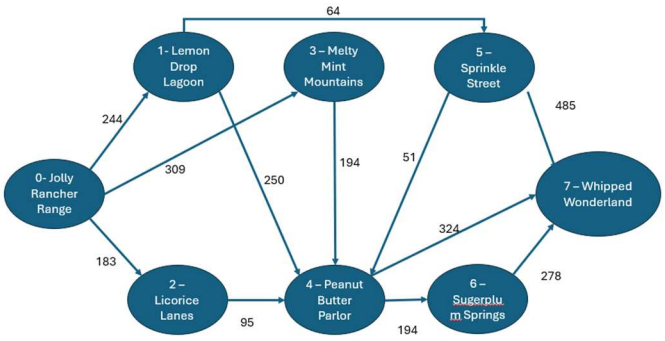
Module 07 – Maximal Flow

Exploratory Data Analysis

In this section, you should perform some data analysis on the data provided to you. Please format your findings in a visually pleasing way and please be sure to include these cuts:

- *Make a visual graph of your data like what we saw for the sample problem*
  - https://excalidraw.com
  - https://mermaid.live
  - https://dreampuf.github.io/GraphvizOnline
  - Powerpoint/Word



Model Formulation

Write the formulation of the model into here prior to implementing it in your Excel model. Be explicit with the definition of the decision variables, objective function, and constraints.

MAX:

$$X_{10} + X_{20} + X_{30}$$

Subject to:

$$+X_{41} + X_{51} - X_{10} = 0$$
$$+X_{42} - X_{20} = 0$$
$$+X_{43} - X_{30} = 0$$
$$+X_{64} + X_{65} - X_{41} - X_{42} - X_{43} = 0$$
$$+X_{75} + X_{76} - X_{51} - X_{54} = 0$$
$$+X_{46} - X_{64} - X_{54} = 0$$
$$+X_{67} - X_{75} - X_{76} = 0$$

with the following bounds on the decision variables:

$$0 \le X_{10} \le 244 \quad 0 \le X_{20} \le 183 \quad 0 \le X_{30} \le 309$$
$$0 \le X_{41} \le 250 \quad 0 \le X_{42} \le 95 \quad 0 \le X_{43} \le 128$$
$$0 \le X_{46} \le 194 \quad 0 \le X_{51} \le 64 \quad 0 \le X_{54} \le 194$$
$$0 \le X_{64} \le 194 \quad 0 \le X_{65} \le 194 \quad 0 \le X_{67} \le 278$$
$$0 \le X_{75} \le 485 \quad 0 \le X_{76} \le 51$$

Model Optimized for Maximal Flow

Implement your formulation into Excel and be sure to make it neat. This section should include:

- *A screenshot of your optimized final model (formatted nicely, of course)*
- *A text explanation of what your model is recommending, especially any identified bottlenecks*

- *Update your graph from the EDA section to bold/color the links being used (and show how much is going through that link)*

Maximal Flow ->	324

Units of Flow	Links To		Links From		Upper Bound
244	0	Jolly Rancher Range	1	Lemon Drop Lagoon	244
80	0	Jolly Rancher Range	2	Licorice Lanes	183
0	0	Jolly Rancher Range	3	Melty Mint Mountains	309
244	1	Lemon Drop Lagoon	4	Peanut Butter Parlor	250
0	1	Lemon Drop Lagoon	5	Sprinkle Street	64
80	2	Licorice Lanes	4	Peanut Butter Parlor	95
0	3	Melty Mint Mountains	4	Peanut Butter Parlor	194
0	3	Melty Mint Mountains	6	Sugarplum Springs	128
324	4	Peanut Butter Parlor	7	Whipped Wonderland	324
0	4	Peanut Butter Parlor	6	Sugarplum Springs	194
0	5	Sprinkle Street	7	Whipped Wonderland	485
0	5	Sprinkle Street	4	Peanut Butter Parlor	51
0	6	Sugarplum Springs	7	Whipped Wonderland	278
324	7	Whipped Wonderland	0	Jolly Rancher Range	9999

	Nodes	Inflow	Outflow	Net Flow	Supply / Demand
0	Jolly Rancher Range	324	324	0	0
1	Lemon Drop Lagoon	244	244	0	0
2	Licorice Lanes	80	80	0	0
3	Melty Mint Mountains	0	0	0	0
4	Peanut Butter Parlor	324	324	0	0
5	Sprinkle Street	0	0	0	0
6	Sugarplum Springs	0	0	0	0
7	Whipped Wonderland	324	324	0	0

The model calculates the maximum possible flow from the source to the sink node, which is 324 units of flow from Whipped Wonderland (Node 7) to Jolly Rancher Range (Node 0). This solution identifies the most efficient paths through the network based on available capacities. Specifically, the model recommends sending 244 units of flow from Peanut Butter Parlor (Node 4) through Lemon Drop Lagoon (Node 1) to Jolly Rancher Range, and 80 units of flow from Peanut Butter Parlor through Licorice Lanes (Node 2) to the same destination. All 324 units originate from Whipped Wonderland and are routed to Peanut Butter Parlor before splitting between Nodes 1 and 2.

Several bottlenecks emerge from the model. The most critical is the link from Whipped Wonderland to Peanut Butter Parlor, which is operating at full capacity (324/324 units). This connection serves as the sole entry point for all flow into the network's main path, making it the primary constraint on overall capacity. The link from Peanut Butter Parlor to Lemon Drop Lagoon is also almost fully utilized (244/250), and the path to Licorice Lanes is nearly full (80/95). While other paths in the network, such as those through Sprinkle Street (Node 5) and Melty Mint Mountains (Node 3), have unused capacity, they are not part of the optimal solution and do not contribute to the maximum flow.

In conclusion, the model efficiently routes all flow through Whipped Wonderland and Peanut Butter Parlor, then to Jolly Rancher Range via the two downstream nodes. The main bottleneck in the network is the initial connection from Whipped Wonderland, which should be the focus of any future capacity expansions if greater flow is desired.

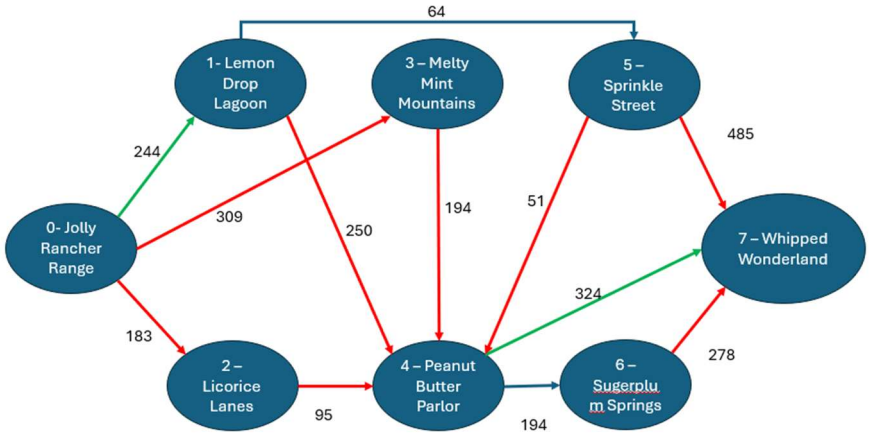
Model with Stipulation

Please copy the tab of your original model before continuing with the next part to avoid messing up your original solution.

Let's demonstrate the "Flow Aggregation" special consideration that was discussed in the textbook and the Follow Along – Model Formulation video. Please follow these steps:

- *Using a copy of the network, show how many units reach each node*

- *Identify the nodes that are underutilized and those that are at capacity with different colors*
- *Write a brief statement on what would help increase the optimal solution*



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In terms of capacity usage, several nodes are at full capacity, including Whipped Wonderland (Node 7), Peanut Butter Parlor (Node 4), Lemon Drop Lagoon (Node 1), Licorice Lanes (Node 2), and Jolly Rancher Range (Node 0). These nodes are fully engaged in the optimal path and do not have any remaining capacity to carry additional flow. On the other hand, some nodes are underutilized, such as Melty Mint Mountains (Node 3), Sprinkle Street (Node 5), and Sugarplum Springs (Node 6). These nodes are not used in the current solution, indicating that their paths either have limited capacity or are not necessary in reaching the maximum flow.

To increase the optimal solution beyond 324 units, the most effective change would be to increase the capacity of the link between Whipped Wonderland and Peanut Butter Parlor, as it is currently the main bottleneck in the system. Expanding this initial connection would allow more units to enter the network, which could then be distributed across the existing or alternate paths to reach the sink. Additionally, improving the capacity on downstream links or activating currently unused nodes could create new flow paths and relieve pressure from the saturated ones.