Decision Analytics – Assignment 2

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Task 1

A. Load the input data from the file "Assignment_DA_2_a_data.xlsx". Note that not all fields are filled, for example Supplier C does not stock Material A. Make sure to use the data from the file in your code, please do not hardcode any values that can be read from the file.

- Data is read from excel sheets into 8 dataframes – supplier_stock, raw_material_costs, raw_material_shipping, product_requirements, production_capacity, production_cost, customer_demand , shipping_costs.
- On reading data from the excel files into Pandas dataframes, the empty cells will be considered as 'nan' values in the dataframes. In order to deal with these 'nan's, we use fillna() function to replace these 'nan's as 0 in 4 dataframes - supplier_stock, product_requirements, production_capacity, customer_demand. The sheets consisting of costs are left as they are.

B. Identify and create the decision variables for the orders from the suppliers, for the production volume, and for the delivery to the customers using the OR Tools wrapper of the GLOP_LINEAR_PROGRAMMING solver.

Three decision variables are created as dictionaries:

- supplier_orders(factory, supplier, material)
- production_volume(factory, product)
- customer_delivery(factory, customer, product)

C. Define and implement the constraints that ensure factories produce more than they ship to the customers.

Linear Equation :

Σ(production_volume(product, volume))
- Σ(customer_delivery(factory, customer, product)) >= 0

Every factory has an upper limit for production of certain products. The above equation ensures that a factory cannot ship to a customer more that its production capacity.

D. Define and implement the constraints that ensure that customer demand is met.

Linear Equation :

Σ(customer_delivery(factory, customer, product)) = customer_demand[customer][product]

The above equation ensures that whatever amount of product is demanded by the customer is produced in the factories.

E. Define and implement the constraints that ensure that suppliers have all ordered items in stock.

Linear Equation:

$$0 <= \Sigma(supplier\_orders(factory, supplier, material)) <= supplier\_stock[material][supplier]$$

The above equation ensures that the orders made by factories to suppliers is within the material stock limits.

F. Define and implement the constraints that ensure that factories order enough material to be able to manufacture all items.

Linear Equation:

$$\Sigma(supplier\_orders(factory, supplier, material)) \\ - (product\_requirements[material][product] * \Sigma(production\_volume(factory, product))) = 0$$

In this constraint, we ensure that factories purchase materials from suppliers such that it receives enough of a particular material required for manufacting all the products that require that material.

G. Define and implement the constraints that ensure that the manufacturing capacities are not exceeded.

Linear Equation:

$$0 <= \Sigma(production\_volume(factory, product)) <= production\_capacity[factory][product]$$

The above equation ensures a product can be produced in a factory only until the factory's capacity to produce the product has been reached, that is, a factory cannot produce more than its production capacity.

H. Define and implement the objective function. Make sure to consider the supplier bills comprising shipping and material costs, the production cost of each factory, and the cost of delivery to each customer.

Linear Equation:

$$cost = ((raw\_material\_costs[material][supplier]+ raw\_material\_shipping[factory][supplier]) \\ * \Sigma(supplier\_orders(factory, supplier, material))) \\ +(production\_cost[factory][product] * \Sigma(production\_volume(factory, product))) \\ +(shipping\_costs[customer][factory] * \Sigma(customer\_delivery(factory, customer, product)))$$

The objective function is represented using the above equation where if material order are made to certain suppliers from certain factories, then the respective material cost and shipping costs are included. Also, production costs based on which product and how much of a product is being produced by a factory and shipping costs tp customers from factories is included in the objective function. Since, we are looking for the most optimal solution with the least cost incurred, we set the cost function to minimization().

I. Solve the linear program and determine the optimal overall cost.

Optimal Overall Cost : 49315.0

J. Determine for each factory how much material has to be ordered from each individual supplier.

How many units of each material does each factory order from each supplier?

Factory C :
Supplier E supplies 25.000000000000007 units of Material A
Supplier E supplies 40.0 units of Material D
Supplier B supplies 6.0000000000000036 units of Material B
Supplier C supplies 20.0 units of Material C
Supplier C supplies 34.99999999999999 units of Material D
Supplier C supplies 10.0 units of Material B

Factory B :
Supplier E supplies 4.000000000000001 units of Material A
Supplier D supplies 5.999999999999998 units of Material C
Supplier B supplies 6.000000000000001 units of Material A
Supplier B supplies 34.0 units of Material B
Supplier C supplies 32.00000000000001 units of Material C
Supplier C supplies 4.999999999999996 units of Material D

Factory A :
Supplier A supplies 20.0 units of Material A
Supplier A supplies 20.0 units of Material B
Supplier D supplies 14.000000000000002 units of Material C
Supplier D supplies 50.0 units of Material D
Supplier B supplies 19.000000000000004 units of Material A
Supplier B supplies 4.000000000000002 units of Material B

K. Determine for each factory what the supplier bill comprising material cost and delivery will be for each supplier.

What is the bill amount to be paid by each factory to each of its suppliers (inclusive of material cost and shipping)?

Factory C :
Supplier A : 0
Supplier E : 215.0
Supplier D : 0
Supplier B : 265.0
Supplier C : 580.0

Factory B :
Supplier A : 0
Supplier E : 65.0
Supplier D : 230.0
Supplier B : 140.0
Supplier C : 360.0

Factory A :
Supplier A : 140.0
Supplier E : 0
Supplier D : 280.0
Supplier B : 220.0
Supplier C : 0

L. Determine for each factory how many units of each product are being manufactured. Also determine the total manufacturing cost for each individual factory.

How many units per product are manufactured in each factory? What is the total manufacturing cost of each factory?

Factory C :
Product D : 5.0 units
Product A : 2.000000000000001 units
Total Manufacturing cost : 175.0

Factory B :
Product A : 2.0 units
Product C : 4.0 units
Product B : 0.9999999999999989 units
Total Manufacturing cost : 240.0

Factory A :
Product D : 3.0 units
Product A : 6.0 units
Product B : 1.000000000000001 units
Total Manufacturing cost : 250.0

M. Determine for each customer how many units of each product are being shipped from each factory. Also determine the total shipping cost per customer.

How many units of each product are being shipped to each customer and from which factory? Also, what is the total shipping cost for each customer?

Customer D :
1.0 units of Product D from Factory C
4.0 units of Product C from Factory B
3.0 units of Product D from Factory A
Total Shipping cost : 175

Customer A :
1.0 units of Product D from Factory C
2.000000000000001 units of Product A from Factory C
4.999999999999999 units of Product A from Factory A
Total Shipping cost : 70

Customer B :
2.0 units of Product A from Factory B
1.0 units of Product A from Factory A
Total Shipping cost : 90

Customer C :
3.0 units of Product D from Factory C
0.9999999999999989 units of Product B from Factory B
1.000000000000001 units of Product B from Factory A
Total Shipping cost : 170

N. Determine for each customer the fraction of each material each factory has to order for manufacturing products delivered to that particular customer. Based on this calculate the overall unit cost of each product per customer including the raw materials used for the manufacturing of the customer's specific product, the cost of manufacturing for the specific customer and all relevant shipping costs.

Material Fractions :

Customer A :

Product D :
Factory C Material C Supplier C 5.0
Factory C Material B Supplier C 5.0
Factory C Material B Supplier B 3.000000000000001
Factory C Material A Supplier E 8.333333333333336
Factory C Material D Supplier E 2.6666666666666665
Factory C Material D Supplier C 2.333333333333333

Product A :
Factory A Material B Supplier B 0.26666666666666683
Factory A Material B Supplier A 1.3333333333333337
Factory A Material A Supplier B 0.7600000000000002
Factory A Material A Supplier A 0.8000000000000002
Factory C Material B Supplier C 1.6666666666666659
Factory C Material B Supplier B 0.9999999999999999
Factory C Material A Supplier E 2.5

Customer B :
Product A :
Factory A Material B Supplier B 1.333333333333334
Factory A Material B Supplier A 6.666666666666667
Factory A Material A Supplier B 3.8000000000000007
Factory A Material A Supplier A 4.0
Factory B Material B Supplier B 5.666666666666667
Factory B Material A Supplier E 0.4000000000000001
Factory B Material A Supplier B 0.6000000000000001

Customer D :

Product C :
Factory B   Material C   Supplier D   0.16666666666666663
Factory B   Material C   Supplier C   0.8888888888888891
Factory B   Material B   Supplier B   1.2142857142857142

Product D :
Factory A   Material C   Supplier D   1.1666666666666667
Factory A   Material B   Supplier B   0.666666666666667
Factory A   Material B   Supplier A   3.3333333333333335
Factory A   Material A   Supplier B   2.1111111111111116
Factory A   Material A   Supplier A   2.2222222222222223
Factory A   Material D   Supplier D   1.1111111111111112
Factory C   Material C   Supplier C   5.0
Factory C   Material B   Supplier C   5.0
Factory C   Material B   Supplier B   3.000000000000001
Factory C   Material A   Supplier E   8.333333333333336
Factory C   Material D   Supplier E   2.6666666666666665
Factory C   Material D   Supplier C   2.333333333333333

Customer C :

Product B :
Factory A   Material C   Supplier D   6.999999999999993
Factory A   Material D   Supplier D   9.99999999999999
Factory B   Material C   Supplier D   3.0000000000000027
Factory B   Material C   Supplier C   16.00000000000002
Factory B   Material D   Supplier C   1.0000000000000002

Product D :
Factory C   Material C   Supplier C   1.6666666666666667
Factory C   Material B   Supplier C   1.6666666666666667
Factory C   Material B   Supplier B   1.0000000000000002
Factory C   Material A   Supplier E   2.7777777777777786
Factory C   Material D   Supplier E   0.8888888888888888
Factory C   Material D   Supplier C   0.7777777777777776

Per customer per product cost:
Customer A   Product D   nan
Customer A   Product A   1196.7666666666667
Customer B   Product A   2071.0000000000005
Customer D   Product C   410.91269841269843
Customer D   Product D   nan
Customer C   Product B   7100.000000000004
Customer C   Product D   nan

Task 2

A. Load the input data from the file "Assignment_DA_2_b_data.xlsx" . Make sure to use the data from the file in your code, please do not hardcode any values that can be read from the file.

The data is read from the excel file as Pandas dataframes – flight_schedule, taxi_distances and terminal_capacity.

B. Identify and create the decision variables for the arrival runway allocation, for the departure runway allocation, and for the terminal allocation using the OR Tools wrapper of the CBC_MIXED_INTEGER_PROGRAMMING solver.

Three decision variables are created as dictionaries:

- arrival_flights_runways(flight, runway)
- departure_flights_runways(flight, runway)
- flights_terminals(flight, terminal)

C. Define and create auxiliary variables for the taxi movements between runways and terminals for each flight.

Two auxiliary variables are created as dictionaries depicting taxi movements to and from runways and terminals.

- flights_runways_to_terminals(flight, runway, terminal)
- flights_terminals_to_runways(flight, runway, terminal)

D. Define and implement the constraints that ensure that every flight has exactly two taxi movements.

Linear Equation:

Σ(flights_runways_to_terminals(flight, runway, terminal)) = 1
Σ(flights_terminals_to_runways(flight, runway, terminal)) = 1

The above equations ensure that for each flight, there is only one taxi movement from a runway to a terminal and back from the terminal to a runway.

E. Define and implement the constraints that ensure that the taxi movements of a flight are to and from the allocated terminal.

Linear Equation:

Σ(flights_runways_to_terminals(flight, runway, terminal))
+Σ(flights_terminals_to_runways(flight, runway, terminal))
-2*Σ(flights_terminals[(flight, terminal)) = 0

The above equation ensures that if a flight has a taxi movement from a runway to a particular terminal, then the flight returns to a runway from the same terminal. So going by the above equation, if the flight has the same terminal involved for both it taxi movements, then the equation holds.

F. Define and implement the constraints that ensure that the taxi movements of a flight include the allocated arrival and departure runways.

Linear Equation:

Σ(arrival_flights_runways(flight, runway))
- Σ(flights_runways_to_terminals(flight, runway, terminal))= 0

Σ(departure_flights_runways(flight, runway))
- Σ(flights_terminals_to_runways(flight, runway, terminal))= 0

The above equations ensure that the if a flight arrives to a particular runway, the its taxi movement should include that runway only and if it departs from a particular runway, its other taxi movement should invlove the same runway.

G. Define and implement the constraints that ensure that each flight has exactly one allocated arrival runway and exactly one allocated departure runway.

Linear Equation:

Σ(arrival_flights_runways(flight, runway))= 1
Σ(departure_flights_runways(flight, runway))= 1

The above equations ensure that only one runway each is allocated to a flight for arrival and departure.

H. Define and implement the constraints the ensure that each flight is allocated to exactly one terminal.

Linear Equation:

Σ(flights_terminals[(flight, terminal)) = 1

The above equation ensures that a flight is allocated to exactly one terminal.

I. Define and implement the constraints that ensure that no runway is used by more than one flight during each timeslot.

Linear Equation:

For a particular timeslot,
0 <= Σ(arrival_flights_runways(flight, runway)) + Σ(departure_flights_runways(flight, runway)) <=1

The above equation ensures that a at a particular timeslot, a maximum of 1 flight can use a runway or a runway can remain unused too.

J. Define and implement the constraints that ensure that the terminal capacities are not exceeded.

Linear Equation:

For a particular timeslot,
0 <= Σ(flights_terminals[(flight, terminal)) <= terminal_capacity['Gates'][terminal])

The above equation ensures that at any particuar time, the number of flights allocated to a terminal does not exceed the number of gates at the terminal.

K. Define and implement the objective function. Solve the linear program and determine the optimal total taxi distances for all flights.

Linear Equation:

Taxi_distance = (taxi_distances[terminal][runway]
*** flights_runways_to_terminals[(flight,runway,terminal))**
+ (taxi_distances[terminal][runway]
*** flights_terminals_to_runways[(flight, runway, terminal))**

The above equation determines the optimal taxi distance covered by all flights.
Total Optimal taxi distance : 164.0

L. Determine the arrival runway allocation , the departure runway allocation, and the terminal allocation for each flight. Also determine the taxi distance for each flight.

Arrivals :
Flight K Runway A Terminal A 3
Flight U Runway A Terminal A 3
Flight N Runway A Terminal A 3
Flight O Runway A Terminal A 3
Flight M Runway A Terminal A 3
Flight A Runway A Terminal A 3
Flight C Runway B Terminal B 4
Flight R Runway A Terminal A 3
Flight T Runway A Terminal A 3
Flight D Runway A Terminal A 3
Flight J Runway A Terminal A 3
Flight G Runway A Terminal A 3
Flight S Runway A Terminal A 3
Flight I Runway A Terminal A 3
Flight V Runway A Terminal A 3
Flight Z Runway A Terminal A 3
Flight W Runway A Terminal A 3
Flight E Runway B Terminal B 4
Flight X Runway A Terminal A 3

Flight F   Runway A   Terminal A   3
Flight B   Runway A   Terminal A   3
Flight P   Runway A   Terminal A   3
Flight Q   Runway B   Terminal B   4
Flight L   Runway B   Terminal B   4
Flight Y   Runway A   Terminal A   3
Flight H   Runway A   Terminal A   3

Departures :
Flight K   Runway A   Terminal A   3
Flight U   Runway A   Terminal A   3
Flight N   Runway A   Terminal A   3
Flight O   Runway A   Terminal A   3
Flight M   Runway A   Terminal A   3
Flight A   Runway A   Terminal A   3
Flight C   Runway B   Terminal B   4
Flight R   Runway A   Terminal A   3
Flight T   Runway A   Terminal A   3
Flight D   Runway A   Terminal A   3
Flight J   Runway A   Terminal A   3
Flight G   Runway A   Terminal A   3
Flight S   Runway A   Terminal A   3
Flight I   Runway A   Terminal A   3
Flight V   Runway A   Terminal A   3
Flight Z   Runway A   Terminal A   3
Flight W   Runway A   Terminal A   3
Flight E   Runway B   Terminal B   4
Flight X   Runway A   Terminal A   3
Flight F   Runway A   Terminal A   3
Flight B   Runway A   Terminal A   3
Flight P   Runway A   Terminal A   3
Flight Q   Runway B   Terminal B   4
Flight L   Runway B   Terminal B   4
Flight Y   Runway A   Terminal A   3
Flight H   Runway A   Terminal A   **3**

Taxi Distances :
Flight K : 6
Flight U : 6
Flight N : 6
Flight O : 6
Flight M : 6
Flight A : 6
Flight C : 8
Flight R : 6
Flight T : 6
Flight D : 6
Flight J : 6
Flight G : 6
Flight S : 6
Flight I : 6
Flight V : 6

Flight Z : 6
Flight W : 6
Flight E : 8
Flight X : 6
Flight F : 6
Flight B : 6
Flight P : 6
Flight Q : 8
Flight L : 8
Flight Y : 6
Flight H : 6

M. Determine for each time of the day how many gates are occupied at each terminal.

No. of gates occupied :
08:45:00
Terminal B 0
Terminal C 0
Terminal A 2
12:00:00
Terminal B 1
Terminal C 0
Terminal A 2
13:30:00
Terminal B 0
Terminal C 0
Terminal A 1
08:00:00
Terminal B 0
Terminal C 0
Terminal A 2
10:15:00
Terminal B 0
Terminal C 0
Terminal A 1
11:00:00
Terminal B 1
Terminal C 0
Terminal A 2
08:15:00
Terminal B 2
Terminal C 0
Terminal A 1
15:00:00
Terminal B 0
Terminal C 0
Terminal A 2
17:45:00
Terminal B 0
Terminal C 0
Terminal A 1
15:45:00

Terminal B 0
Terminal C 0
Terminal A 1
14:30:00
Terminal B 0
Terminal C 0
Terminal A 1
14:00:00
Terminal B 1
Terminal C 0
Terminal A 2
17:30:00
Terminal B 0
Terminal C 0
Terminal A 1
11:15:00
Terminal B 0
Terminal C 0
Terminal A 1
15:15:00
Terminal B 0
Terminal C 0
Terminal A 1
09:30:00
Terminal B 0
Terminal C 0
Terminal A 1
15:30:00
Terminal B 0
Terminal C 0
Terminal A 2
16:00:00
Terminal B 0
Terminal C 0
Terminal A 2
17:00:00
Terminal B 0
Terminal C 0
Terminal A 2
13:45:00
Terminal B 0
Terminal C 0
Terminal A 1
12:15:00
Terminal B 0
Terminal C 0
Terminal A 1
13:00:00
Terminal B 1
Terminal C 0
Terminal A 0
10:00:00

Terminal B 1
Terminal C 0
Terminal A 2
10:45:00
Terminal B 0
Terminal C 0
Terminal A 1
16:15:00
Terminal B 0
Terminal C 0
Terminal A 2
09:15:00
Terminal B 0
Terminal C 0
Terminal A 1
10:30:00
Terminal B 1
Terminal C 0
Terminal A 2
11:45:00
Terminal B 0
Terminal C 0
Terminal A 1
08:30:00
Terminal B 0
Terminal C 0
Terminal A 2
09:00:00
Terminal B 0
Terminal C 0
Terminal A 2
16:30:00
Terminal B 0
Terminal C 0
Terminal A 1