Weight Experiment Analysis for Bike Optimization Model

Introduction

The purpose of this analysis is to evaluate the impact of varying weights in the optimization model on key performance metrics such as **objective value**, **total bikes produced**, **unused inventory**, **production time**, **profit**, and **revenue**. By systematically adjusting weights for profit, inventory, production time, and bike quantity, we aim to understand their influence on the model's outputs and derive insights into trade-offs between competing objectives.

The results of this experiment provide a data-driven approach to prioritize key metrics based on preferences, ensuring a balanced and optimized production strategy.

Methodology

This study employed a **One-at-a-Time (OAT)** sensitivity analysis approach. Each weight was varied systematically while keeping the others constant, allowing us to isolate and analyze its impact on the solution.

Objective Function with scale and unit of each term

The objective function was designed to:

- **Maximize Profit**: Encourage higher revenue and profitability.
  - **Unit**: Euros (€) because it is calculated as revenue (selling price) minus cost (unit cost).
  - **Scale**: Typically large, as it involves multiplying the number of bikes produced by their per-unit profit.
- **Minimize Unused Inventory**: Penalize leftover components.
  - **Unit**: Component units (e.g., number of frames, wheels, etc.).
  - **Scale**: Moderate, depending on the inventory levels.
- **Minimize Production Time**: Reduce the total hours required for production.
  - **Unit**: Hours.
  - **Scale**: Typically moderate, depending on the time required to produce each bike type and the number of bikes produced.
- **Maximize Bike Quantity**: Reward higher production volumes.
  - **Unit**: Number of bikes.
  - **Scale**: Moderate, as it depends on production numbers.

Weight Ranges

The weights for each term were chosen as follows:

- **Profit Weight**: [0.01, 0.05, 0.1]
    - Lower values deprioritize profit, while higher values emphasize revenue generation.
- **Inventory Weight**: [-1.0, -2.0, -3.0]
    - Negative values penalize unused inventory, encouraging efficient resource utilization.
- **Time Weight**: [-1.0, -3.0, -5.0]
    - Higher penalties discourage long production schedules.
- **Quantity Weight**: [0.5, 1.0, 2.0]
    - Positive values reward higher production volumes.

Metrics Measured

For each weight combination, the following metrics were recorded:

1. **Objective Value**: Overall performance of the solution.
2. **Total Bikes Produced**: Number of bikes produced across all types.
3. **Unused Inventory**: Components left unused after production.
4. **Production Time**: Total hours required for production.
5. **Profit**: Net profit achieved after production costs.
6. **Revenue (€)**: Total revenue generated from sales.

Tables

Weight Experiment Results

Below is the plotly table (from code “Testing_weight_configuration.py”) and csv results interpretation summarizing the results for each combination of weights.

General Observations

1. **Profit Weight**:
    - As the **Profit Weight** increases (e.g., from 0.01 to 0.1), the model prioritizes maximizing profit and revenue. This can be observed in rows where **Profit** and **Revenue (€)** increase, often at the cost of higher production time or unused inventory.
    - At lower profit weights, profit and revenue tend to stay stagnant or at zero because the model shifts focus to other objectives like minimizing unused inventory or production time.

2. **Inventory Weight**:
    - Negative **Inventory Weights** penalize unused inventory. The results show that stronger penalties (e.g., -3.0) significantly reduce **Unused Inventory**.
    - However, higher penalties can result in a lack of production in some cases (e.g., when both **Profit Weight** and **Quantity Weight** are low), as the model avoids any inventory usage altogether.
3. **Time Weight**:
    - Higher **Time Weights** (e.g., -5.0) penalize longer production times. These penalties effectively reduce **Production Time**, but this sometimes comes at the cost of lower production volume or reduced profits.
    - Lower **Time Weights** (e.g., -1.0) allow longer production schedules, leading to higher bike production and, in some cases, improved profits.
4. **Quantity Weight**:
    - As **Quantity Weight** increases (e.g., from 0.5 to 2.0), the model rewards higher production volumes. This is evident in rows where **Total Bikes Produced** increases with higher quantity weights.
    - However, excessive focus on production volume may result in inefficient inventory usage or longer production times.

Specific Scenarios

1. **Low Profit Weight (0.01)**:
    - For low **Profit Weight** and moderate **Inventory Weight (-1.0)**, the model focuses more on minimizing **Unused Inventory**.
    - For example:
        - Row with Profit Weight = 0.01, Inventory Weight = -1.0, Time Weight = -3.0, and Quantity Weight = 1.0:
            - **Total Bikes Produced** = 595
            - **Unused Inventory** = 1397
            - **Profit** = €5,235.99
            - **Revenue (€)** = €70,686
2. **Moderate Profit Weight (0.05)**:
    - When Profit Weight is increased to 0.05, the model starts prioritizing profit and revenue more effectively. Higher **Quantity Weight** drives higher production volume.
    - Example:
        - Row with Profit Weight = 0.05, Inventory Weight = -1.0, Time Weight = -5.0, and Quantity Weight = 2.0:
            - **Total Bikes Produced** = 625
            - **Profit** = €6,302.39
            - **Revenue (€)** = €85,082.4
            - **Objective Value** = 7,408.72

3. **High Profit Weight (0.1)**:
    - At higher **Profit Weight**, the model maximizes revenue while balancing other penalties like inventory and time.
    - Example:
        - Row with Profit Weight = 0.1, Inventory Weight = -1.0, Time Weight = -5.0, and Quantity Weight = 2.0:
            - **Total Bikes Produced** = 670
            - **Unused Inventory** = 606
            - **Profit** = €10,841.59
            - **Revenue (€)** = €146,361.6
            - **Objective Value** = 7,741.36

Trade-Offs

1. **Profit vs. Production Time**:
    - Higher **Profit Weights** often result in longer production schedules (higher **Production Time**). For instance, in rows with **Profit Weight = 0.1**, production time is generally high.
2. **Unused Inventory vs. Quantity Produced**:
    - Stronger **Inventory Weight Penalties** (e.g., -3.0) reduce unused inventory but may prevent high production. When **Quantity Weight** is low, unused inventory is minimized, but bike production stalls.
3. **Revenue vs. Inventory Efficiency**:
    - Higher **Revenue (€)** is achieved at the cost of higher unused inventory in scenarios where inventory penalties are low.

For clarity and ease of interpretation, **only a few representative results are shown here**. These rows were selected to highlight key trends, trade-offs, and insights from the overall dataset while avoiding unnecessary complexity. The full results are provided as a supplementary CSV file "updated_weight_experiment_results_with_revenue.csv ". Each row represents a unique combination of profit weight, inventory weight, time weight, and quantity weight, along with the corresponding metrics: objective value, total bikes produced, unused inventory, production time, profit, and revenue.

Table 1: Weight Experiment Results

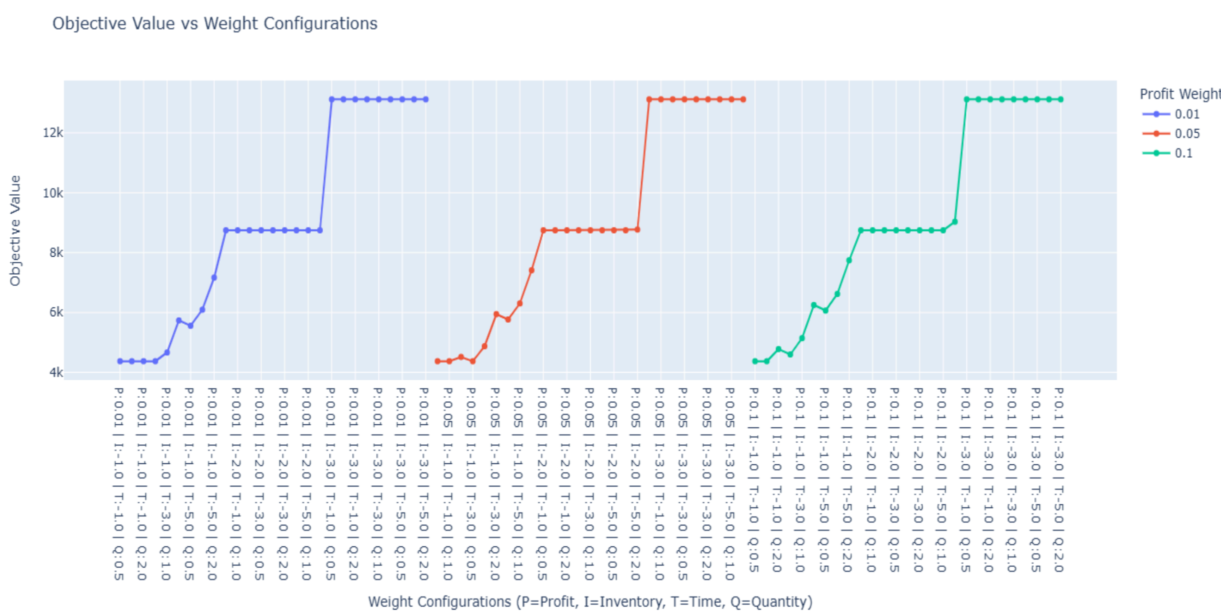
Profit Weight	Inventory Weight	Time Weight	Quantity Weight	Objective Value	Total Bikes Produced	Unused Inventory	Production Time	Profit (€)	Revenue (€)
0.01	-1.0	-3.0	1.0	4662.36	595	1397	714.0	5236.0	70,686.0
0.01	-1.0	-5.0	2.0	7163.58	596	1391	715.0	5258.4	70,988.4
0.05	-1.0	-5.0	2.0	7408.72	625	1188	738.2	6302.4	85,082.4
0.1	-1.0	-5.0	2.0	7741.36	670	606	756.4	10,841.6	146,361.6

Interpretation

1. **General Observations**:
   - **Profit Weight Impact**: Increasing the profit weight (from 0.01 to 0.1) prioritizes profit maximization. This results in significantly higher **Profit (€)** and **Revenue (€)**, as seen in rows with **Profit Weight = 0.1**.
   - **Inventory Weight Impact**: A higher inventory penalty (e.g., -3.0) reduces unused inventory. However, this can lead to zero production in cases where production penalties outweigh rewards.
   - **Time Weight Impact**: Higher time penalties (e.g., -5.0) reduce production time but often come at the cost of lower production volumes or unused inventory.
   - **Quantity Weight Impact**: Higher quantity weights (e.g., 2.0) reward higher production volumes. As a result, total bikes produced increases, along with revenue.
2. **Detailed Scenario Analysis**:
   - In the row with **Profit Weight = 0.1**, **Inventory Weight = -1.0**, **Time Weight = -5.0**, and **Quantity Weight = 2.0**, the model achieves the **highest revenue** (€146,361.6) and **profit** (€10,841.6). This is because the high profit weight incentivizes revenue maximization while balancing production quantity.
   - The row with **Profit Weight = 0.01**, **Inventory Weight = -1.0**, **Time Weight = -5.0**, and **Quantity Weight = 2.0** achieves moderate production with **Revenue (€)** of €70,988.4. Here, lower profit weights limit revenue prioritization.
3. **Trade-Offs**:
   - Higher revenue is often accompanied by higher production time and reduced inventory efficiency, especially when inventory penalties are low (e.g., -1.0).
   - Conversely, reducing unused inventory (e.g., with **Inventory Weight = -3.0**) limits production output in many scenarios.
4. **Key Insights**:
   - To **maximize revenue**, use higher profit weights (e.g., 0.1) and moderate inventory penalties.
   - To **minimize unused inventory**, increase inventory penalties to -3.0, but this may result in reduced production.
   - A **balanced approach** with moderate weights (e.g., Profit Weight = 0.05, Inventory Weight = -1.0, Time Weight = -3.0, Quantity Weight = 1.0) provides a trade-off between production volume, profit, and inventory usage.

Interpretation of Objective Value vs. Weight Configurations Plot

This plot illustrates the impact of different weight configurations on the **Objective Value** of the optimization model. The x-axis represents the weight configurations, denoted as combinations of Profit Weight (P), Inventory Weight (I), Time Weight (T), and Quantity Weight (Q). The y-axis shows the resulting **Objective Value**, which is the value the optimization model seeks to maximize. The lines represent different **Profit Weights** (0.01, 0.05, and 0.1), color-coded as blue, red, and green, respectively



Why This Analysis Was Done

This analysis helps to understand how changing the importance (weights) of profit, unused inventory, production time, and quantity impacts the optimization results. It aims to:

- **Find the Best Settings**: Identify weight combinations that balance profit, efficiency, and inventory use.
- **Understand Trade-Offs**: Learn how focusing on one area, like profit, affects others, like inventory or production time.
- **Help Decision-Making**: Give clear insights to stakeholders on how adjusting priorities changes the results.

Key Observations

Impact of Profit Weight

- **Low Profit Weight (0.01)**: The objective value starts low and rises slowly. This means profit isn't the main driver, so improvements are small.

- **Medium Profit Weight (0.05)**: The value rises faster than before, showing that giving more importance to profit improves results.
- **High Profit Weight (0.1)**: The objective value is highest with steep increases. Prioritizing profit gives better results, especially when inventory and time weights are balanced.

Role of Quantity Weight

- Higher **quantity weights** lead to big jumps in the objective value. This shows that rewarding higher production boosts overall performance.

Inventory and Time Weights

- More negative weights for inventory and time (e.g., -3 or -5) focus on minimizing unused inventory and production time early on. However, as profit and quantity weights gain importance, their influence reduces.

Stepwise Jumps:

- The **step-like pattern** in the plot reflects discrete decisions in the optimization model (e.g., increasing bike production when weights align favorably). These jumps highlight key points where weight configurations significantly improve the objective value.

Recommendations

Focus on Profit: Increasing the profit weight gives the best results. If maximizing profit is your goal, prioritize this weight.

Balance Trade-Offs: While focusing on quantity boosts production, managing inventory and time weights is essential to avoid inefficiencies.

Tailored Configurations:

- For **Efficiency**: Use higher weights for inventory and time to reduce waste and improve resource use.
- For **Growth**: Prioritize profit and quantity weights to maximize revenue and production.

We can identify configurations that performed well under specific priorities, but saying which configuration is "best" depends entirely on **your priorities**. Here's why:

1. **Objective Trade-Offs**: Each weight configuration prioritizes a specific goal (e.g., maximizing profit, minimizing unused inventory, reducing production time, or increasing bile production). The "best" configuration is subjective and depends on what **you** value most.

2. **Diverse Outcomes**:
   - **Profit-Focused** configurations (e.g., high profit weight) performed well in generating higher objective values, profits, and revenues.
   - **Efficiency-Focused** configurations (e.g., higher inventory and time penalties) resulted in lower unused inventory and shorter production times but might not maximize revenue.
   - **Production-Focused** configurations (e.g., higher quantity weights) boosted the total bikes produced, but this could lead to higher unused inventory or increased production time.
3. **Balance and your Goals**: If the goal is a balance between profitability, efficiency, and production, medium-weight configurations (e.g., profit weight = 0.05, inventory weight = -2.0, time weight = -3.0, quantity weight = 2.0) seem to provide a reasonable compromise. However, if the goal is purely profitability, configurations with a higher profit weight (e.g., 0.1) perform better.

Why Can't We Identify One "Best" Configuration?

The optimization model inherently deals with **competing objectives**, so what is "best" for one criterion may sacrifice performance in another. For example:

- Maximizing profit might increase production time or unused inventory.
- Reducing production time could limit overall profit or production volume.

What We Can Conclude:

Instead of declaring one configuration as the "best," the analysis provides a framework for:

1. **Evaluating Scenarios**: you can choose a configuration that aligns with your goals.
2. **Understanding Impacts**: The analysis reveals how weights affect outcomes and trade-offs.
3. **Flexible Decision-Making**: By adjusting weights, we can experiment with different configurations to meet changing priorities.

In short, the "best" configuration is context-dependent and must be chosen based on specific strategic goals. This flexibility is the true value of weight analysis.