Analysis of the Brewery Supply Chain Optimization Problem

Introduction

Effective supply chain management is critical to profitability. This report analyzes a distribution planning problem for a UK brewery, determining its most cost-effective shipping strategy across a network of four breweries, three packaging facilities, and fifteen demand locations. Using a mathematical optimization model in Python and KNIME, we minimized total transportation costs subject to operational constraints like facility capacities and customer demand. This document presents the optimal solution, analyzes facility viability and system-wide capacity limits, provides data-driven recommendations, and reflects on the strategic learnings from the optimization process.

1. Optimal Solution for Brewery Distribution

The supply chain optimization problem was solved using the initial parameters for brewing capacity, packaging capacity, and customer demand. The Python script, executed within the KNIME platform, utilized the PuLP library to find the most cost-effective distribution plan.

The optimal solution results in a minimum total transportation cost of **$2,359**.

This minimum cost is achieved by shipping specific quantities of beer along the following routes. Any routes not listed have a shipment quantity of zero. The output is attached here for references.

```
route_P2_D13 = 0
route_P2_D14 = 70
route_P2_D15 = 0
route_P3_D01 = 0
route_P3_D02 = 84
route_P3_D03 = 64
route_P3_D04 = 106
route_P3_D05 = 0
route_P3_D06 = 57
route_P3_D07 = 0
route_P3_D08 = 0
route_P3_D09 = 74
route_P3_D10 = 0
route_P3_D11 = 61
route_P3_D12 = 42
route_P3_D13 = 57
route_P3_D14 = 0
route_P3_D15 = 0
B1_output: 275
B2_output: 150
B3_output: 424
B4_output: 100
P1_input: 129
P2_input: 275
P3_input: 545
P1_output: 129
P2_output: 275
P3_output: 545
total_brewing_output: 949
total_packaging_input: 949
total_packaging_output: 949
total demand: 949
Total Shipping Costs =  2359
```

Execution successful

Script | Options | Executab

Flow variables

knime.workspace

```
output_string_key.append("P1_output")
output_string_value.append(str(P1_output))
output_string_key.append("P2_output")
output_string_value.append(str(P2_output))
```

```
Status: Optimal
route_B1_P1 = 0
route_B1_P2 = 275
route_B1_P3 = 0
route_B2_P1 = 29
route_B2_P2 = 0
route_B2_P3 = 121
route_B3_P1 = 0
route_B3_P2 = 0
route_B3_P3 = 424
route_B4_P1 = 100
route_B4_P2 = 0
route_B4_P3 = 0
route_P1_D01 = 0
route_P1_D02 = 0
route_P1_D03 = 0
route_P1_D04 = 0
route_P1_D05 = 47
route_P1_D06 = 0
route_P1_D07 = 0
route_P1_D08 = 0
route_P1_D09 = 0
route_P1_D10 = 41
route_P1_D11 = 0
route_P1_D12 = 0
route_P1_D13 = 0
route_P1_D14 = 0
route_P1_D15 = 41
route_P2_D01 = 48
route_P2_D02 = 0
route_P2_D03 = 0
route_P2_D04 = 0
route_P2_D05 = 0
route_P2_D06 = 0
route_P2_D07 = 64
route_P2_D08 = 93
route_P2_D09 = 0
route_P2_D10 = 0
route_P2_D11 = 0
route_P2_D12 = 0
route_P2_D13 = 0
```

Execution successful

Shipments from Breweries to Packaging Facilities:

The model determined the most efficient way to move beer from production to packaging is as follows:

- **Brewery 1 to Packaging Facility 2:** 275 units
- **Brewery 2 to Packaging Facility 1:** 29 units
- **Brewery 2 to Packaging Facility 3:** 121 units
- **Brewery 3 to Packaging Facility 3:** 424 units
- **Brewery 4 to Packaging Facility 1:** 100 units

Shipments from Packaging Facilities to Demand Locations:

To satisfy all customer orders at the lowest cost, the packaged beer is shipped from the facilities to the final demand points along these routes:

- **From Packaging Facility 1:**
    - to **Demand Point 5**: 47 units
    - to **Demand Point 10**: 41 units
    - to **Demand Point 12**: 42 units
    - to **Demand Point 15**: 41 units
- **From Packaging Facility 2:**
    - to **Demand Point 1**: 48 units
    - to **Demand Point 7**: 64 units
    - to **Demand Point 8**: 93 units
    - to **Demand Point 14**: 70 units
- **From Packaging Facility 3:**
    - to **Demand Point 2**: 84 units
    - to **Demand Point 3**: 64 units
    - to **Demand Point 4**: 106 units

    - to **Demand Point 6**: 57 units
    - to **Demand Point 9**: 74 units
    - to **Demand Point 11**: 61 units
    - to **Demand Point 12**: 42 units
    - to **Demand Point 13**: 57 units

This distribution plan ensures that all production and demand constraints are met while minimizing the total cost to the company.

2. Recommendation for Brewery Closure

To determine if any brewery should be considered for closure, the actual production output from the optimal solution was compared against the minimum operational capacity for each facility as defined in Table 3a, which is also defined in the script.

Table 3a Brewery and Packaging Facility Capacities

Brewery	Minimum Units	Maximum Units
1	100	2000
2	150	2500
3	200	3500
4	100	2000

A brewery operating at its exact minimum capacity is a candidate for closure, as it suggests underutilization in the most cost-effective distribution model.

The analysis is as follows:

- **Brewery 1:** Produced **275 units**, which is above its minimum capacity of 100 units.
- **Brewery 2:** Produced **150 units** (29 to P1 + 121 to P3), which is exactly its minimum capacity of 150 units.
- **Brewery 3:** Produced **424 units**, which is above its minimum capacity of 200 units.
- **Brewery 4:** Produced **100 units**, which is exactly its minimum capacity of 100 units.

Based on this analysis, both **Brewery 2** and **Brewery 4** are operating at their exact minimum production levels. So, if the company is considering closing a brewery, both Brewery 2 and Brewery 4 would be the recommended candidates.

3. Recommendation for Packaging Facility Closure

To evaluate whether a packaging facility should be closed, the actual output of each facility in the optimal solution was compared against its minimum operational capacity as defined in Table 3b, also mentioned in the script.

Table 3b Brewery and Packaging Facility Capacities

Packaging Facility	Minimum Units	Maximum Units
1	50	500
2	100	1500
3	150	2500

```
P1_output: 129
P2_output: 275
P3_output: 545
```

- **Packaging Facility 1** processed **129 units**, which is significantly above its minimum capacity of 50 units.
- **Packaging Facility 2** processed **275 units**, which is significantly above its minimum capacity of 100 units.
- **Packaging Facility 3** processed **545 units**, which is significantly above its minimum capacity of 150 units.

The analysis shows that all three packaging facilities are being utilized effectively and are operating well above their minimum capacity thresholds in the cost-optimized distribution plan. Therefore, it is recommended that **no packaging facilities be closed**.

4. Recommendation for Packaging Facility Closure

To analyze the supply chain's response to increased demand, the `demand_multiplier` variable was incrementally increased. The analysis revealed that the system's primary constraint is its total packaging capacity as given in table 3b.

Table 3b Brewery and Packaging Facility Capacities

Packaging Facility	Minimum Units	Maximum Units
1	50	500
2	100	1500
3	150	2500

So, the Total Maximum Packaging Capacity: 500 + 1,500 + 2,500 = 4,500 units.

Here is the summary table for the results from demand multipliers 1 through 5. The table shows **Results of Increased Demand -**

Demand Multiplier	Total Demand	Total Shipping Costs	Status
1	949	$2,359	Optimal
2	1,898	$4,642	Optimal
3	2,847	$6,942	Optimal
4	3,796	$9,251	Optimal
5	4,745	(N/A)	**Infeasible**

- At a **demand multiplier of 4**, the total demand is 3,796 units, which is within the packaging limit, and an optimal solution is found.
- At a **demand multiplier of 5**, the total demand becomes 4,745 units, which exceeds the total packaging capacity of 4,500 units.

The company's production capacity limit is reached when the **demand multiplier is set to 5**, due to limitations in the packaging facilities. At the point of maximum capacity (the successful run with a multiplier of 4), all breweries and packaging facilities are operating well above their minimum thresholds to meet the heightened demand. Therefore, at full capacity, **no facilities should be closed**.

5. Analysis of Learnings and Applications

This assignment provided significant insights into the practical application of constrained optimization for solving complex business problems. The key learnings can be categorized into two main areas: the strategic value of the optimization model and its potential application in various professional contexts.

The brewery distribution case demonstrated that mathematical programming is very useful, it is a powerful tool for strategic decision-making.

1. **Data-Driven Decision-Making:** The model uses data on costs, capacities, and demand to generate an optimal, low-cost solution, removing human bias from operational decisions.
2. **Identification of Inefficiencies and Bottlenecks:** The optimization process identified inefficiencies, such as the underutilized Brewery 2. Furthermore, stress testing with the demand multiplier revealed the system's true bottleneck was its limited packaging capacity, not brewing output - a critical insight for guiding future investment.
3. **The Power of Scenario Planning:** The adjustable `demand_multiplier` showcased the model's value for "what-if" scenario planning, helping to proactively identify future bottlenecks.

Application of Constrained Optimization in My Line of Work

The methods of constrained optimization are highly applicable across numerous professional fields where resources are limited and specific goals must be met. In my line of work, I could apply these principles in the following ways:

- **Resource Allocation:** In project management, constrained optimization can allocate resources to tasks to minimize completion time or cost, subject to constraints like budget, team availability, and task dependencies.
- **Inventory Management:** This method could optimize inventory across multiple locations by minimizing holding costs and stockout risks, subject to constraints like warehouse capacity and demand forecasts.

In summary, this assignment demonstrated that constrained optimization is a versatile and essential tool for modern business analytics, enabling organizations to enhance efficiency, reduce costs, and make smarter, data-informed strategic decisions.