Prescriptive analytics: Optimization of fertilizer supply to meet demand using linear programming

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ABSTRACT

This case is designed to provide an example of prescriptive analytics in an introduction to data analytics course. Prescriptive models provide the most value to organizations as they are designed to provide an answer to the problem and not simply describe the problem or predict an outcome. This case is a version of the transportation problem that can be solved in Excel using the Solver add-in. Excel is still one of the most widely used tools for analyzing data and we should strive to teach how it may be used to solve various problems. This case handles the optimization of fertilizer hauling for an agricultural cooperative from multiple suppliers to multiple retail outlets to meet expected demand with least cost shipping.

Keywords: Prescriptive Analytics, Linear Programming, Transportation Problem, Excel, Solver

INTRODUCTION

A Descriptive Model approach to analytics is common, especially at an entry-level, as would be experienced in a college classroom. This analytical methodology has value because it is commonly used in businesses entering the realm of Business Intelligence (BI). These organizations will also typically follow a progressive continuum from Descriptive to Predictive and then to Prescriptive Modeling as the organization matures in its BI pursuit. This allows the organization to develop a normative approach to analyzing alternatives and arriving at the alternative best meeting the organization's needs (Delen, 2021).

There is a risk of bias with lower-level analytical techniques that can be overcome with more next-level techniques. The use of Heuristics and System One thinking can lead to inappropriate decisions, failure to recognize the Regression to the Mean bias for example, resulting in over-confidence in historic data and assumptions made regarding forecasts and associated decisions (Bazerman, 2013).

Descriptive and predictive analytics certainly serve important functions, such as discovering previously unknown patterns and naturally occurring processes. However, they generally lack the ability to produce optimal solutions (Delen, 2020). Forecasting demand presents significant challenges, especially if the decision-maker is relying only on historic data. It is Prescriptive Analytics that adds value by leading to optimization, or the "best possible outcome" (Delen 2020, p. 49). Optimization can be as exact as the constraints that are put into place and can be a great teaching example as it demonstrates the value of analytics and also can be used as a point of discussion of the difficulties in other parts of analytics.

BACKGROUND

Analytic Model Types and Their Value

Descriptive analytics utilizes historical data that often helps management make decisions. This is usually done by maintaining a robust history of data that can be easily accessed with tools such as an online dashboard with a search engine. But, as organizations become more developed in their decision-making, they typically need and will seek a next level analytical approach.

Predictive analytics are typically that next progression from Descriptive modeling. This means using tools such as Linear Regression, Time-Series Analysis and Simulation to forecast future outcomes. The primary challenge, though, is the validity of those forecasts considering whether the data and models are reliable enough to forecast accurately. In other words, Predictive modeling takes the output of descriptive modeling and predicts what is likely to happen in the future based on what has already occurred. Then, it becomes a feeder of alternatives into Prescriptive models in order to produce optimal decisions. (Delen 2021).

The next natural progression for maturing BI, then, is prescriptive analytics where the analysis results in a valid decision for a course of action. The model guides the decision-maker (Camm, et al., 2021). This, of course, still relies on valid historic data and forecasts, which must be carefully analyzed and developed. The word 'optimization' is inevitably tied to a best, possible outcome. This indicates rational models that ultimately guide the decision-maker to the best possible decision. In other words, the best alternatives leading to the best decision (Delen, 2020). Alternatives may vary as the organization may wish to meet certain service levels and therefore using techniques to evaluate the distribution and using upper and lower control limits

may be appropriate to introduce. That an instructor may refer to various aspects of the predictive model in optimization may make it a technique that should be introduced earlier in teaching analytics.

Linear Programming and the Transportation Problem

Linear Programming is a tool that supports Prescriptive Analytics in that it provides the necessary analytical support to produce optimal solutions. Rather than simply predicting a linear relationship between data values, it solves for the best outcome based on incoming parameters (Camm, et al. 2021). These solutions may take on multiple formats, such as profit maximization or cost minimization. Early developers of optimization solutions quickly found themselves in an impossibly complex mathematical dilemma. Required computerization to formulate even relatively simple assignment problems was beyond what was available. Dantzig was the first to apply Linear Programming with the simplex method and soon found that optimized solutions were not only possible, but the solution drastically reduced the number of required iterations (Delen 2020).

The Transportation Problem is a traditional operational research problem showing how a company dealing with multiple locations, both supply and demand, can solve the distribution problem allowing management to minimize costs of shipping when demand is known, but supply is limited from the several supply locations (Camm et al, 2021). What makes Linear Programming an ideal optimization tool for this problem is the ability to manage and incorporate multiple constraints within the program. For example, the following would be included with a typical transportation problem:

- Objective Function (normally to minimize the total cost of transportation by including locations – supply and demand – and the cost for shipping from each supply point to each demand point)
- Supply Constraints (subject to how many units are available from each supply location – either a manufacturing site or warehouse, for example)
- Demand Constraints (how many units are demanded by each warehouse or customer)
- Typically, a non-negativity constraint is also included since zero (0) is the lowest acceptable volume and negative values would otherwise be factored into the solution.

Soft Skills

Technical skills are not enough for students in the business world as industry demands soft skills such as written communication (Boyce et al., 2001). Additionally written communication incorporated into cases or simulations may be a vital component of pedagogy (Druliolle, 2017), and reflective pedagogy also plays a key role in learning (Bailey et al., 1997). As demonstrated in this case, memos written after an activity require students to reflect on the activity, a valuable tool to teach and reinforcing technical skills, and at the same time provide an opportunity for the students to practice valuable soft skills such as writing clearly and presenting effectively.

THE EXERCISE

Note: This is a fictitious case. All information contained herein was fabricated by the authors. Any similarity contained herein to actual persons, businesses, events, etc. is purely coincidental and is the responsibility of the authors. Please contact the case authors directly with any concerns.

Problem Description

Retail fertilizer cooperatives in the US face many challenges, such as variable windows of opportunity to apply fertilizer that are caused by the weather and limited or varied access to suppliers due to factors such as local facility age and upkeep and access to railways. A retail fertilizer company has a goal of delivering enough product to each of their retail outlets to exactly meet the predicted demand (Appendix – Table 1) in the most cost-effective way possible. In order to ensure product availability, the purchasing manager has signed several contracts with various plants or distribution centers that need to be fulfilled and has obtained an agreement to be able to pull some additional product from each plant although each plant has a maximum that can be obtained (Appendix – Table 2).

You are tasked to act as an analytical advisor to the logistics manager to help them to minimize the cost. You must fulfill the retail outlets' demand need, pull the minimum product ordered per plant and not exceed the maximum available.

Instructions

The Microsoft Excel Solver tool can be used in finding the best solution to single objective optimization problems, both non-linear and linear programming models. Solver is an Excel add-in that must be activated prior to first use. Instructions for activation can be found on the Microsoft Support site for both PC (Microsoft, 2022, 1) and MAC (Microsoft, 2022, 2). Once activated, Solver can be found in the Analysis group of the Data tab in current Excel versions for PC. Depending on versions, MAC users should locate Solver either on the Data tab itself or in the Analysis group of the Data tab.

Before initiating the Solver tool, you need to set up a starting spreadsheet with the following:

- a table of unit costs between all sources and destinations (see Table 1 in Appendix),
- a result table of number of units shipped along each route with a formula (SUM function) to add up the number of units shipped from each supplier (see Figure 1 in Appendix),
- the maximum number of units available from that supplier, and, if applicable, the minimum number of units that can be shipped from a source (see Table 2 in Appendix),
- formulas to total the number of units shipped to a destination and the estimated demand number of units to be shipped to each destination (see Figure 1 in Appendix),
- a objective target cell should be established with a formula to multiply every shipment amount in the result table by its corresponding unit cost in the assumptions table and compute the overall total of these products. The Excel function SUMPRODUCT (range 1, range 2) would be applicable here. This cell represents the objective function of the linear programming problem. (See Figure 1 in Appendix).

In this transportation example there are six sources (plants) and 20 destinations (retail outlets). If there is limited class time, an initial workbook may be provided to the students, and students are instructed to enter the SUM functions for each row and column total of the results table and the SUMPRODUCT function for the objective cell.

For the transportation problem, where the objective is to minimize the sum of all transportation costs, once we select Solver we need to enter the address of the objective cell, select the radio button associated with a minimization problem and select the Simplex LP solving engine for this linear programming problem (Figure 2). The other solving engines, the GRG nonlinear for smooth curve models and the Evolutionary for more complex nonlinear models, may or may not result in the same solution as the Simplex LP engine. In this example only the GRG nonlinear engine result will match the Simplex LP solution. You must also provide the range of cells that you wish to represent your prescription in the by changing variable cells area (Figure 2). This range of cells represent the amounts being shipped along each route. The next step is to add the constraints.

As discussed previously in the section on Linear Programming and the Transportation Problem, transportation problems typically include supply and demand constraints and non-negativity constraints. The constraints for this transportation problem are:

- Partial shipments are not desirable. The number of units shipped should be set to whole numbers.
- The sum of all shipments from each plant should be less than or equal to the plant capacity
- The sum of all shipments from each plant should be greater than or equal to the contract minimum.
- The sum of all shipments to each destination retail outlet must be equal to the estimated demand.
- The number of shipments from each plant to each location should be non-negative.

For this transportation example that would be 32 individual constraints, in addition to the 120 non-negativity constraints and the 120 whole number constraints. Solver allows that these 32 constraints and the whole number constraints be entered in the form of four constraints as follows:

- The values in the range of cells containing the shipments should be set to integer.
- The values in the range of cells containing the sums for the source plant shipments must be less than or equal to the values in the range of cells representing the plant capacities.
- The values in the range of cells containing the sums for the source plant shipments must be greater than or equal to the values in the range of cells representing the contract minimum values.
- The values in the range of cells containing the sums for the destination shipments must be equal to the values in the range of cells representing the estimated demands.

The non-negativity constraints are handled by making sure to check the box beside the option "Make Unconstrained Variables Non-Negative". The completed Solver Parameters dialog box is shown in Figure 2 in the Appendix.

Once all the constraints are entered, clicking on the Solve button will cause the changing values in the results table and the objective cell to adjust to the final solution values (see Figure 3 Completed Model in Appendix). Note that a common mistake made by new users is not to include the constraints. For a maximization problem, this would result in an unbounded solution. For our transportation example without the constraints that force shipments the solution would be to ship nothing at a total cost of zero dollars. The instructor may choose to demonstrate solving the problem before adding the constraints, possibly solving after addition of each constraint to emphasize the importance of the constraints.

Teaching Notes

This case was used in an introductory information systems course. Such courses often use texts that provide several topics where this case could be used as a class exercise. For example, when models such as the Porter's competitive strategies and value supply chain are discussed, this case could be used to encourage discussion of supply chain issues of commodity-based companies. Additional discussion on how such companies may use a cost-based approach and how all functional areas of the company need to communicate to optimize costs. Inbound logistics and operations need to be able to use optimization in planning to deliver products in narrow time windows with least cost. Their optimization relies on the accuracy of sales and marketing being able to predict demand and purchasing to obtain contracts that allow for versatility to make sure that product is available to be pulled without creating bottlenecks.

Linear programming and the transportation problem should be discussed as prescriptive analytics are covered to provide an example of prescriptive analytics and the estimated demand may be discussed for prescriptive analytics. This may be covered on a specific lab day that allows at least 40 minutes to discuss as most undergraduate students will not have any background on either solver or linear programming. The case has been used as an instructor led walkthrough that ends with a completed model (Figure 3) but may also be given as an independent case to students who have knowledge of linear programming. While prescriptive analytics are often viewed as the highest value of the analytical types, they are often viewed as the end product. However, in most cases they are a part of a larger model that requires other analytical procedures to be run. In this case this is reflected by the predicted demand for each retail outlet and potentially the predicted maximum supply that can be pulled from each plant. This case can be used to underscore the value of the end point of many analytical procedures.

The instructor should connect where the solution fits in the value chain and underscore communication across departments as analytics team-based and span across functions and departments. There are risks involved with the model if either demand or supply is not projected correctly or if additional factors such as time constraints are not addressed in the model. These issues should be discussed to underscore the need to understand not only how the model works, but also how analytics need to be team-based to understand the entire problem domain.

Soft skills should be underscored as an essential skill that students need. We recommend a general template to be provided with the paragraphs that should be discussed. This provides a logical layout of what should be addressed in the communication. Figure 4 provides an example of the memo template that the students should complete as a deliverable. However, with more experienced students less structure may be given.

Learning Objectives

1. Understanding of the role of prescriptive analytics
2. Exposure to solver function as an important feature in Excel
3. Connection of analytical solutions to strategic and operational objectives
4. Exposure to the fact that various analytical models may be needed prior to optimization.
5. Practice in written communication of the value and the limitations of an analytical solution.

Deliverables

1. Completed Spreadsheet (Figure 3)
2. Memo (Figure 4)

BENEFITS AND LIMITATIONS OF THE CASE

This case allows for the discussion of multiple concepts. It connects operational decisions to the strategic and allows students to see a clear example of prescriptive analytics. By utilizing a written memo as feedback, the students teach back the concept, discuss the value of the model that they ran, develop an understanding of teamwork within an organization, and practice their soft skills. Excel is a valuable tool and Solver is a key feature to which they should have exposure.

By using the case in an introductory class, students are not likely to be able to use linear programming for additional problems without additional practice. The case may be used to supplement a more advanced class in operations management, but as utilized it is simply providing some exposure to prescriptive techniques and the potential complexities involved in creating a final prescriptive solution. By using a specific industry or problem the students may find it difficult to relate to the problem, but by using a commodity-based example the students should be able to relate to how the solution connects operational decisions to the overall strategic plans of the company.

POTENTIAL FOR CASE EXPANSION

The case may be expanded to include estimating both the supply and demand. These can be estimated by various methods such as regression, time series, or creating an information system that allows salespeople to enter forecasts that can be summarized. Other areas such as process modeling can be covered to make sure that the linear programming model is complete. This could lead to additional constraints to be added such as time constraints. By forcing the students to add additional constraints the students may then be forced to demonstrate an advanced understanding of how to perform linear programming in Excel.

APPENDIX

Table 1

Retail Outlet Cost by Plant and Estimated Demand

Retail Outlet	Cost Plant 1	Cost Plant 2	Cost Plant 3	Cost Plant 4	Cost Plant 5	Cost Plant 6	Estimated Demand
1	170	190	90	80	160	120	210
2	100	110	90	180	120	200	150
3	200	120	140	110	130	120	200
4	100	170	160	70	190	70	170
5	190	130	190	70	90	150	210
6	180	140	170	80	70	120	180
7	170	110	100	160	150	100	190
8	100	200	200	130	160	170	180
9	80	170	70	70	160	100	160
10	80	200	70	140	130	160	170
11	190	200	160	100	200	140	210
12	80	200	80	80	160	70	190
13	170	80	90	180	140	190	300
14	80	190	100	110	160	90	120
15	80	120	110	100	150	190	180
16	100	140	200	160	190	70	140
17	200	170	80	120	150	110	120
18	160	100	190	100	130	110	160
19	180	80	100	130	80	170	190
20	120	110	200	100	190	80	120

Table 2

Minimum and Maximum Product by Plant

Plant	Minimum Product	Maximum Product
1	400	700
2	500	1,000
3	300	800
4	350	750
5	650	1,000
6	200	500
Total	2,400	4,750

Figure 1

Preliminary Results Table in Formula View

	Retail Outlet	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Total Delivered	Estimated Demand
38	Retail Outlet	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Total Delivered	Estimated Demand
39	1							=SUM(B39:G39)	210
40	2							=SUM(B40:G40)	150
41	3							=SUM(B41:G41)	200
42	4							=SUM(B42:G42)	170
43	5							=SUM(B43:G43)	210
44	6							=SUM(B44:G44)	180
45	7							=SUM(B45:G45)	190
46	8							=SUM(B46:G46)	180
47	9							=SUM(B47:G47)	160
48	10							=SUM(B48:G48)	170
49	11							=SUM(B49:G49)	210
50	12							=SUM(B50:G50)	190
51	13							=SUM(B51:G51)	300
52	14							=SUM(B52:G52)	120
53	15							=SUM(B53:G53)	180
54	16							=SUM(B54:G54)	140
55	17							=SUM(B55:G55)	120
56	18							=SUM(B56:G56)	160
57	19							=SUM(B57:G57)	190
58	20							=SUM(B58:G58)	120
59	Total Delivered	=SUM(B39:B58)	=SUM(C39:C58)	=SUM(D39:D58)	=SUM(E39:E58)	=SUM(F39:F58)	=SUM(G39:G58)	=SUM(H39:H58)	=SUM(I39:I58)
60	Contracts	400	500	300	350	650	200		
61	Maximum	700	1000	800	750	1000	500		
64	Transportation Cost	=SUMPRODUCT(B39:G58,B16:G35)							

Figure 1

Completed Solver Paraments Dialog Box

Figure 2

Completed Model

Excel spreadsheet "transportation Proble.." — cell reference R20

Contracts and Maximum Product Per Plant

Plant	Product Contract	Maximum Product
1	400	700
2	500	1000
3	300	800
4	350	750
5	650	1000
6	200	500
	2400	4750

Demand and Transportation Costs (100s of Dollars)

Retail Outlet	Cost Plant 1	Cost Plant 2	Cost Plant 3	Cost Plant 4	Cost Plant 5	Cost Plant 6	Estimated Demand
1	170	190	90	80	160	120	210
2	100	110	90	180	120	200	150
3	200	120	140	110	130	120	200
4	100	170	160	70	190	70	170
5	190	130	190	70	90	150	210
6	180	140	170	80	70	120	180
7	170	110	100	160	150	100	190
8	100	200	200	130	160	170	180
9	80	170	70	70	160	100	160
10	80	200	70	140	130	160	170
11	130	200	160	100	200	140	210
12	80	200	80	80	160	70	190
13	170	80	90	180	140	190	300
14	80	190	100	110	160	90	120
15	80	120	110	100	150	190	180
16	100	140	200	160	190	70	140
17	200	170	80	120	150	110	120
18	160	100	190	100	130	110	160
19	180	80	100	130	80	170	190
20	120	110	200	100	190	80	120

Retail Outlet	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Total Delivered	Estimated Demand
1	0	0	0	210	0	0	210	210
2	0	0	150	0	0	0	150	150
3	0	40	0	2	158	0	200	200
4	0	0	0	120	0	50	170	170
5	0	0	0	88	122	0	210	210
6	0	0	0	0	180	0	180	180
7	0	0	190	0	0	0	190	190
8	180	0	0	0	0	0	180	180
9	0	0	160	0	0	0	160	160
10	0	0	170	0	0	0	170	170
11	0	0	0	210	0	0	210	210
12	0	0	0	0	0	190	190	190
13	0	300	0	0	0	0	300	300
14	120	0	0	0	0	0	120	120
15	180	0	0	0	0	0	180	180
16	0	0	0	0	0	140	140	140
17	0	0	120	0	0	0	120	120
18	0	160	0	0	0	0	160	160
19	0	0	0	0	190	0	190	190
20	0	0	0	0	0	120	120	120
Total Delivered	480	500	790	630	650	500	3550	3550
Contracts	400	500	300	350	650	200		
Maximum	700	1000	800	750	1000	500		

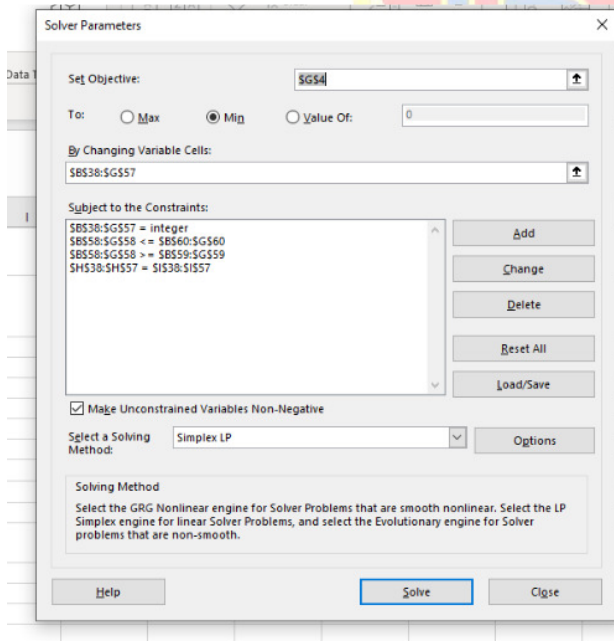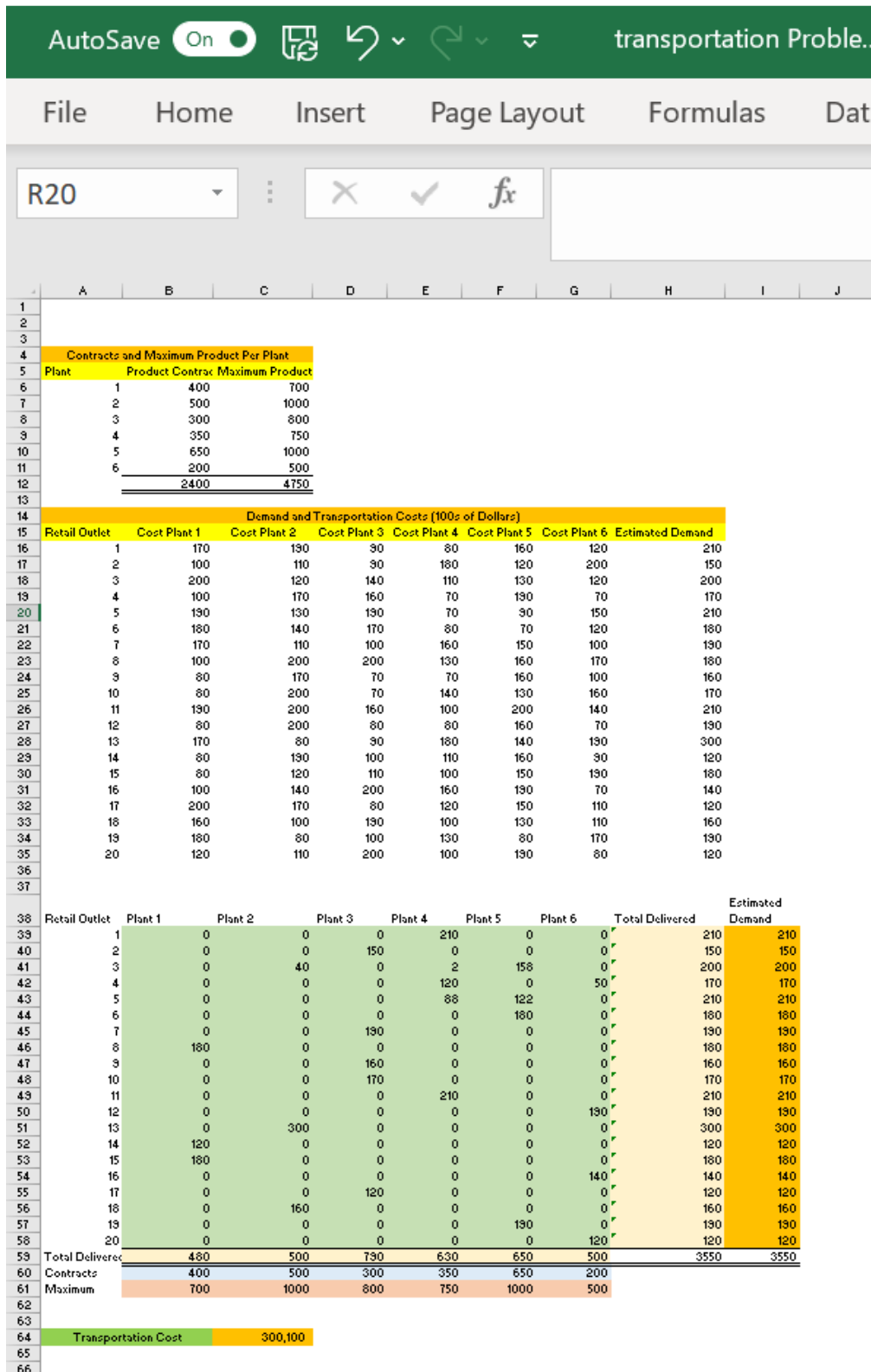| Transportation Cost	300,100

Figure 3

Memo Template

Date

From: Student's Name

To: Professor's Name

Subj: Fertilizer Logistics

1. Write a paragraph to a manager within Fertilizer Inc. explaining what linear programming and the transportation problem is and how it can be used to optimize inbound logistics. (Write as if you are an employee not a student.)

2. Write a paragraph to the manager explaining your optimized solution so they may understand where product should be pulled from. You should make a professional looking table with your solution so that you may refer to the results of the model that you ran. For the sake of convenience assume that the company hauled the same product for $400,000 last year. You should stress the value of the model by discussing the cost savings that you found.

3. Write a paragraph detailing the potential risks of the model. Make sure that you convey that your model relies on other parts of the supply chain.

*** After the body of the memo you should include a professional looking table that shows the optimized results generated by your model.

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