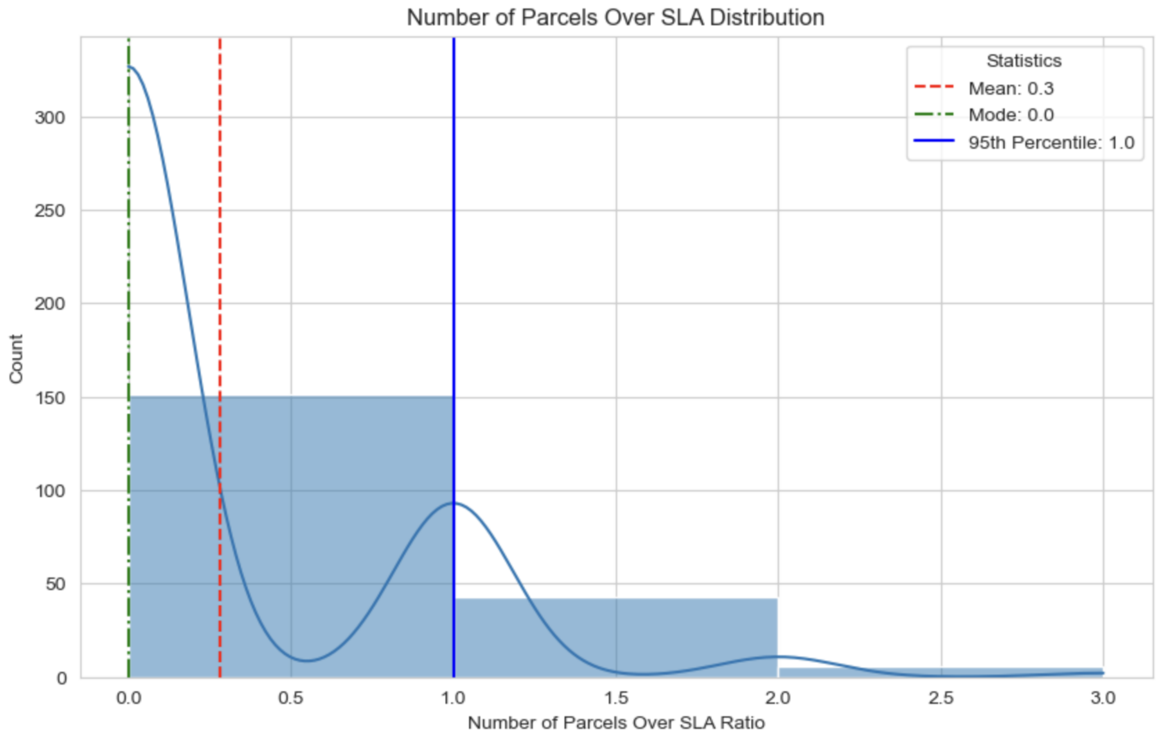
➔ The maximum value of 2.1 indicates that some lockers are experiencing a much higher inflow than outflow, potentially leading to capacity issues. The minimum of 0.08 suggests the opposite problem: lockers that are frequently emptying but not receiving parcels, possibly indicating underutilization.

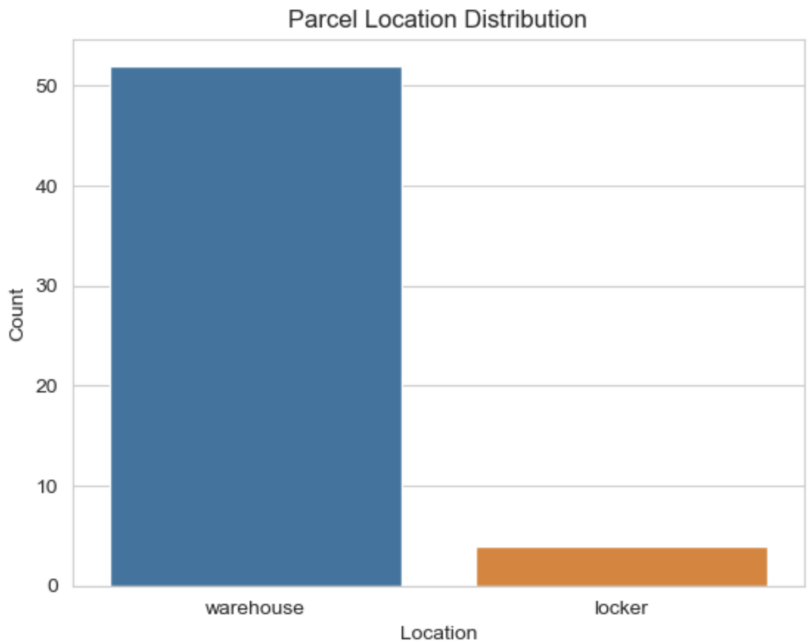
➔ High in-out ratios could indicate potential congestion, leading to reduced locker availability for new parcels. Low ratios could signify underutilization, resulting in wasted space and operational inefficiency.

The in-out ratio could be strongly correlated with both the occupancy ratio and average days since drop-off. A balanced in-out ratio likely contributes to a well-utilized locker system (higher occupancy ratio) and a lower risk of SLA violations (lower average days since drop-off).

SLA Violation



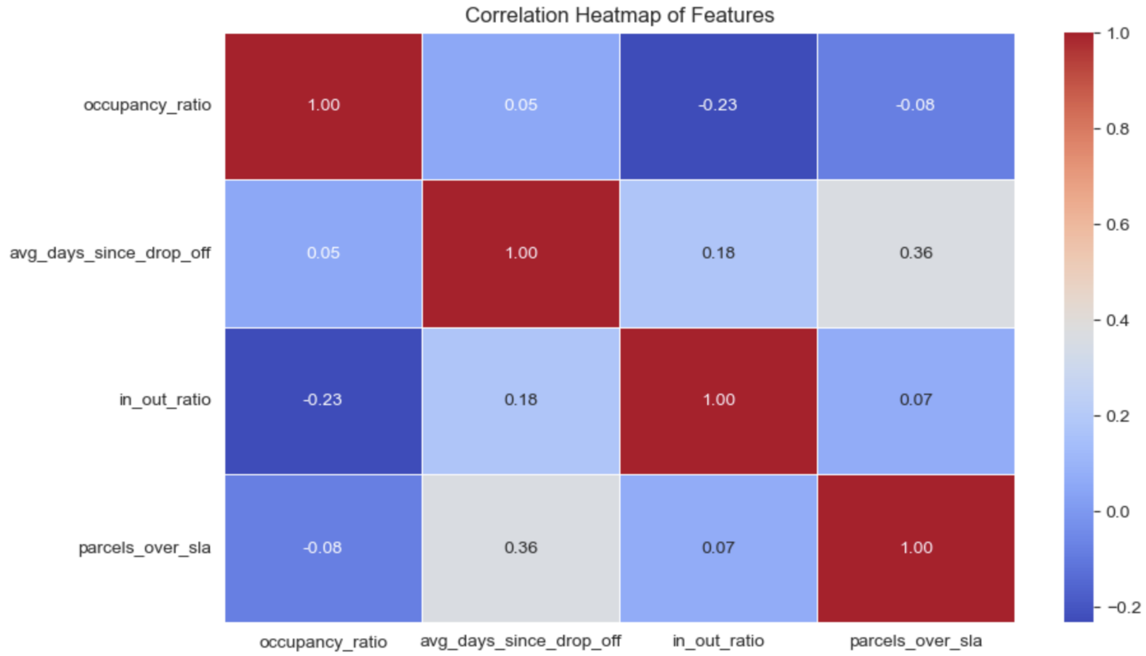




- ➔ Most lockers generally don't have parcels over the Service Level Agreement (SLA). This is positive from a customer satisfaction perspective.
- ➔ The maximum value is 3, which means that even the worst-performing lockers are not egregiously violating SLAs. However, any violation may negatively impact customer experience and should be investigated.
- ➔ Having a low average of parcels over SLA minimizes the risk of customer dissatisfaction, refunds, or even loss of clients due to delayed parcels. However, any non-zero value should be a flag for review.

The low number of parcels exceeding SLAs across most lockers suggests that, from this perspective, the system is operating efficiently and effectively. However, even a few *SLA violations* can be significant in terms of customer satisfaction, and therefore those outliers warrant closer inspection.

Business Implications



SLA Focus: Given the moderate positive correlation between *Average Days Since Drop-Off* and *Parcels Over SLA*, a focus on reducing the average days can help in minimizing *SLA violations*, which is crucial for customer satisfaction.

Efficiency vs. Turnover: The negative correlation between *Occupancy Ratio* and *In-Out Ratio* might require a closer look. High occupancy with lower in-out could suggest efficient space utilization but may also indicate slower turnover, which can be a business concern.

Holistic Approach: No single metric here is highly correlated with another, suggesting that each provides unique information and should be considered for a balanced and efficient locker management system.

Operational Fine-Tuning: Very weak correlations for most pairs suggest that changes in one metric won't necessarily result in significant changes in another. This independence allows for more flexible operational adjustments.

Customer Service: Given the lack of a strong correlation between occupancy and parcels over SLA, the business seems to be managing capacity well without compromising on service quality.

Understanding these correlations can provide valuable insights into how changes in one operational area may affect another, helping to inform a more strategic approach to improving locker efficiency and customer satisfaction.

(C) Based on the results of the EDA, develop a lockers prioritization framework. The framework should tell us, on a daily frequency, which lockers should be visited.

Objective Function

Finally, the objective function could look like:

$$\max \sum_{i=1}^{M} (a \times \text{OccupancyRatio}_i + b \times \text{AvgDaysSinceDropOff}_i + c \times \text{InOutRatio}_i + P \times \text{SLA\_Violation}_i)$$

This accomplishes the best of both worlds. At the same time that we want to maximize directly occupancy rate, we also want to maximize the value for *AvgDaysSinceDropOff*. *a*, *b* and *c* are the weights for each metric. *P* is a penalty term for *SLA violations*.

Constraints

SLA Constraint: Enforces that the number of days a parcel has been waiting since it was dropped off by the seller should be less than or equal to 5. This ensures that each parcel meets the 5-day Service Level Agreement (SLA) for delivery.

$$\text{DaysSinceSellerDropOff}_i \leq 5$$

Driver's Locker Visits: A driver can visit at most 20 lockers per day.

$$\sum_{i=1}^{M} \text{LockerVar}_i \leq 20$$

Full Optimization Problem Statement

$$\max \quad \sum_{i=1}^{M} (a \times \text{OccupancyRatio}_i + b \times \text{AvgDaysSinceDropOff}_i + c \times \text{InOutRatio}_i + P \times \text{SLA\_Violation}_i)$$

$$\text{Subject to:}$$

$$\text{DaysSinceSellerDropOff}_i \leq 5, \quad \forall i \in \{1, 2, \ldots, M\}$$

$$\sum_{i=1}^{M} \text{LockerVar}_i \leq 20$$

Occupancy Ratio

- ➔ Business Perspective: A locker that is almost full should be prioritized for emptying, as it has less space for new parcels.
- ➔ Objective: Maximized. The higher the occupancy ratio, the more urgent the need for emptying it.
- ➔ *a*: Allows us to control the importance of this metric relative to others.

Average Days Since Drop-Off

- ➔ Business Perspective: Parcels that have been in the locker for an extended period should be moved as they risk violating the Service Level Agreement (SLA). Delivery time is one of the most important factors from the client perspective.
- ➔ Objective: Maximized. However, it's more about flagging those that have high average days, indicating urgency.
- ➔ *b*: Allows us to give importance to lockers that have parcels nearing *SLA violation*.

In-Out Ratio

- ➔ Business Perspective: A higher in-out ratio is desirable as it indicates that more parcels are being moved from the warehouse to the lockers, thus reducing the parcel count in the warehouse and maximizing locker usage.
- ➔ Objective: Maximized. A high value for in-out ratio directly contributes to reducing the warehouse load and improving locker utilization.
- ➔ *c*: Helps control the emphasis we put on this balance between incoming and outgoing parcels.

SLA Violation

- ➔ Business Perspective: Any *SLA violation* is a serious issue and can damage customer trust and result in penalties.
- ➔ Objective: Maximized. We add a penalty term for each locker that has an *SLA violation*, indicating the urgency to resolve these cases.
- ➔ *Penalty P*: A value that helps ensure that any locker with an *SLA violation* gets prioritized for emptying.

Data Assumptions

- ➔ The snapshot is an accurate representation of a typical day.
- ➔ Drivers work in 8-hour shifts, and it takes an average of 20 minutes to empty a locker.
- ➔ The number of drivers is not known, so we aim to minimize locker visits within the given constraint of 20 lockers per driver per day.
- ➔ We want to reduce the parcel count in the warehouse and maximize locker usage.

Section II: Implementing Framework

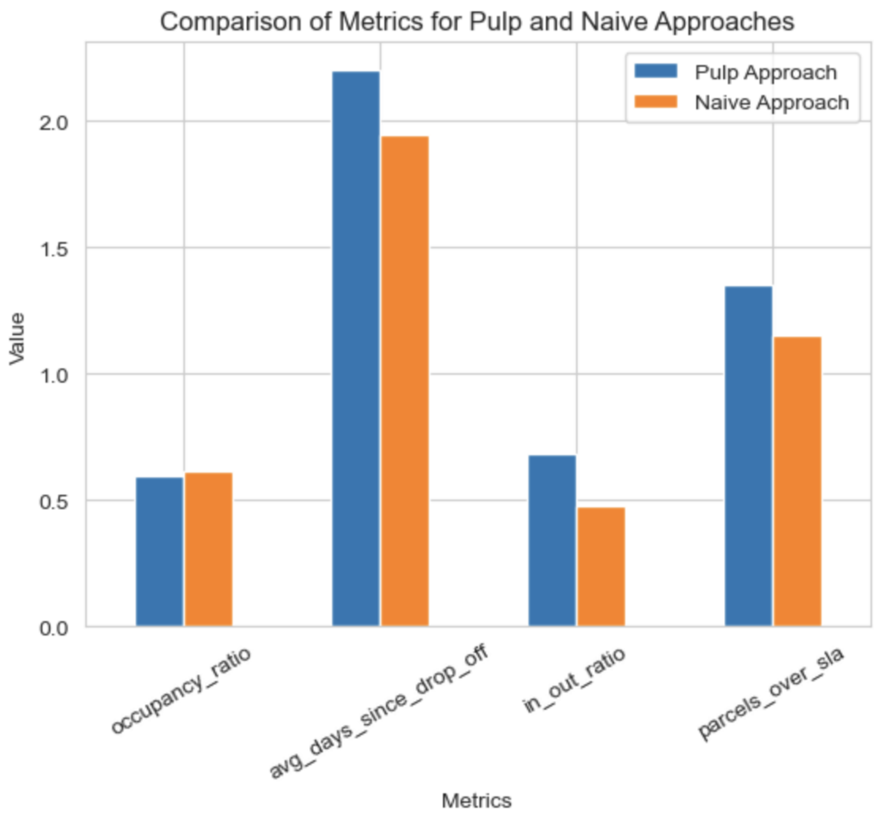
(A) Implement your proposed prioritization framework & summarize the results. Which lockers are prioritized for delivery, and why?

[In the jupyter notebook]

Two different approaches:

- **Naive approach:** Using the combination between 3 different rules:
  - $urgent\_lockers = lockers\_df[lockers\_df['parcels\_over\_sla'] > 0]$
  - $high\_occupancy\_lockers = lockers\_df[lockers\_df['occupancy\_ratio'] > 0.7]$
  - $aged\_parcels\_lockers = lockers\_df[lockers\_df['avg\_days\_since\_drop\_off'] > 3]$
  - Lockers - [1, 4, 6, 13, 15, 16, 18, 20, 23, 24, 29, 30, 34, 39, 52, 54, 60, 68, 71, 75]

- **PuLP approach:** Using the full optimization problem statement and PuLP
  - Lockers - [1, 20, 29, 30, 39, 75, 83, 92, 100, 122, 133, 134, 153, 161, 166, 169, 176, 181, 185, 186]



Metrics Comparison

Occupancy Ratio - Better approach: **Naive**. The Naive approach targets lockers with higher occupancy, aligning better with the goal of maximizing locker usage.

Average Days Since Drop-off - Better Approach: **Pulp**. Targets lockers with higher average days since drop-off, which suggests it is more aligned with the goal of minimizing *SLA violations.*

In-Out Ratio - Better Approach: **Pulp**. A higher in-out ratio is desirable as it indicates more parcels are moved from the warehouse to the locker, thus reducing the parcel count in the warehouse and maximizing locker usage. Pulp has a higher in-out ratio, making it better aligned with this objective.

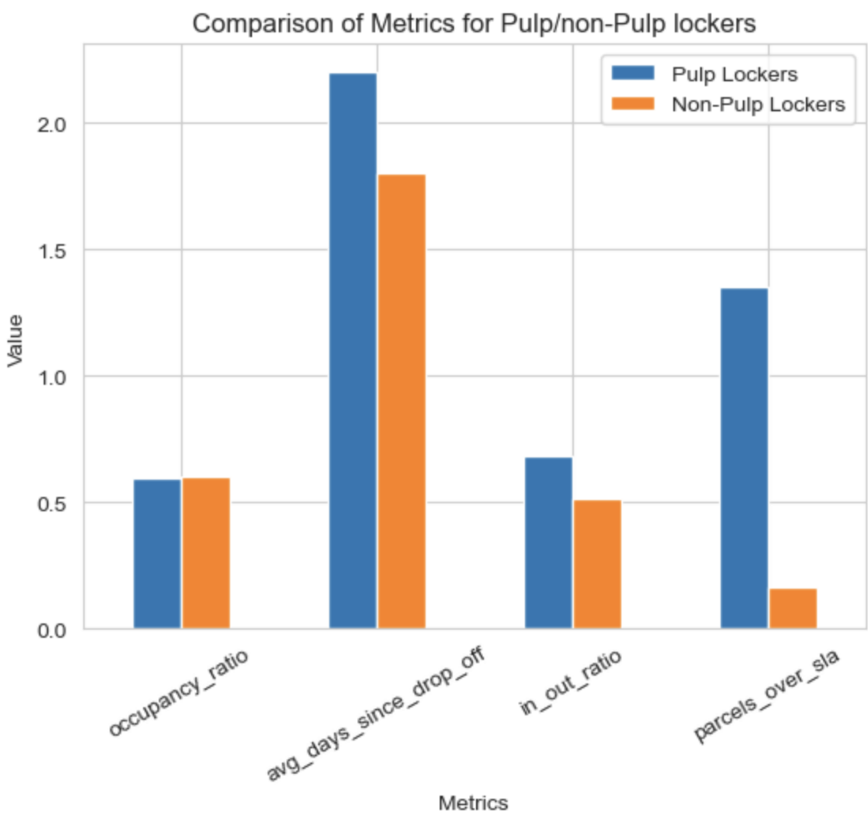
Parcels Over SLA - Better Approach: **Pulp**. It targets lockers with a higher number of parcels that are over the SLA time period.

The naive approach is better in terms of maximizing locker occupancy.

The Pulp approach performs better on three out of four metrics: it aligns more with the goals of reducing *SLA violations*, reducing the warehouse load, and maximizing locker utilization.

Depending on the business priorities, one might be more suitable than the other. If the most critical factor is to avoid *SLA violations*, the pulp approach might be more appropriate. If the focus is mainly on maximizing locker occupancy, the naive approach could be better.

(B) Measure the success of the prioritization framework. That is, how do you know if the framework is doing a good job prioritizing lockers? If needed, assume that one driver can visit 20 lockers in one shift.



- ➔ Both samples have high occupancy ratios, but the Non-Pulp Lockers have a slightly higher occupancy ratio. This aligns better with the goal of maximizing locker usage, although the difference is minimal.
- ➔ The Pulp is identifying lockers where parcels have been waiting longer. This is aligned with the business objective of avoiding *SLA violations.*
- ➔ The Pulp approach has a higher in-out ratio, making it better aligned with this objective.
- ➔ The Pulp is selecting lockers with more parcels that have violated the SLA. This might look like a disadvantage, but if the objective is to urgently clear out lockers that are close to or have violated SLA, then it makes sense.

Mann-Whitney U Test for occupancy_ratio:
Statistics=205.0, p=0.902834918212914
No significant difference between Pulp and random non-Pulp lockers for occupancy_ratio

Mann-Whitney U Test for avg_days_since_drop_off:
Statistics=364.5, p=8.962531006816031e-06
Significant difference between Pulp and random non-Pulp lockers for avg_days_since_drop_off

Mann-Whitney U Test for in_out_ratio:
Statistics=261.0, p=0.10110245372659285
No significant difference between Pulp and random non-Pulp lockers for in_out_ratio

Mann-Whitney U Test for parcels_over_sla:
Statistics=400.0, p=3.199671103214705e-09
Significant difference between Pulp and random non-Pulp lockers for parcels_over_sla

Two tailed t-test for occupancy_ratio:
Statistics=0.20594727168713362, p=0.8379315152399545
No significant difference between Pulp and random non-Pulp lockers for occupancy_ratio

Two tailed t-test for avg_days_since_drop_off:
Statistics=5.602181760211695, p=2.000133708788193e-06
Significant difference between Pulp and random non-Pulp lockers for avg_days_since_drop_off

Two tailed t-test for in_out_ratio:
Statistics=1.8080828553049317, p=0.0785132848204218
No significant difference between Pulp and random non-Pulp lockers for in_out_ratio

Two tailed t-test for parcels_over_sla:
Statistics=10.282646761776899, p=1.5644690447412305e-12
Significant difference between Pulp and random non-Pulp lockers for parcels_over_sla

Section III: Recommendation & Next Steps

(A) Given your analysis, what would you recommend to management?

First I would start by discussing with management the best way to measure the current challenges. I would suggest the metrics I devised for this challenge, but my feeling is that their input could be of value.

Focus on SLA Violations: If reducing the time parcels spend in lockers (minimizing *SLA violations*) is a priority, the Pulp approach is demonstrably more effective.

In-Out Ratio & Occupancy: If the focus is on optimizing locker usage efficiency (in-out ratio, occupancy), the Pulp approach doesn't offer a significant advantage over a random selection of lockers. Therefore, if these metrics are a priority, maybe there's a need to tweak the Pulp objective function or consider another optimization approach for these specific metrics.

Review and Iterate: Given the lack of impact on some metrics, consider revising the weights (*a, b, c, P*) in the objective function to better align with business goals.

Further Investigation: For lockers that consistently show up as underutilized or overfilled in both the Pulp and non-Pulp groups, a more in-depth analysis may be required to determine underlying causes and solutions.

(B) Discuss the risks and limitations of your proposed prioritization framework.

Risks

Sensitivity to Weights: The weights *a, b, c* and *P* in the objective function play a crucial role in determining the effectiveness of the solution. Incorrect weighting can lead to misalignment with business objectives.

Exclusion of Other Metrics: The model focuses on four key metrics (occupancy ratio, average days since drop-off, in-out ratio, and parcels over SLA). If there are other metrics that are also important but not included, this could be a limitation.

Unaccounted External Factors: Factors like seasonality, holidays, or special promotions could suddenly change parcel flows, and the model may not adapt quickly enough to these changes.

Limitations

Computational Complexity: If the number of lockers *M* is very large, the Pulp solver might struggle with computational performance, although this is generally more of an issue for extremely large-scale problems.

Static Nature: The model doesn't take into account the dynamic nature of the system. Metrics can change quickly, and a once optimal solution might become suboptimal.

Inter-Metric Trade-offs: The model does not inherently understand the trade-offs between metrics. For example, reducing the in-out ratio too much might improve occupancy but worsen *SLA violations*.

Local vs Global Optimization: The model aims to optimize each locker individually, but there may be global logistics or network considerations that are not captured.

Validation and Testing: Before full-scale implementation, the model needs to be rigorously tested to ensure that it's providing the intended benefits without unintended negative consequences.

Go beyond the snapshot: Use a ML model (like LightGBM) to predict ahead of time to plan/optimize better. A really interesting approach would be to predict the costs. Another idea would be to predict how many *SLA violations* or how many days since seller drop-off.

(C) Outline a plan to address the framework's current limitations in future iterations.

Sensitivity to Weights

- ➔ Periodic reviews to fine-tune the weights *a, b, c* and *P* in the objective function.
- ➔ Stakeholder Input: Obtain insights from key business stakeholders to align the weights better with business objectives.

Data Quality

- ➔ Real-Time Data Integration: Consider incorporating a real-time data pipeline to keep the model updated.

Exclusion of Other Metrics

- ➔ Metrics Review: Periodically review and possibly include other relevant metrics based on business needs and data analysis.
- ➔ Extended KPIs: Run pilot tests to see the effect of including new KPIs in the model.

Unaccounted External Factors

- ➔ Seasonality and Trends: Include seasonality factors in the model, or adjust the weights dynamically based on the time of year or special events.

Computational Complexity

- ➔ Optimization Algorithms: Explore more efficient algorithms or solvers if scalability becomes an issue.
- ➔ Cloud Computing: Utilize cloud-based solutions for added computational power.

Static Nature

- ➔ Dynamic Optimization: Implement real-time or near-real-time optimization to capture the dynamic nature of the system.
- ➔ Alert Mechanisms: Incorporate alert mechanisms for sudden changes in metrics, triggering an immediate re-optimization.

Inter-Metric Trade-offs
- ➔ Multi-Objective Optimization: Adapt the model to consider multiple objectives simultaneously, potentially applying Pareto optimality concepts.
- ➔ Scenario Analysis: Perform "what-if" analysis to understand trade-offs better.

Local vs Global Optimization
- ➔ Network-Level Modeling: Extend the model to include network-wide considerations like transportation costs and time.
- ➔ Hierarchical Modeling: Use a two-step optimization process, optimizing at the locker level first and then at the network level.

Validation and Testing
- ➔ Pilot Testing: Before rolling out any major change, conduct a pilot test to measure its impact.
- ➔ Feedback Loop: Establish a mechanism for collecting feedback from end-users and other stakeholders.