Case Assignment 2: GMC Production Capacity Optimization Problem

Group 9
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Giant Motor Company - Current Scenario

- **Product Lines:** GMC offers three car models—Lyra (budget-friendly), Libra (sporty compact), and Hydra (luxury).
- **Production Setup:** Three plants, each dedicated to producing one specific model.
- **Capacity vs. Demand:** Demand forecasts show GMC may struggle to meet customer needs with current capacity.
- **Demand Diversion:** When one model is out of stock, customers may choose an available, higher-tier model.
- **Strategic Opportunity:** GMC is evaluating retooling options to increase capacity and flexibility across plants.

Problem Overview: To Retool or Not To Retool

- **Key Issue**: GMC faces insufficient production capacity to meet demand and considers retooling options
- **Pros of retooling the plants**: Increased efficiency, lower marginal production costs, multiple model production capability
- **Cons of retooling the plants**: Increased fixed cost
- The additional renovation cost will include the previous fixed costs plus the additional cost of the renovation

The Decision Variables

- **Binary Variables (Plant Operation)** : There are 5 binary variables that represent whether each plant is open (1) or closed (0).
- **Integer Variables (Production Quantities)**: There are 15 integer variables that represent production levels for each car model at each plant (5 plants x 3 car models).
- **Integer Variables (Demand Variables)**: There are 3 integer variables representing the actual demand met for each car type (Lyra, Libra, Hydra).

Constraints

1. **Mutual Exclusivity Constraints**:
   - Only one of the original Lyra plant or the new Lyra plant can be open.
   - Similarly, only one of the original Libra plant or the new Libra plant can be open.

2. **Plant Open Constraint (Force Open or Optional)**:This constraint ensures that the solution uses 3 plants (if we are not allowed to shut down the hydra plant) if true and fewer than 3 plants if false

3. **Plant Capacity Constraints**: The total production at each plant cannot exceed the plant's capacity.

4. **Demand Satisfaction Constraints**: The total production of each car model, plus any demand diverted from that model, must be greater than or equal to the original demand for that model.

5. **Production Possibility Constraints**: If a plant cannot produce a certain car model, the production of that model at that plant is constrained to 0.

```
# Constraints
# 1.Retooling Constraint:
for plant in ["Lyra", "Libra"]:
    m.addConstr(
        (O[f"{plant}"] + O[f"New {plant}"] <= 1),
        name="Retool"
    )


# 2.Plant Open Constraint (Force Open or Optional):

if force_open_plants:
   m.addConstr(
       gp.quicksum(O[plant] for plant in plants) == 3
   )
else:
   m.addConstr(
    gp.quicksum(O[plant] for plant in plants) <= 3
)

# 3.Capacity Constraint
m.addConstrs(
    (gp.quicksum(P[(plant, car)] for car in cars) <= O[plant] * DATA["Plants"][plant]["Capacity"]
     for plant in plants),
    "Capacity"
)
```

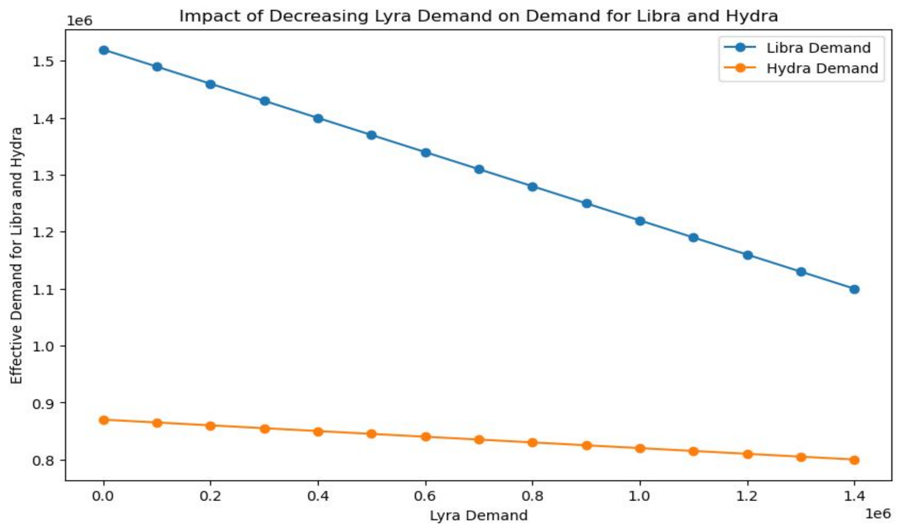
```
    # Solve it!
    m.optimize()
    print(f"Optimal objective value: ${round(m.objVal, 2)}")
    get_solution(m)

    return m, O, P, D

# Run the function
m, O, P, D = solve_model(DATA, force_open_plants=True)
```

Does intentional underproduction of Lyra’s drive more demand for Libra’s and Hydra’s

Yes, as we can see from the graph as we move towards the left(underproduction of Lyra’s) the demand goes up for Libra and Hydra models. The slope is steeper for Libra since the diversion rate is higher (0.3) compared to Hydra (0.05)




```python
# Function to calculate demand diversion based on reduced demand for Lyra
def solve_demand_diversion(lyra_demand):
    # Calculate unmet demand for Lyra
    unmet_lyra_demand = lyra_demand_start - lyra_demand

    # Diversion rates from Lyra to Libra and Hydra
    diversion_rate_libra = DATA["Demand Diversion"]["Lyra"]["Libra"]
    diversion_rate_hydra = DATA["Demand Diversion"]["Lyra"]["Hydra"]

    # Calculate diverted demand
    diverted_demand_libra = diversion_rate_libra * unmet_lyra_demand
    diverted_demand_hydra = diversion_rate_hydra * unmet_lyra_demand

    # Calculate effective demand for Libra and Hydra after diversion
    effective_libra_demand = DATA["Demand"]["Libra"] + diverted_demand_libra
    effective_hydra_demand = DATA["Demand"]["Hydra"] + diverted_demand_hydra

    return effective_libra_demand, effective_hydra_demand

# Test different levels of reduced demand for Lyra
for reduction in range(0, lyra_demand_start + 1, 100000):  # Decrease in steps of 100,000
    lyra_demand = lyra_demand_start - reduction
    effective_libra_demand, effective_hydra_demand = solve_demand_diversion(lyra_demand)

    # Store the demand levels in solutions
    solutions['Lyra_Demand'].append(lyra_demand)
    solutions['Libra_Demand'].append(effective_libra_demand)
    solutions['Hydra_Demand'].append(effective_hydra_demand)
```

Should GMC retool the Libra plant?

- If we keep the hydra plant open the the answer is no, we should not retool the plant but if we are allowed to shut down the hydra plant then yes, we should retool the plant

```
Optimal objective value: $2585707500.0
Solution Values:
    Plant[Lyra]: 0.0
    Plant[Libra]: 1.0
    Plant[Hydra]: 1.0
    Plant[New Lyra]: 1.0
    Plant[New Libra]: -0.0
    Production[Lyra,Lyra]: -0.0
    Production[Lyra,Libra]: -0.0
    Production[Lyra,Hydra]: -0.0
    Production[Libra,Lyra]: -0.0
    Production[Libra,Libra]: 799998.0
    Production[Libra,Hydra]: -0.0
    Production[Hydra,Lyra]: 7.0
    Production[Hydra,Libra]: -0.0
    Production[Hydra,Hydra]: 802857.0
    Production[New Lyra,Lyra]: 1257143.0
    Production[New Lyra,Libra]: 342857.0
    Production[New Lyra,Hydra]: -0.0
    Production[New Libra,Lyra]: -0.0
    Production[New Libra,Libra]: -0.0
    Production[New Libra,Hydra]: -0.0
    Demand[Lyra]: 1400000.0
    Demand[Libra]: 1142855.0
    Demand[Hydra]: 802857.0
```

```
Optimal objective value: $4040000000.0
Solution Values:
    Plant[Lyra]: 0.0
    Plant[Libra]: -0.0
    Plant[Hydra]: 0.0
    Plant[New Lyra]: 1.0
    Plant[New Libra]: 1.0
    Production[Lyra,Lyra]: -0.0
    Production[Lyra,Libra]: -0.0
    Production[Lyra,Hydra]: -0.0
    Production[Libra,Lyra]: -0.0
    Production[Libra,Libra]: 0.0
    Production[Libra,Hydra]: -0.0
    Production[Hydra,Lyra]: -0.0
    Production[Hydra,Libra]: -0.0
    Production[Hydra,Hydra]: -0.0
    Production[New Lyra,Lyra]: 1400000.0
    Production[New Lyra,Libra]: 100000.0
    Production[New Lyra,Hydra]: -0.0
    Production[New Libra,Lyra]: -0.0
    Production[New Libra,Libra]: 1000000.0
    Production[New Libra,Hydra]: 800000.0
    Demand[Lyra]: 1400000.0
    Demand[Libra]: 1100000.0
    Demand[Hydra]: 800000.0
```

How much additional demand is driven for Hydra’s?

Additional demand for Hydra’s = Demand[Hydra] - Data[“Demand”][“Hydra”]

= 800000 - 802857

= 2857

```
In [22]: total_production_hydra = get_production("Hydra")
         additional_demand_for_hydra = total_production_hydra - DATA["Demand"]["Hydra"]

         print("Additional demand for Hydras:", additional_demand_for_hydra)

         Additional demand for Hydras: 2857.0
```

Is closing the Hydra plant beneficial to GMC?

As we can see from the previous slide the objective value for Hydra plant being shut is higher ($4040000000.0) compared to when it is open ($ 2585707500.0)

```
Optimal objective value: $4040000000.0
Solution Values:
    Plant[Lyra]: 0.0
    Plant[Libra]: -0.0
    Plant[Hydra]: 0.0
    Plant[New Lyra]: 1.0
    Plant[New Libra]: 1.0
```

```
# Run the function
m, O, P, D = solve_model(DATA, force_open_plants=True)
```

```
Optimal objective value: $2585707500.0
Solution Values:
    Plant[Lyra]: 0.0
    Plant[Libra]: 1.0
    Plant[Hydra]: 1.0
    Plant[New Lyra]: 1.0
    Plant[New Libra]: -0.0
```

If demand for the Libra increases, does that affect the retooling plan?

If we increase the demand of libra to 200000, we have to retool the libra plant as well and it is more profitable as we can see from the increase in objective value.

```
from copy import deepcopy
assumption = deepcopy(DATA)
assumption["Demand"]["Libra"] = 2000000
new_model, new_O, new_P, new_D = solve_model(new_data, force_open_plants=False)
retooling_changed = any(new_O[plant].X != O[plant].X for plant in DATA["Plants"].keys())
print("Does changing Libra's demand affect the retooling plan?", retooling_changed)
```

```
Optimal objective value: $4958779000.0
Solution Values:
    Plant[Lyra]: 0.0
    Plant[Libra]: 0.0
    Plant[Hydra]: 0.0
    Plant[New Lyra]: 1.0
    Plant[New Libra]: 1.0
```

Key Observations and Conclusion

It is more profitable to shut down the Hydra plant and retool both the Libra and Lyra plants since they have lesser fixed costs, a higher profit margin and a diversion option