R In Supply Chain:

Intro to Supply Chain Network Design

Ralph Asher
ralph@datadrivensupplychain.com
January 18, 2022

Who Am I?

- MS Operations Research, Florida Inst. Tech. 2012
- US Marine Corps, 2006-2012 (Full-Time / Active Duty), 2013-Present (Part-Time / Reservist)
- General Mills & Target: Supply Chain Design & Simulation (2013-2021)

- ***Data Driven Supply Chain LLC:*** Consulting & Training in Supply Chain Analytics, Design, Optimization and Simulation
  - www.datadrivensupplychain.com

- Adjunct @ University of Minnesota, Carlson School of Management
- R user since 2012
- Math, maps, and coding enthusiast since childhood
  - USSR, MS-DOS, BASIC, and other antiquated acronyms

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Supply Chains… From Back Office to the Front Page

THE WALL STREET JOURNAL.

U.S.

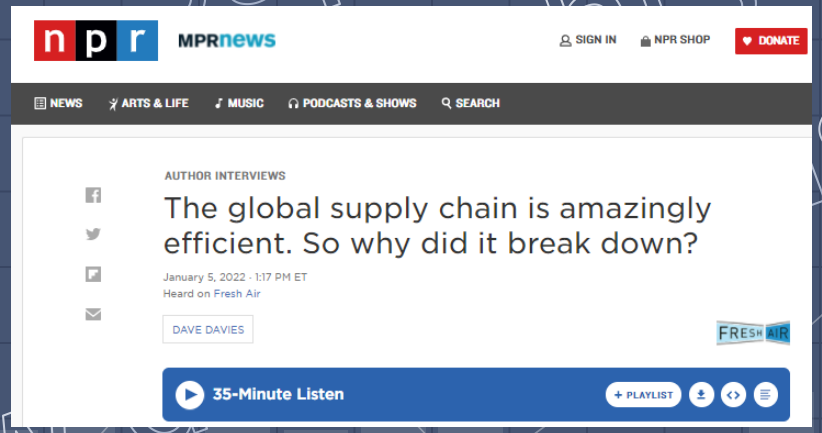
Supply-Chain Issues Leave New Homes Without Garage Doors and Gutters

Home builders blame bottlenecks for huge backlog of uncompleted homes

The New York Times

Supply Chain Woes Prompt a New Push to Revive U.S. Factories

Companies are testing whether the United States can regain some of the manufacturing output it ceded in recent decades to China and other countries.



The Washington Post
Democracy Dies in Darkness

Federal Reserve officials expect supply chain bottlenecks and labor shortages will continue to hamper the economy and drive up inflation for longer than previously expected, with the omicron variant posing further economic uncertainty, according to minutes released Wednesday from the Fed's December policy meeting.

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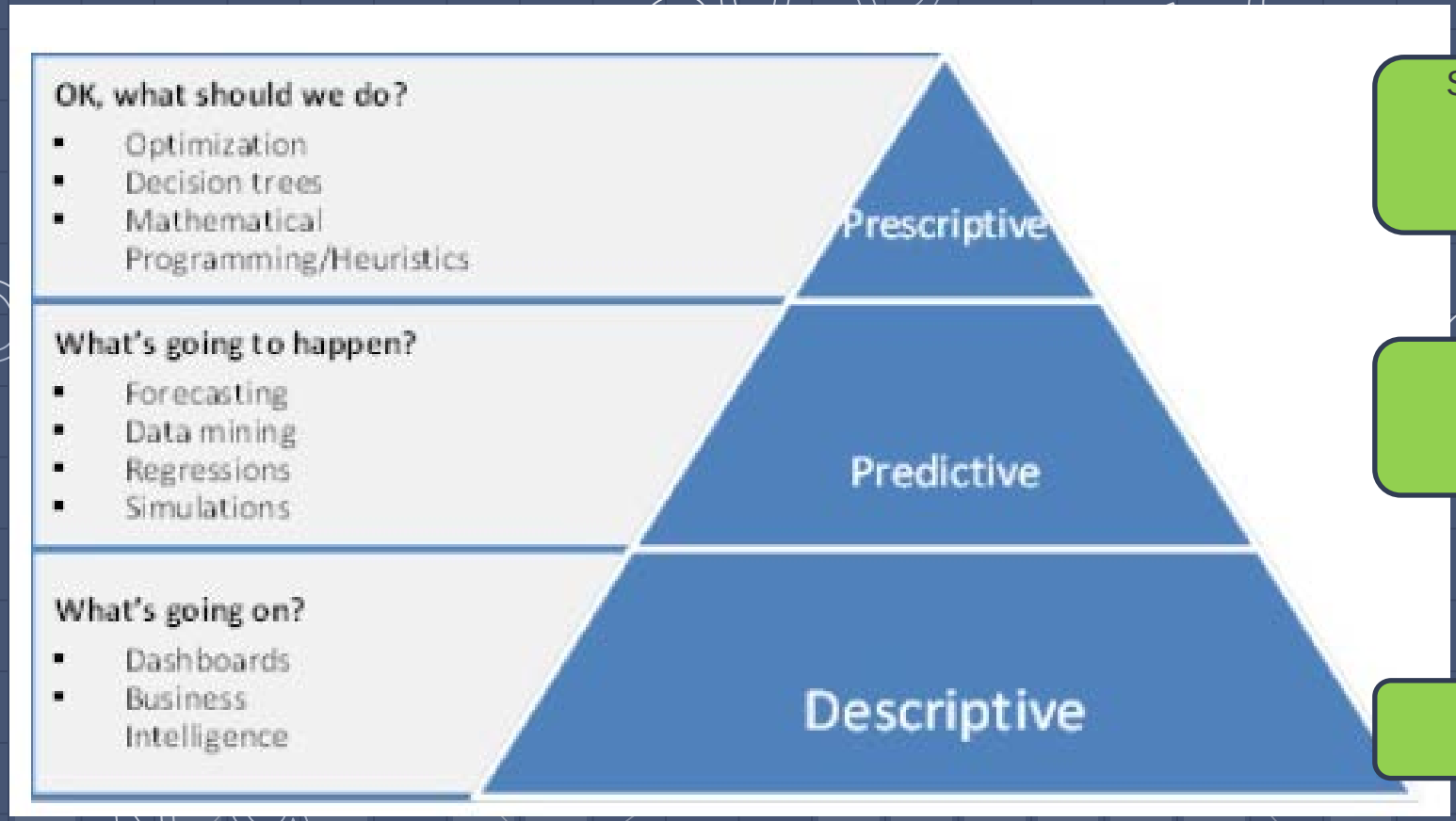
How Can Analytics Be Used in Supply Chain Management?



Supply Chain Network Design
Inventory Optimization
Manufacturing Optimization
Supply Chain Simulation

Sales Forecasting
Cost Input Forecasting
Supply Chain Simulations

BI & Diagnostic Analytics

Open-Source Technologies Are Changing the Game Across the Spectrum of Supply Chain Management Activities

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What is Supply Chain Network Design?

Strategic analysis of the locations and activities of the various elements of a firm's supply chain:

- Warehouses for Raw Materials & Semi-Finished Goods
- Manufacturing Facilities (Plants or Factories)
- Distribution Centers (Warehouses) for Finished Goods
- Retail Stores

All with the intent to understand the impacts on profitability, cost, service, and other key metrics; and with a goal to minimize or maximize one or two key metrics (usually cost or profitability).

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Distribution Network Design

Given a customer base of demand (aggregated to a city level):

- Where should we open Distribution Center(s) to satisfy that demand?
- How much volume should each Distribution Center contain?
- What customer should be serviced by ("aligned to") each Distribution Center?

- Two "echelons" of the supply chain: Distribution Centers and Customers

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How Do We Do This?

Optimization modeling is a mathematical technique that allows a practitioner to optimize a set of interconnected decisions, where the decisions are constrained by real-world limitations. Optimization solvers take the set of decisions, formulated as a mathematical model, and return the set of decisions that optimizes (minimizes or maximizes) an equation ("objective function") that includes the decisions as inputs.

Decisions:

- How many Distribution Centers to open, and where to locate them?
- What customers to align to each Distribution Center?

Limitations (Constraints):

- All Customer demand must be met
- Minimum or maximum number of Distribution Centers (DCs)
- Distribution Centers may be only realistically opened in certain locations
- Maximum volume per Distribution Center (capacity)
- Maximum distance from a Customer to its servicing Distribution Center

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Heartland Widgets, Inc.

You are a Supply Chain Data Scientist at Heartland Widgets, Inc. Your company is the market leader in widget sales across an eight-state area of the American Midwest.

The pandemic-induced shift in consumer demand from services to goods, as well as stay-at-home orders, has led to a boom in demand for your company's flagship product, the @HomeWidget.

Faced with record demand, the Director of Supply Chain Network Planning has asked you to "re-imagine" the company's distribution network.

You are to recommend where to open Heartland's Distribution Centers, as well as customer-DC alignment, at minimal cost.

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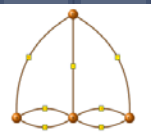

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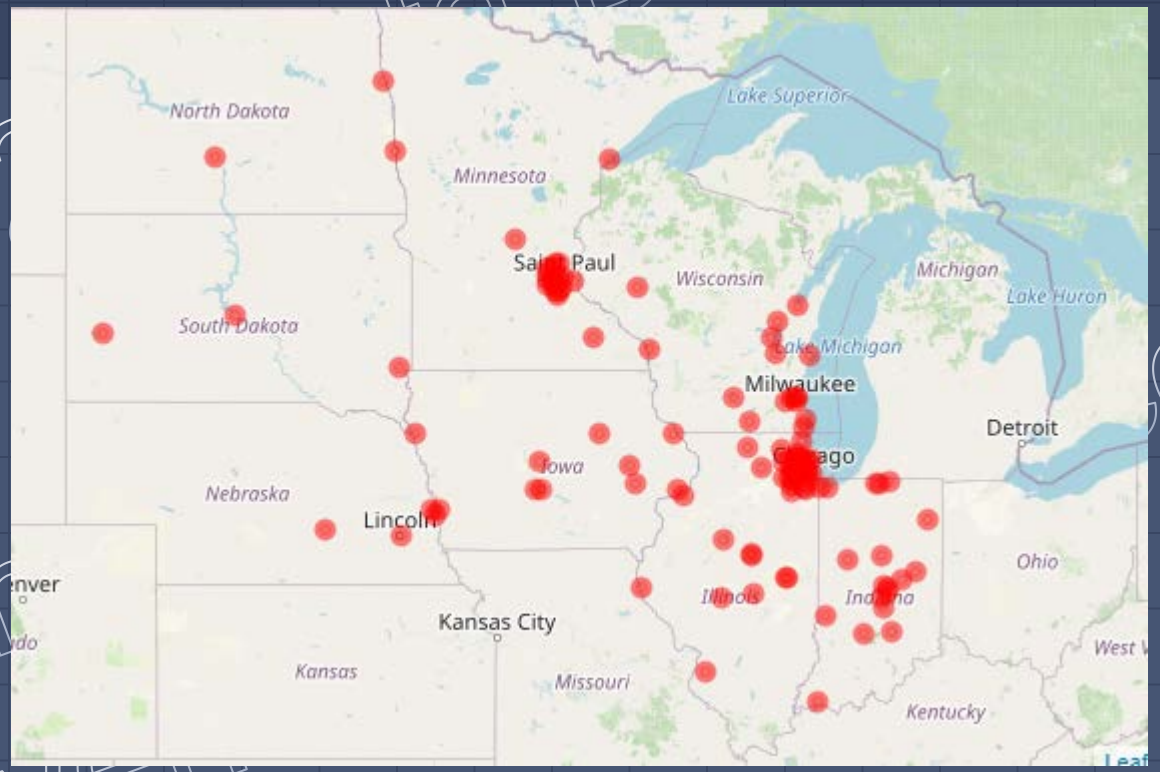
Heartland Widgets: Customer Demand By City

	Customer_Name	Customer_State	lat	long	demand
1	Ames IA	IA	42.02	-93.63	5769.00
2	Anderson IN	IN	40.09	-85.69	5704.00
3	Apple Valley MN	MN	44.75	-93.20	5161.00
4	Appleton WI	WI	44.27	-88.40	7009.00
5	Arlington Heights IL	IL	42.09	-87.98	7477.00
6	Aurora IL	IL	41.77	-88.29	18112.00
7	Belleville IL	IL	38.53	-90.00	4075.00
8	Bellevue NE	NE	41.16	-95.92	4890.00
9	Berwyn IL	IL	41.84	-87.79	5091.00
10	Bismarck ND	ND	46.81	-100.77	5693.00
11	Blaine MN	MN	45.17	-93.21	5614.00
12	Bloomington IL	IL	40.48	-88.97	7181.00
13	Bloomington IN	IN	39.17	-86.52	7126.00
14	Bloomington MN	MN	44.83	-93.32	8063.00
15	Bolingbrook IL	IL	41.70	-88.08	7700.00
16	Brookfield WI	WI	43.06	-88.12	4033.00
17	Brooklyn Park MN	MN	45.11	-93.35	6766.00
18	Buffalo Grove IL	IL	42.17	-87.96	4336.00



117 Midwestern Cities in Demand Table
Demand is Proportional to Population
Demand table created using maps::us.cities

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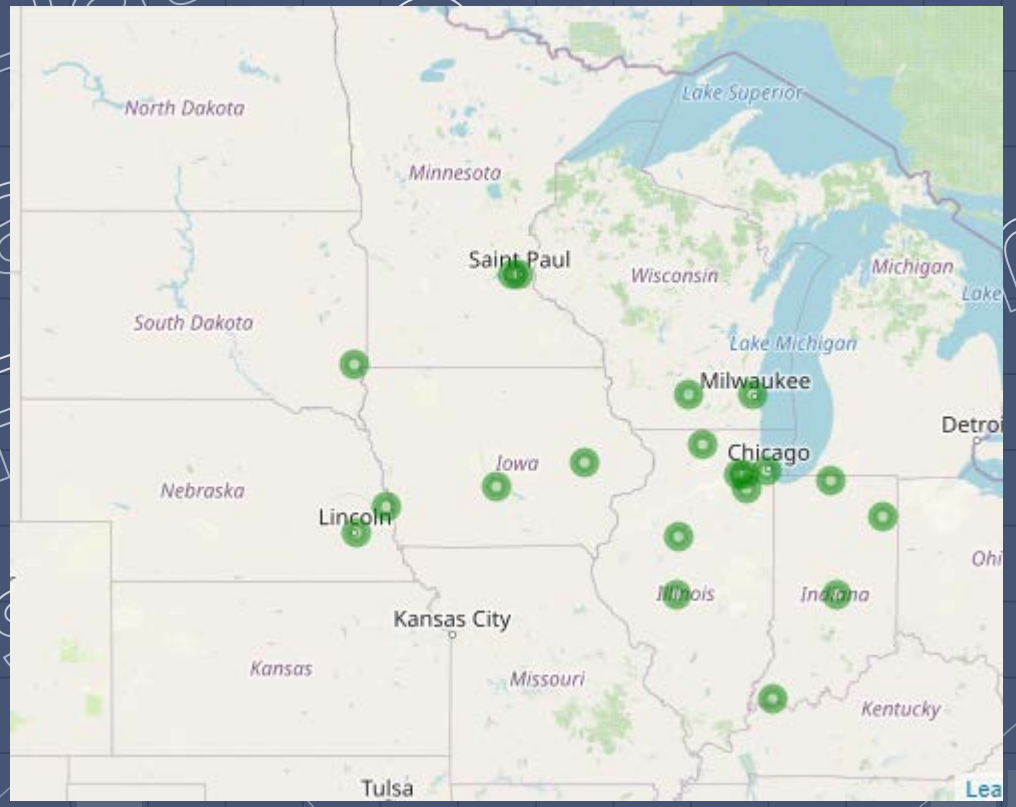
Heartland Widgets: Potential Distribution Center Locations

	DC_Name	State	lat	long	Capacity	Opening_Cost	Handling_Cost_Per_Unit
1	Aurora IL	IL	41.77	-88.29	13286070.00	1000000.00	0.01
2	Cedar Rapids IA	IA	41.97	-91.67	13286070.00	1000000.00	0.01
3	Chicago IL	IL	41.84	-87.68	13286070.00	1000000.00	0.01
4	Des Moines IA	IA	41.58	-93.62	13286070.00	1000000.00	0.01
5	Evansville IN	IN	37.98	-87.54	13286070.00	1000000.00	0.01
6	Fort Wayne IN	IN	41.07	-85.14	13286070.00	1000000.00	0.01
7	Indianapolis IN	IN	39.78	-86.15	13286070.00	1000000.00	0.01
8	Joliet IL	IL	41.53	-88.12	13286070.00	1000000.00	0.01
9	Lincoln NE	NE	40.82	-96.69	13286070.00	1000000.00	0.01
10	Madison WI	WI	43.08	-89.39	13286070.00	1000000.00	0.01
11	Milwaukee WI	WI	43.06	-87.97	13286070.00	1000000.00	0.01
12	Minneapolis MN	MN	44.96	-93.27	13286070.00	1000000.00	0.01
13	Naperville IL	IL	41.76	-88.15	13286070.00	1000000.00	0.01
14	Omaha NE	NE	41.26	-96.01	13286070.00	1000000.00	0.01
15	Peoria IL	IL	40.74	-89.61	13286070.00	1000000.00	0.01
16	Rockford IL	IL	42.27	-89.06	13286070.00	1000000.00	0.01
17	Saint Paul MN	MN	44.95	-93.10	13286070.00	1000000.00	0.01
18	Sioux Falls SD	SD	43.54	-96.73	13286070.00	1000000.00	0.01
19	South Bend IN	IN	41.68	-86.27	13286070.00	1000000.00	0.01
20	Springfield IL	IL	39.78	-89.64	13286070.00	1000000.00	0.01



Top 20 Cities (by Demand) in Midwest are considered for DC Locations
Each DC is assumed to cost $1 Million to open

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Heartland Widget Distributors, Inc.

What customers to align to each Distribution Center?

This is a series of yes/no decisions: for every combination of a Customer and a Distribution Center, should I align Customer *i* to Distribution Center *j* ?

Limitations: Exactly one "Yes" per Customer. (Each city is serviced by exactly one DC).

How many Distribution Centers to open, and where to locate them?

This is a series of if-then decisions, related to our alignment decisions: *if* at least one Customer is aligned to a DC, *then* we must open it.

The decision sets are interconnected – we cannot separate our decision on where to locate DCs, from our decision on how to align Customers to DCs.

	DC: Chicago IL	DC: Indianapolis IN	DC: Minneapolis MN
Customer: Ames IA	Align? Y/N	Align? Y/N	Align? Y/N
Customer: Anderson IN	Align? Y/N	Align? Y/N	Align? Y/N
Customer: Apple Valley MN	Align? Y/N	Align? Y/N	Align? Y/N
Customer: Appleton WI	Align? Y/N	Align? Y/N	Align? Y/N
Customer: Arlington Heights IL	Align? Y/N	Align? Y/N	Align? Y/N
Customer: Aurora IL	Align? Y/N	Align? Y/N	Align? Y/N

Table abridged for presentation

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Heartland Widget Distributors, Inc.

Distribution Center Opening Costs ($1M each)

+

Distribution Center Handling Costs ($0.01 Per Unit)

+

*DC-to-Customer Transportation Costs ($0.05 Per Unit-Mile. e.g., 2 units traveling 100 miles = 2*100 = 200 unit-miles → $10 cost)*

=

Total Supply Chain Cost

Optimization modeling helps us to find the set of interconnected decisions – which Distribution Centers to open, and which Customers to align with each Distribution Center – that minimizes the Total Supply Chain Cost

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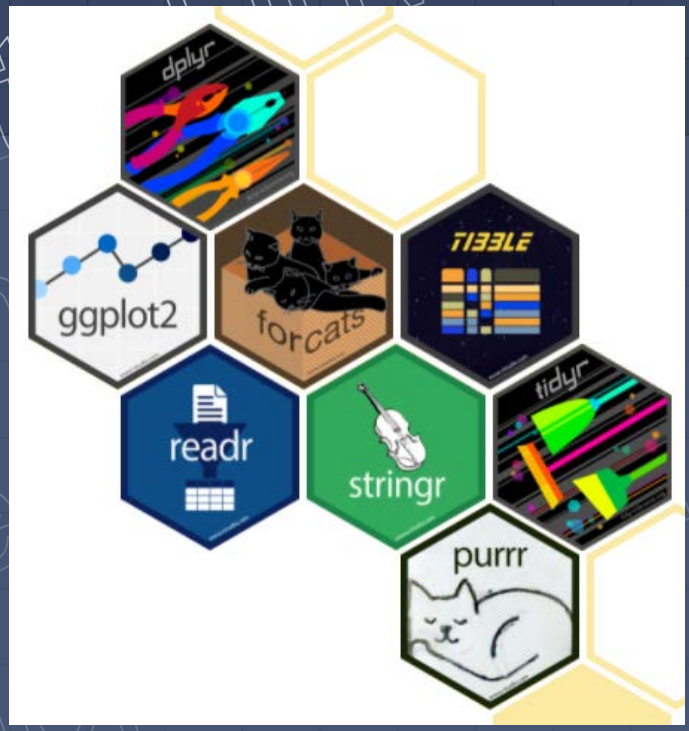
R Packages Used

- Data Import, Prep, Analysis, & Export
  - tidyverse: dplyr, tidyr, & magrittr
  - vroom
  - DT
  - openxlsx
- Data Visualization
  - shinydashboard
  - rhandsontable (interactive tables in Shiny)
  - leaflet & leaflet.minicharts (mapping)
  - Shinybusy (busy bar)
- Optimization
  - ompr & ompr.roi (linear optimization modeling framework)
  - ROI.plugin.symphony (model solver: **Support the COIN-OR Foundation! github.com/coin-or to donate**)
- Geospatial Analysis
  - geosphere
  - measurements



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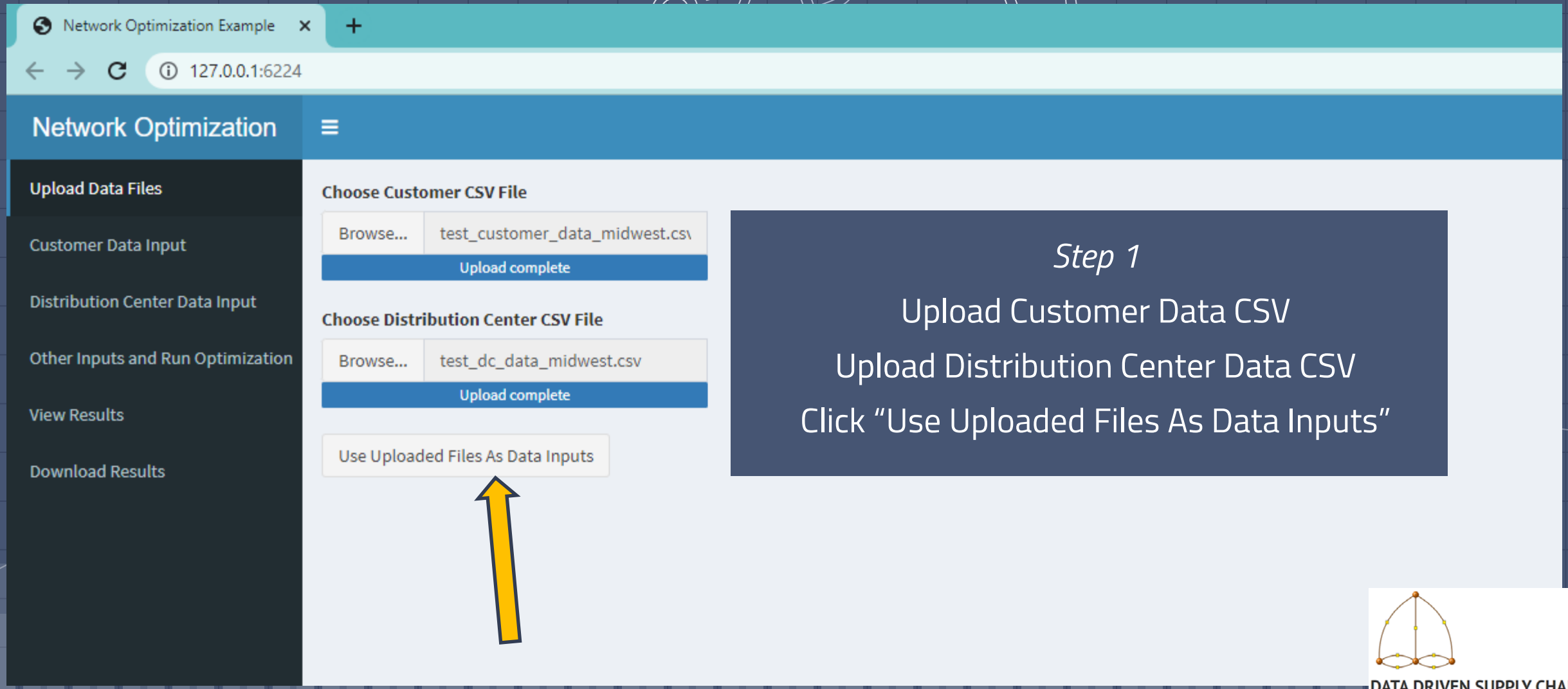
Shiny App: Upload Input Files



Step 1

Upload Customer Data CSV

Upload Distribution Center Data CSV

Click “Use Uploaded Files As Data Inputs”

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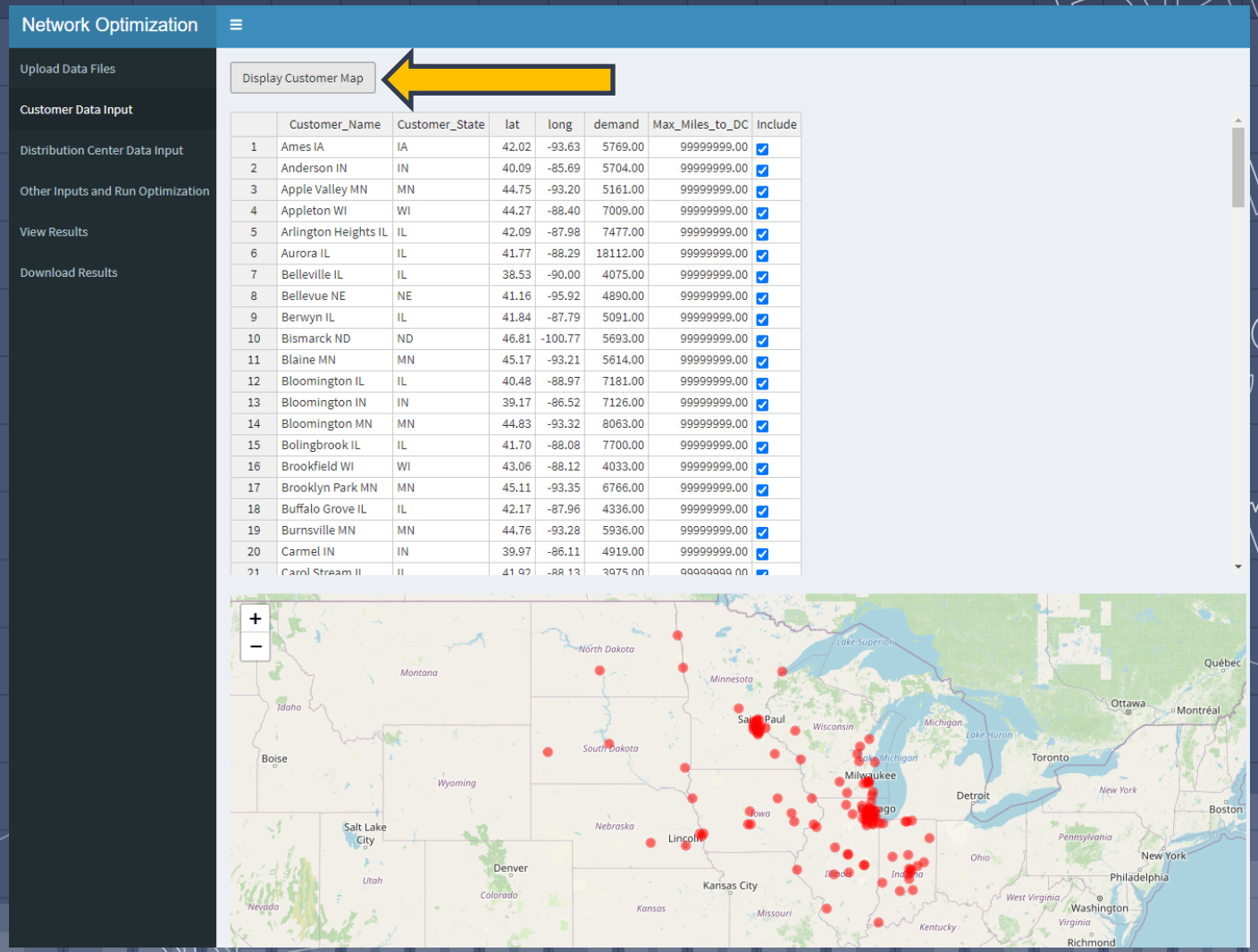
Shiny App: Check Inputs



	Customer_Name	Customer_State	lat	long	demand	Max_Miles_to_DC	Include
1	Ames IA	IA	42.02	-93.63	5769.00	99999999.00	☑
2	Anderson IN	IN	40.09	-85.69	5704.00	99999999.00	☑
3	Apple Valley MN	MN	44.75	-93.20	5161.00	99999999.00	☑
4	Appleton WI	WI	44.27	-88.40	7009.00	99999999.00	☑
5	Arlington Heights IL	IL	42.09	-87.98	7477.00	99999999.00	☑
6	Aurora IL	IL	41.77	-88.29	18112.00	99999999.00	☑
7	Belleville IL	IL	38.53	-90.00	4075.00	99999999.00	☑
8	Bellevue NE	NE	41.16	-95.92	4890.00	99999999.00	☑
9	Berwyn IL	IL	41.84	-87.79	5091.00	99999999.00	☑
10	Bismarck ND	ND	46.81	-100.77	5693.00	99999999.00	☑
11	Blaine MN	MN	45.17	-93.21	5614.00	99999999.00	☑
12	Bloomington IL	IL	40.48	-88.97	7181.00	99999999.00	☑
13	Bloomington IN	IN	39.17	-86.52	7126.00	99999999.00	☑
14	Bloomington MN	MN	44.83	-93.32	8063.00	99999999.00	☑
15	Bolingbrook IL	IL	41.70	-88.08	7700.00	99999999.00	☑
16	Brookfield WI	WI	43.06	-88.12	4033.00	99999999.00	☑
17	Brooklyn Park MN	MN	45.11	-93.35	6766.00	99999999.00	☑
18	Buffalo Grove IL	IL	42.17	-87.96	4336.00	99999999.00	☑
19	Burnsville MN	MN	44.76	-93.28	5936.00	99999999.00	☑
20	Carmel IN	IN	39.97	-86.11	4919.00	99999999.00	☑
21	Carol Stream IL	IL	41.92	-88.13	3975.00	99999999.00	☑

Step 2

Review Customer Dataset

Make Adjustments As Needed

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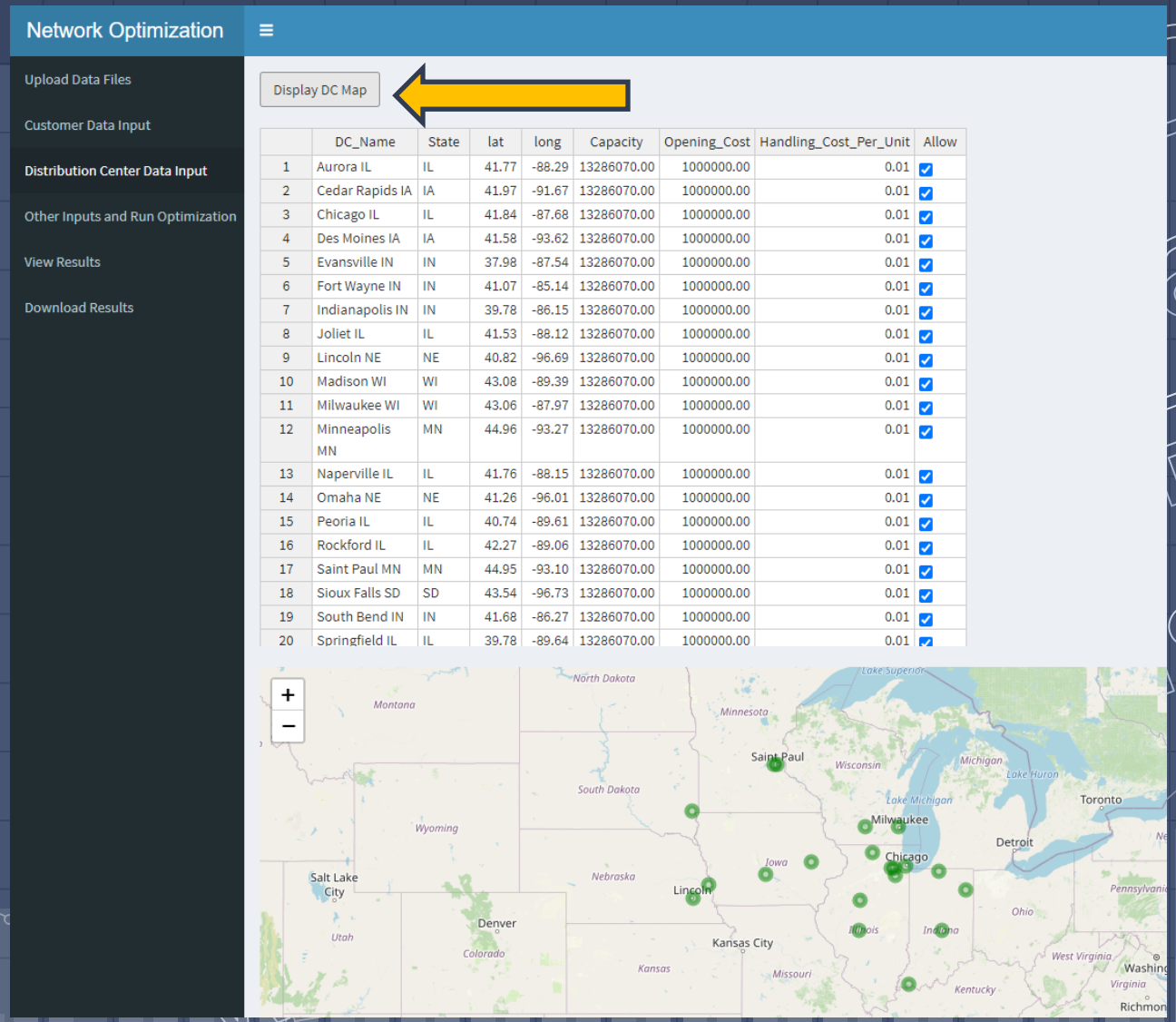
Shiny App: Check Inputs



	DC_Name	State	lat	long	Capacity	Opening_Cost	Handling_Cost_Per_Unit	Allow
1	Aurora IL	IL	41.77	-88.29	13286070.00	1000000.00	0.01	☑
2	Cedar Rapids IA	IA	41.97	-91.67	13286070.00	1000000.00	0.01	☑
3	Chicago IL	IL	41.84	-87.68	13286070.00	1000000.00	0.01	☑
4	Des Moines IA	IA	41.58	-93.62	13286070.00	1000000.00	0.01	☑
5	Evansville IN	IN	37.98	-87.54	13286070.00	1000000.00	0.01	☑
6	Fort Wayne IN	IN	41.07	-85.14	13286070.00	1000000.00	0.01	☑
7	Indianapolis IN	IN	39.78	-86.15	13286070.00	1000000.00	0.01	☑
8	Joliet IL	IL	41.53	-88.12	13286070.00	1000000.00	0.01	☑
9	Lincoln NE	NE	40.82	-96.69	13286070.00	1000000.00	0.01	☑
10	Madison WI	WI	43.08	-89.39	13286070.00	1000000.00	0.01	☑
11	Milwaukee WI	WI	43.06	-87.97	13286070.00	1000000.00	0.01	☑
12	Minneapolis MN	MN	44.96	-93.27	13286070.00	1000000.00	0.01	☑
13	Naperville IL	IL	41.76	-88.15	13286070.00	1000000.00	0.01	☑
14	Omaha NE	NE	41.26	-96.01	13286070.00	1000000.00	0.01	☑
15	Peoria IL	IL	40.74	-89.61	13286070.00	1000000.00	0.01	☑
16	Rockford IL	IL	42.27	-89.06	13286070.00	1000000.00	0.01	☑
17	Saint Paul MN	MN	44.95	-93.10	13286070.00	1000000.00	0.01	☑
18	Sioux Falls SD	SD	43.54	-96.73	13286070.00	1000000.00	0.01	☑
19	South Bend IN	IN	41.68	-86.27	13286070.00	1000000.00	0.01	☑
20	Springfield IL	IL	39.78	-89.64	13286070.00	1000000.00	0.01	☑

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Step 3

Review Distribution Center Dataset
Make Adjustments As Needed

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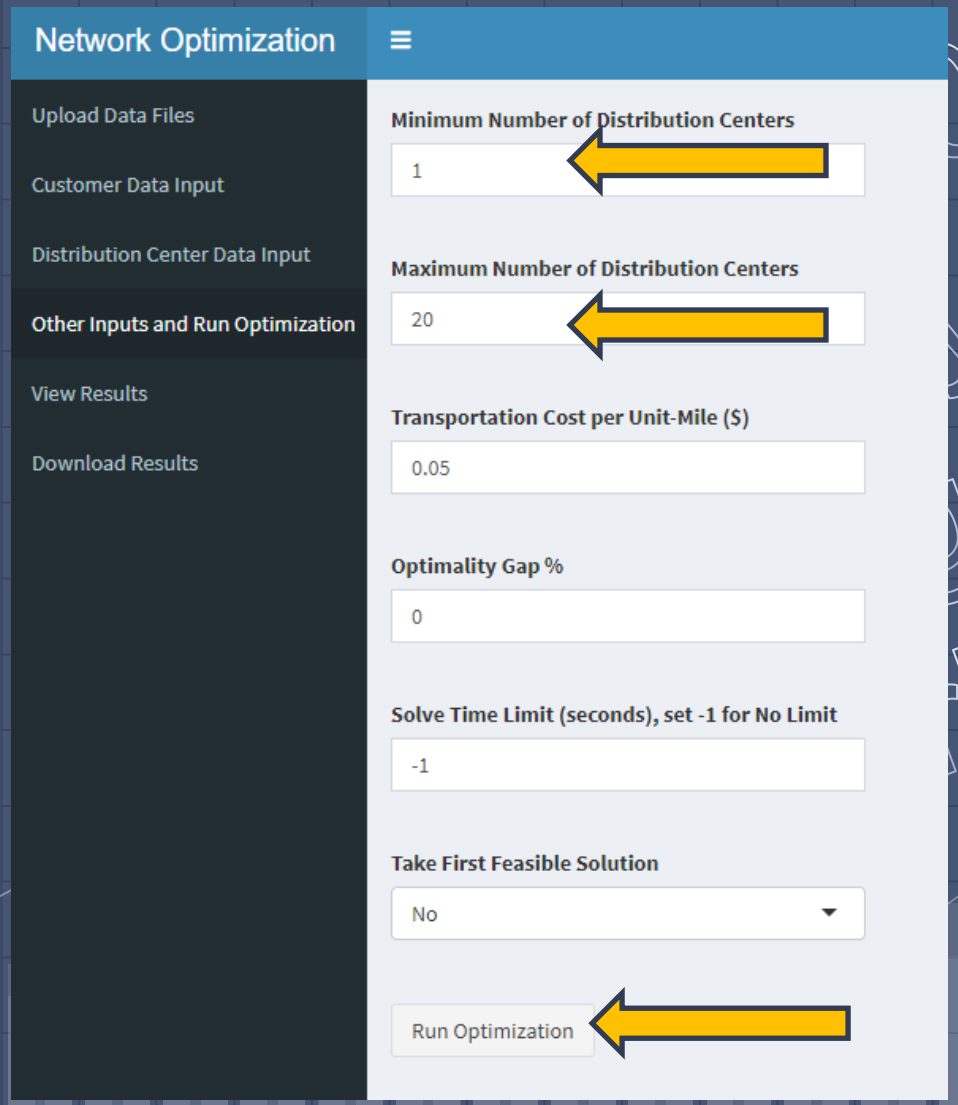
Shiny App: Adjust Settings



Step 4

Set Minimum Number of Distribution Centers to 1, Maximum to 20

Only 20 options… so this is as unconstrained as possible

Click Run Optimization

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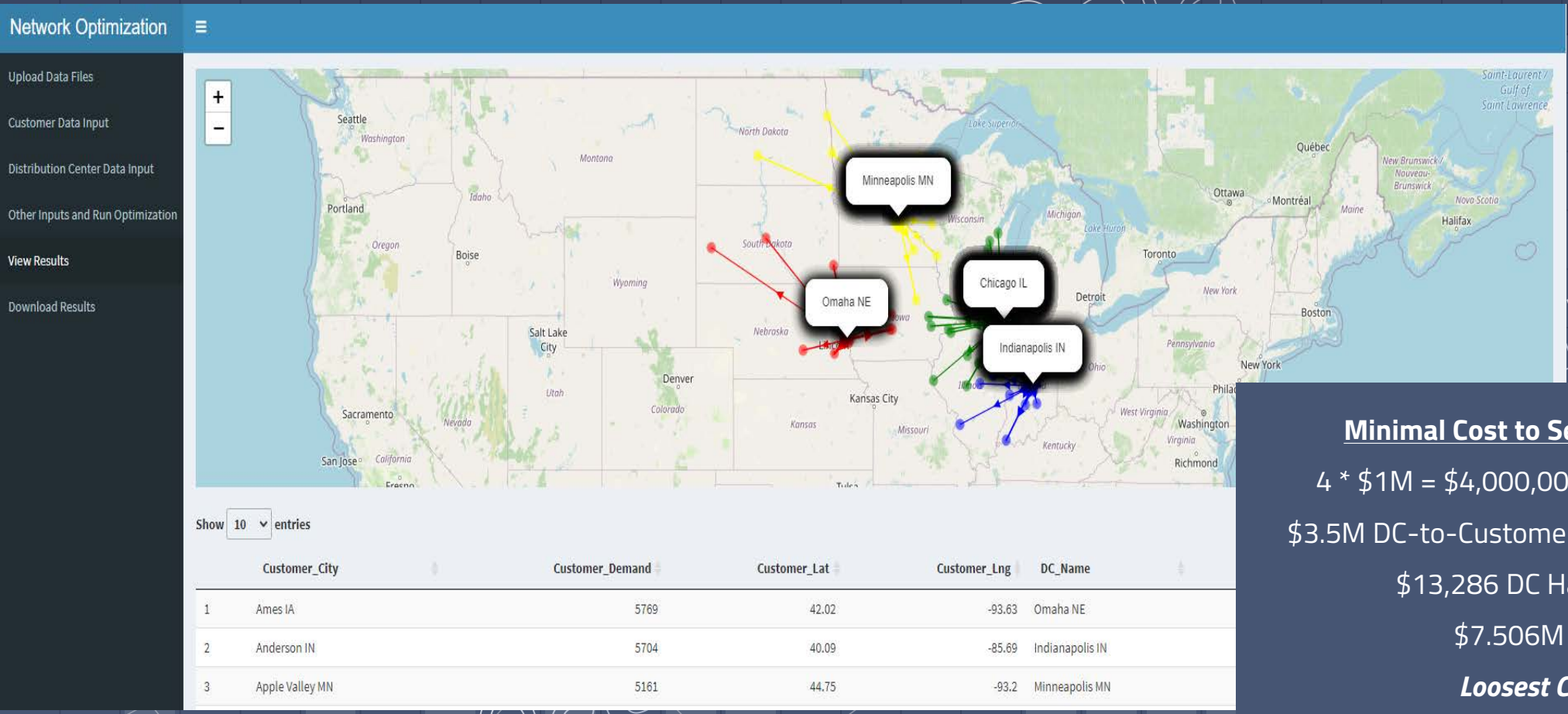
Shiny App: Results



Show 10 entries

	Customer_City	Customer_Demand	Customer_Lat	Customer_Lng	DC_Name
1	Ames IA	5769	42.02	-93.63	Omaha NE
2	Anderson IN	5704	40.09	-85.69	Indianapolis IN
3	Apple Valley MN	5161	44.75	-93.2	Minneapolis MN

Minimal Cost to Serve All Customers:

4 * $1M = $4,000,000 DC Opening Costs +

$3.5M DC-to-Customer Transportation Costs +

$13,286 DC Handling Costs =

$7.506M Total Cost

Loosest Constraints

	Opening_Cost	DC_Handling_Cost_	Transportation_Cost	Total_Cost
1	$4,000,000.00	$13,286.07	$3,492,874.81	$7,506,160.88

Showing 1 to 1 of 1 entries

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A Side Discussion About Constraints…

- In optimization modeling, *constraints* are mathematical limitations on what set of decisions you can make, that correspond to real-life limitations.
- The more constraints you have in your model (and in real life), the worse your objective function becomes.
- Optimization modeling, including supply chain network design, is an exercise in understanding the tradeoffs involved in tightening or loosening constraints.

In designing your supply chain, the tighter the constraints, the higher the total cost becomes. Supply Chain Design is partly an art around understanding the additional expenses associated with tighter constraints.

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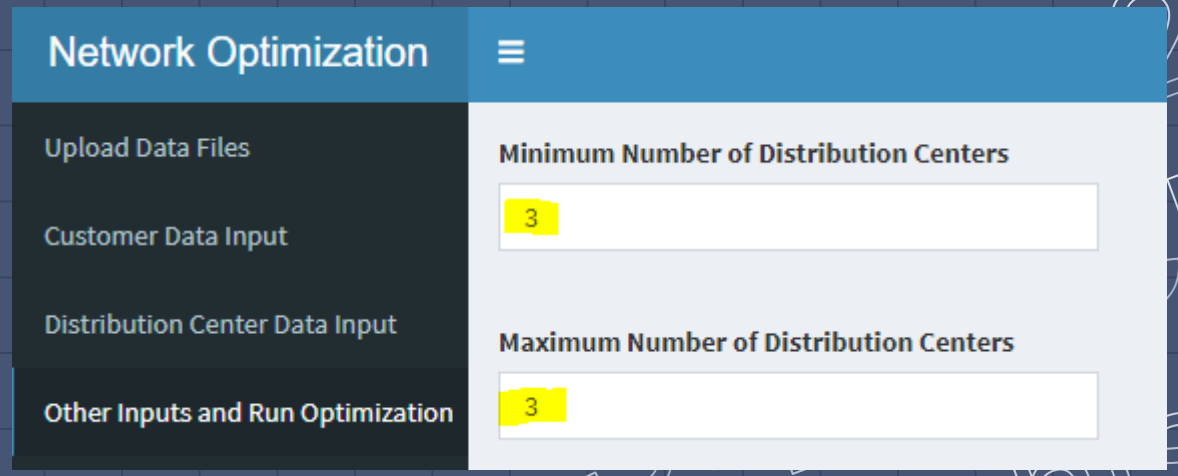
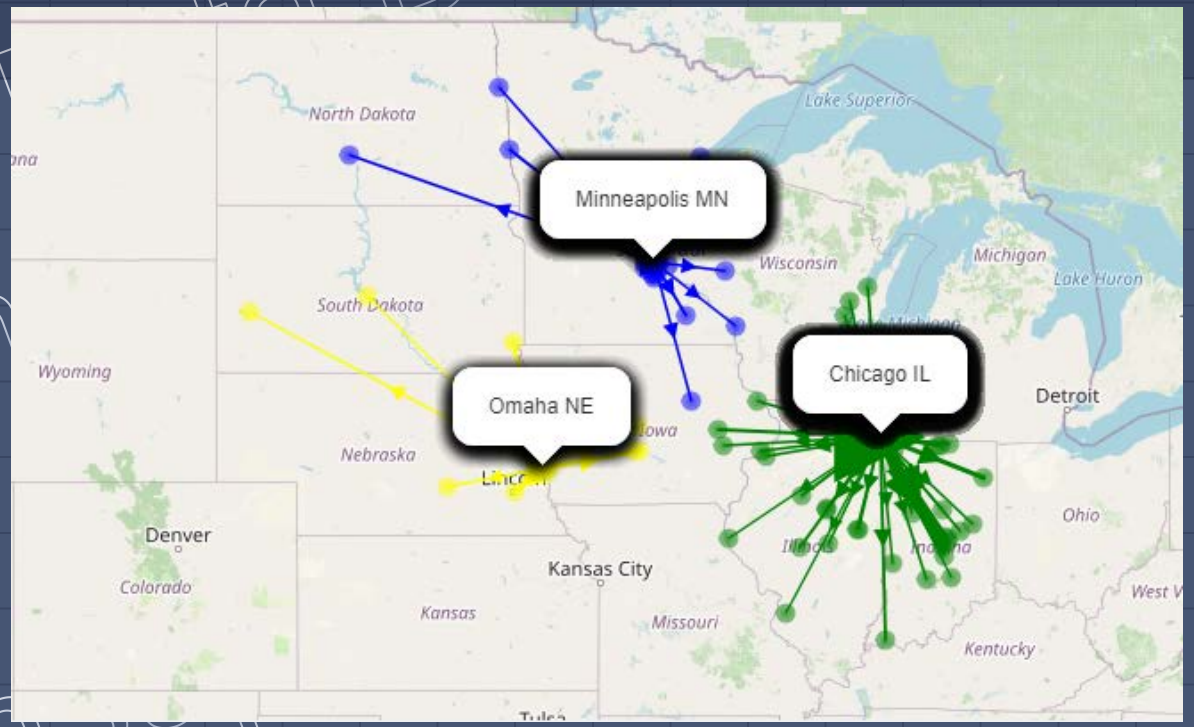
Shiny App: Requiring Exactly 3 DCs Opened





Opening_Cost	DC_Handling_Cost_	Transportation_Cost	Total_Cost
$3,000,000.00	$13,286.07	$4,611,723.32	$7,625,009.39

When we set the constraint to allow between 1 and 20 DCs, the Total Cost was $7.5M and 4 DCs were recommended
When we require exactly 3 DCs (tighter constraint), the Total Cost rises $125K to $7.6M.

Tighter Constraints → Higher Cost (Worse Objective Function)

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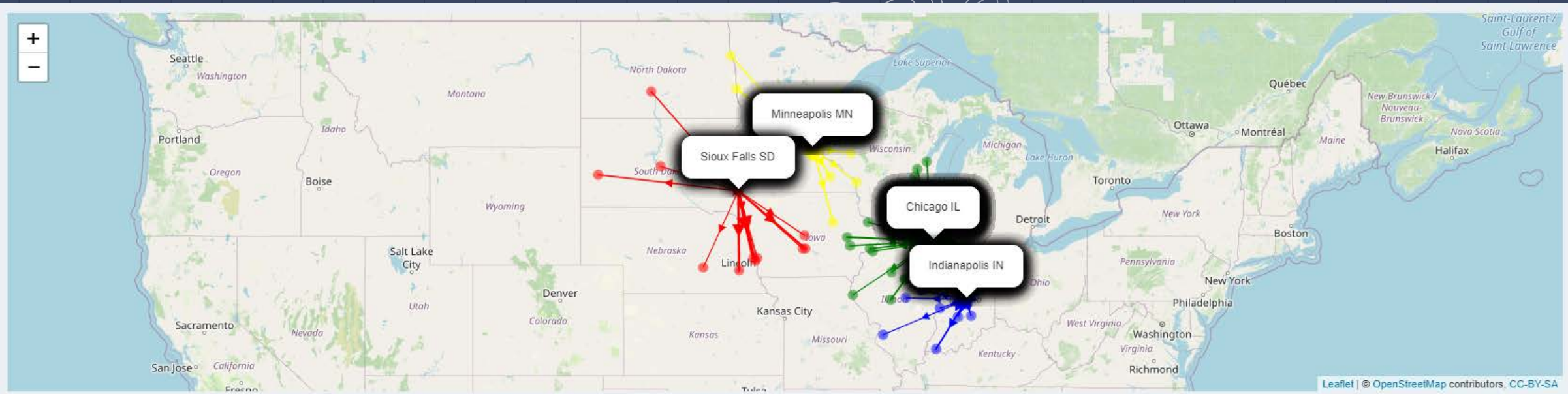
Shiny App: Max 400 Miles to DC



Show 10 entries Search:

	Customer_City	Customer_Demand	Customer_Lat	Customer_Lng	DC_Name	DC_Lat	DC_Lng	Distance
93	Rapid City SD	6231	44.08	-103.23	Sioux Falls SD	43.54	-96.73	326.5

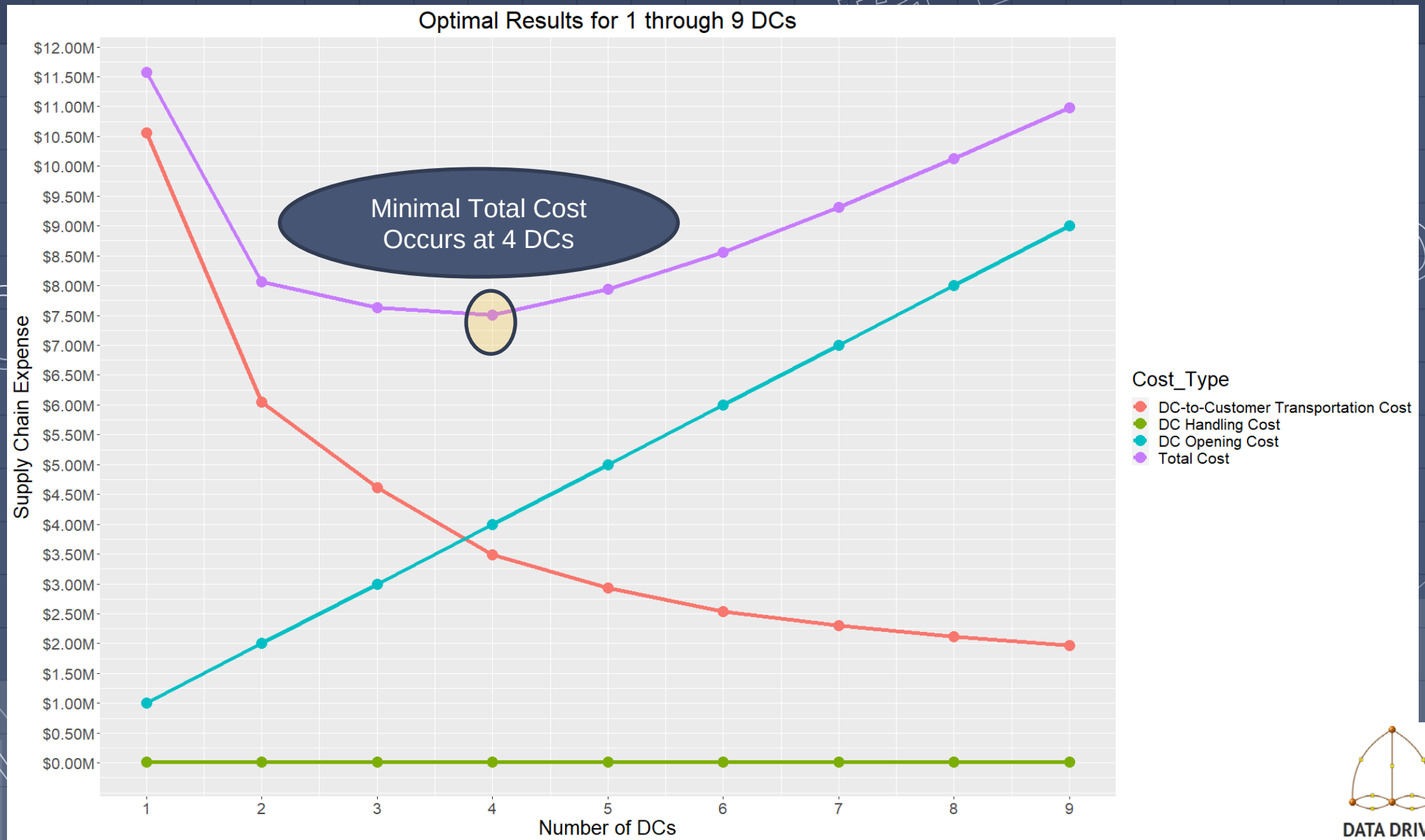
Show 10 entries Search:

	Opening_Cost	DC_Handling_Cost_	Transportation_Cost	Total_Cost
1	$4,000,000.00	$13,286.07	$4,043,391.71	$8,056,677.78

Showing 1 to 1 of 1 entries

When the max distance to the Distribution Center was set to 99,999,999 miles, the max distance from a DC to a Customer was 415.6 miles. What if we set the max distance to 400 miles?

Shiny App: Tradeoffs In Cost Functions



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Conclusion

- Supply Chain Management, once a “behind-the-scenes” corporate function, is now front-page news.
- Analytics, powered by open-source programming languages like R and Python, are changing the nature of Supply Chain Management
- Supply Chain Network Design is a powerful tool in devising and evaluating your organization’s supply chain strategy

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