Determining the Location of a Tennessee Milk Condensing Plant

Selected Paper, 2017 Southern Agricultural Economics Association Meetings, Mobile, AL.

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Introduction

Several value-added dairy production plants are located in Tennessee. These plants use differing combinations of condensed milk, powdered milk, and cream as their main production inputs. Currently, this demand is not supplied by Tennessee dairy farmers, in part due to the lack of in-state condensing plants. From the viewpoint of the value-added processors, milk shipped from other locations has relatively high transportation costs as compared to a possible in-state source of supply. Further, in general food processors are becoming interested in shorter supply chains because of consumer interest in local foods and perceptions regarding carbon footprint (Hughes and Boys, 2015). Tennessee dairy farmers have a need for new markets with declining revenues and increasing production costs. Shrinking profits margins continue to lead to a decline in the number of dairy operations in the state (Hughes et al., 2016).

This research presented here is in response to this perceived need from the viewpoint of milk processors and state dairy farmers. The goal is to evaluate the optimal (transportation cost minimizing) location of a milk condescending plant, where milk is converted to useable output for the processors (such as condensed milk). Analysis of this topic has multiple factors, including deciding on possible locations for the condensing plant, determining the supply of liquid milk in Tennessee, and determining the demand for condensed milk, powdered milk, and/or cream at the value-added processing plants. Key parameters in the analysis include distance from source of supply to the potential locations for the milk condensing plant, liquid milk transportation costs, cream transportation costs, condensed milk transportation costs, and conversions from liquid milk to condensed milk, powdered milk, and cream.

The objective of this project is to determine the location for the condensing plant that minimizes total costs, including costs of transporting milk from farms to the plant and costs of transporting the processed milk and cream from the plant to the value-added processing plants.

In this study, costs associated with the creation of a new dairy processing plant in Tennessee are minimized, with the goal of reduced input costs for Tennessee firms purchasing the processed dairy produced (i.e., the outputs of a condensed milk operation). These reduced input costs can be achieved by reducing the shipping costs of fluid milk to the new dairy processing plant. Decreasing the distance traveled of fluid milk and processed milk can have a potential secondary benefit of a smaller carbon footprint. The reduced input costs and higher profits for these firms could ultimately create a demand for local Tennessee milk, giving Tennessee dairy farmers a new market in which they can sell their milk. The value-added dairy producers can also market their product as local to Tennessee consumers.

While cost minimization does not incorporate sales, prices, or other factors on the consumer side, it analyzes the factors involved with producing a product. In this study, the costs being minimized are those associated with the processing of milk and the transportation of fluid milk and processed milk products. The study attempts to find the optimal location of a milk condensing plant that can sufficiently supply and minimize input costs for the value-added plants.

Also factoring into the cost minimization are the costs for farmers transporting fluid milk to the processing facility. Along with distance from the processing facility to the value-added facility, the distance from farms to the processing facility needs to be considered. If the distance to the processing facility is too far away from a farm, that farmer might not be interested in sending their milk. Transportation costs to ship fluid milk could become prohibitive if the facility is too far away. In addition, farmers would likely demand a price premium to send their milk to a new buyer.

Initially presented is a discussion of the relevant literature with an emphasis on mixed integer programming models (the tool employed in our analysis).

Literature Review

A diverse selection of previous studies are relevant to this research. A few use a mixed-integer linear programming to find an optimal location for a processor and a number of them focus on dairy processing. Yet no studies found specifically look at a condensing plant.

Casey (2013) examines the economic impact of a new powdered milk plant on the Nevada dairy industry. As compared to fluid milk, powdered milk has a longer shelf life (up to three years), better maintains nutritional value, and is easier to package and transport. New Zealand is the largest producer of powdered milk in the world while Asia (especially China) is a growing center of demand. Casey notes that the location of the dry milk plant in Churchill County, Nevada was strategic due its proximity to Interstate 80 and the Port of Oakland, reducing transportation costs of powdered milk to its primary market (Asia). Also Churchill County is an area concentrated with high-yield dairies with the potential for expansion. In the early years of the plant, milk would be shipped from California until local farms expanded enough to fulfill the supply. Given the consistent demand, it is assumed the milk plant will have stable production, with revenues exclusively affected by world prices.

Literature that examines the location and cost minimization of processing plants in general is relevant (Hilger, et. al. 1977, Faminow and Sarhan 1983, Tembo et. al. 1999, Wu et. al. 2010, and Garcia-Flores et. al. 2015). Applicable models evaluate the costs of converting inputs to outputs including relevant transportation costs, with the most relevant examining the transportation of fluid and processed milk (Kloth and Blakley 1971, Beck and Goodin 1980, Dalton et. al. 2002, and Wouda et. al. 2002).

Hilger, et. al. (1977) use a mixed integer programming model to find optimal locations for grain subterminals in Northwest Indiana. Due to the size of the problem, the authors used Benders Decomposition, which adds researcher judgment factors to the solution process. The model minimizes annual cost of grain transportation from local elevators and sub-terminals to the destinations. The authors found that to supply the newly constructed sub-terminals chosen by the model, the capacity of local elevators should be expanded.

Faminow and Sarhan (1983) implemented a mixed integer linear programming model that uses nodes to represent beef origins, slaughter locations, processing locations, and final demand locations to make decisions on the optimal locations for new slaughter and processing locations. The authors found that in most cases, the slaughter and processing locations were located adjacent to each other to reduce beef carcass shipping distance.

Tembo, et. al. (1999) used a mixed integer model to look at the potential for expanding the flour milling industry in Oklahoma. The authors minimized all relevant costs to decide how many new mills to open and where to locate these mills by finding the optimal size and location of potential new mills. They found that the Oklahoma flour-milling industry could expand by 23 percent.

Wu, Sperow, and Wang (2010) used a mixed integer model to maximize net present value (NPV) of a woody biomass-based ethanol facility. The authors used the General Algebraic Modeling System (GAMS) to run the programming model due to the complexity of their model. The study looks at a confined area (Central Appalachia) that contains a supply and a demand. The authors found the factor that most affects the location decision was distance and the cost of delivering the inputs to the plant.

Garcia-Flores, et. al. (2015), used a mixed integer programming model to find the optimal amount of equipment, plant locations, and transportation routes for a whey processing facility. The authors found that the solution mostly remained constant when factors such as transportation costs and budget were adjusted. The most influential factor in changing the optimal set of locations was the availability and capacity of equipment.

Kloth and Blakley (1971) used a cost minimization model to find the least-cost location for a dairy plant. The authors factor in assembly, processing, and distribution of fluid milk. They also include a nonlinear function to represent the total processing cost curve. For input and output shipping costs, the authors use a function for a pay load, where the cost per hundredweight is equal to a constant plus a cost per mile times the mileage.

Beck and Goodin (1980) used a cost minimization model to find the optimal number of and location for manufacturing milk plants. The authors gathered data for the location of processing centers, transportation costs, processing cost functions, supplies of milk, and plant capacities. They organized the supply of milk by county and assumed the supply of milk was shipped from the county to the processing plants. Like Kloth and Blakley, Beck and Goodin use a shipping pay load function, where the cost per hundredweight is equal to a constant plus a cost per mile times the mileage.

Dalton, Criner, and Halloran (2002) used an economic-engineering model to minimize processing and distribution costs of fluid milk in Maine. An economic-engineering model is used to examine the costs of each step in the production process with detailed focus on specific engineering processes. The study discusses specifics concerning construction of a milk processing plant that processes and packages fluid white milk. The authors found that a milk processing plant needs a minimum of eight acres of land with space for a plant, a distribution area, and a small office building. The estimated range of construction costs was from $24.5 million to $33.6 million.

Wouda, et. al. (2002) used a mixed integer programming model to minimize the production and transportation costs of Hungarian company, Nutricia's milk supply network by finding the optimal number and location of plants and each plant's optimal product mix. The authors ran six alternative scenarios and three sensitivity analyses. A main finding is that when one location (instead of multiple locations) is a model requirement, the plant is located between the largest milk supplier and the largest market.

The Nutricia dairy paper by Wouda, et al (2002) that dealt with milk processing included constraints not only for the finished milk, but also for milk byproducts (whey, buttermilk, permeate, and cream). Whey, buttermilk, and permeate constraints are calculated by taking the required amount of the byproduct and subtracting the amount of the byproduct that was produced. The resulting number then must equal the amount of the byproduct produced per pallet of milk times the number of pallets of milk produced. The cream constraint is calculated by taking the required amount of cream and subtracting the surplus of cream. The resulting number then must equal the amount of cream produced per pallet times the number of pallets produced minus the cream percentage of raw milk times the amount of milk.

The Brazilian whey utilization case study by Garcia-Flores, et al (2015) also analyzes and makes constraints for dairy processing plants. These constraints include whey production, flow conservation, facility type, maximum plant capacity, budget, and finished production. The whey production and flow constraints ensure all whey that is produced will enter the supply chain and all processed whey must be concentrated. The facility type constraint ensures that only one facility of any type can be located at a site. The maximum plant capacity constraint requires the amount of whey processed at a plant must be less than or equal to the maximum amount of whey a plant can process. The budget constraint ensures that the budget includes estate, equipment, construction, and utilities expenses. The finished production constraint states that the total product produced is equal to the conversion fraction (converting input to output) times the total input used.

In the grain subterminal paper by Hilger, McCarl, and Uhrig (1977), constraints are added for storage by looking at more detailed inflows and outflows. This more accurately represents real shipping scenarios, where storage might be needed.

Methods

This study is concerned with finding the optimal location for a milk condensing plant. The condensing plant will use fluid milk as an input. The fluid milk will be supplied by Tennessee dairies and dairies from the surrounding region of Southern Kentucky and Northern Alabama. With the assumption that a single value-added processing plant demanding powdered whole milk will be the buyer, the fluid milk will be condensed and dried. This dried, condensed non-fat milk will be shipped to the valued-added plant in Murfreesboro, Tennessee.

A mixed integer programming model will be used to determine an optimal location for the middleman (milk condensing plant, in this case) in the transshipment problem. This model allows for a binary decision variable to be included when deciding which possible location for the dry condensing plant minimizes shipping costs. Alongside that binary decision variable, continuous decision variables determine the optimal amount of milk that will be shipped from dairy farms to the condensing plant and the optimal amounts of milk powder shipped from the condensing plant to the value-added processing plants.

The work presented here in part rests on prior analysis, where seventy-six Tennessee dairy farmers completed a survey concerning the potential for new dairy markets (Hughes et al., 2016). Farmers were asked the county in which their operation is located and their per year milk production in pounds. Farmers were also asked at what price premium would they be willing to sell to a new processor, and how far, whether directly or indirectly, they would be willing to haul their milk.

The supply of milk was determined from the results of the survey and the 2012 Ag Census data for county milk supply in Tennessee and Kentucky counties adjacent to or one county removed from the Tennessee border, and Alabama counties adjacent to the Tennessee border or two counties removed from the border. Milk supply estimates were calculated based on price premiums reported in Hughes et al. by surveyed farmers. Each county's supply had to be determined from county milk sales numbers. The total county sales was divided by that county's average milk marketing order price for 2012, changing the supply unit to pounds. Then price premiums form the survey were introduced. At a 10 - 12.5% price premium, 68.4% of surveyed dairy farmers indicated a willingness to supply a new milk processing facility. Thus, 68.4% of each county's total supply of milk was determined to be the fluid milk supply for this study.

Since this model is location based, the aggregate supplies are located in the county seat of each county. The aggregate supplies for the counties and accompanying county seats in Tennessee are given in Table 1.

Table 1. Estimated Available Tennessee and Surrounding Region Milk Supplies by County and County Seat at a 10 – 12.5% Price Premium (2012).

Location (County)	County Seat	Pounds of Milk
Bedford	Shelbyville	13,500,776.43
Bledsoe	Pikeville	4,138,651.11
Blount	Maryville	6,586,397.28
Bradley	Cleveland	16,174,498.29
Carter	Elizabethton	1,561,579.97
Cocke	Newport	7,828,720.91
Coffee	Manchester	8,596,967.96
Fentress	Jamestown	1,333,074.15
Franklin	Winchester	4,628,351.82
Gibson	Trenton	3,254,469.28
Giles	Pulaski	3,019,821.02
Grainger	Rutledge	2,800,433.41
Greene	Greeneville	33,768,299.26
Grundy	Altamont	1,479,304.22
Hamblen	Morristown	7,301,253.89

Henry	Paris	18,285,560.41
Humphreys	Waverly	1,057,617.50
Jefferson	Dandridge	12,843,127.69
Johnson	Mountain City	145,747.46
Lawrence	Lawrenceburg	10,147,686.87
Lincoln	Fayetteville	6,634,764.43
Loudon	Loudon	32,033,210.40
Marion	Jasper	1,041,053.31
Marshall	Lewisburg	29,514,669.67
Maury	Columbia	21,233,966.75
McMinn	Athens	43,505,617.90
Meigs	Decatur	6,128,333.83
Monroe	Madisonville	25,967,339.77
Obion	Union City	367,275.53
Overton	Livingston	7,015,642.76
Polk	Benton	26,283,125.95
Putnam	Cookeville	4,910,609.86
Roane	Kingston	2,134,159.29
Robertson	Springfield	20,193,352.75
Rutherford	Murfreesboro	3,839,389.57
Smith	Carthage	3,138,845.50
Sullivan	Blountville	4,233,616.80
Sumner	Gallatin	5,478,526.66
Warren	McMinnville	13,959,870.83
Weakley	Dresden	2,951,807.04
White	Sparta	20,125,338.76
Williamson	Franklin	3,383,695.86
Wilson	Lebanon	3,876,797.26
Cullman, AL	Cullman	18,479,400.28
De Kalb, AL	Fort Payne	2,951,807.04
Etowah, AL	Gadsden	2,723,960.18
Franklin, AL	Russellville	680,139.87
Morgan, AL	Decatur	16,506,994.65
Adair, KY	Columbia	46,430,977.70
Allen, KY	Scottsville	3,808,783.28
Barren, KY	Glasgow	95,896,321.00
Christian, KY	Hopkinsville	32,687,522.16
Graves, KY	Mayfield	1,761,562.27
Laurel, KY	London	614,221.45
Logan, KY	Russellville	67,303,240.86
Metcalfe, KY	Edmonton	22,060,336.69
Monroe, KY	Tompkinsville	27,960,550.06
Pulaski, KY	Somerset	13,894,591.54
Russell, KY	Jamestown	18,287,836.51
Simpson, KY	Franklin	7,848,814.10

Todd, KY	Elkton	38,472,111.76
Trigg, KY	Cadiz	5,087,446.23
Warren, KY	Bowling Green	32,694,323.56
Wayne, KY	Monticello	1,818,373.12

Source: 2012 Agricultural Census, NASS.

For this study, the demand for whole milk powder at a value-added processing plant is assumed to be translated into a given fluid milk value. Using a conversion factor to convert fluid milk to powdered milk of 0.125, the demand of whole, powdered milk is estimated.

Selections for possible condensing plant locations are limited to industrial parks with availabilities in the state of Tennessee will be limited to those with access to utilities and enough land for a condensing plant to be built (Menard 2016). In addition, the industrial parks will be limited to those that are a reasonable distance away from an interstate and have a sufficient number of acres available.

Possible locations have been found using nonlinear location programming models. All of the supply and demand nodes are be weighted to find possible central locations for the condensing plant. GPS coordinates of the nodes are used to determine the straight-line distances and the model will find a location that minimizes the total distance. Central points will be found and used as possible condensing plant locations. Further condensing plant locations have been found based on our knowledge of the state dairy and milk processing industry. There are potential plants located near the value-added processors, some near the heart of fluid milk supply in Tennessee, and some that are located between the heart of supply and the value-added processors.

Since this model relies on the minimization of shipping costs, first a unit cost was found for shipping fluid milk from farms to the condensing plant and powdered milk from the condensing plant to the value-added plants. Over the road fluid milk transportation cost is assumed to be \$3 per mile per a loaded 50,000 pound capacity tanker (Griffith, 2016). Hauling costs for a loaded 50,000 pound truck carrying powdered milk is assumed to be \$1.65 (DAT Solutions, 2016). Distances are in miles. Google Maps was used to find the distances for all possible shipments and Google's recommended route was chosen because it is usually the shortest and uses interstates, which are best for trucks.

Distances have been found from each county seat listed in Table 1 to each potential condensing plant. When using Google Maps, the name of the city/town is typed into the "from" line and the address of the industrial park into the "to" line.

The distances from each county seat to each potential condensing plant are shown below in Table 2.

Table 2. Distances (in miles) from each County to each Potential Condensing Plant

County	Distance to Haywood	Distance to Humphreys	Distance to Maury	Distance to Rutherford	Distance to Warren	Distance to Blount-Alcoa	Distance to Blount-Rockford	Distance to Cumberland	Distance to Loudon	Distance to Rhea
Bedford	177	106	39.1	27	41.1	211	211	137	174	120
Bledsoe	283	210	146	94.1	60.6	94.3	96.6	35.3	66.3	19.4
Blount	336	263	218	189	142	3.1	8.5	77.3	40.3	84.6
Bradley	309	224	171	131	112	87	87.1	75.9	51.8	30.9
Carter	455	359	332	296	249	130	125	185	148	192
Cocke	389	293	259	230	183	63.9	58.4	119	81.7	126
Coffee	210	137	73	32.9	15.7	176	155	81	144	93.5
Fentress	278	205	159	130	99.5	87.2	97.8	32.4	96	76.9
Franklin	234	148	95.5	56.1	36.8	183	183	97	148	110
Gibson	36.3	74.9	140	170	215	331	327	253	316	297
Giles	156	102	49.8	75.6	84.6	251	251	178	210	172
Grainger	364	289	244	215	168	50.4	43.3	104	66.6	111
Greene	411	315	281	252	205	85.8	80.3	141	104	148
Grundy	233	160	95.7	56.3	23.2	141	146	75	113	67.3
Hamblen	388	292	258	229	182	63.2	57.8	118	81.1	125
Henry	84.8	47.1	116	146	191	293	294	220	283	260
Humphreys	101	3.7	70.4	100	146	262	258	184	247	240
Jefferson	362	288	243	214	167	49	42	102	65.3	110
Johnson	135	410	365	336	289	171	164	225	188	232
Lawrence	135	86.7	48.4	83.8	104	260	260	186	249	192
Lincoln	192	122	65.1	52.9	54.1	215	215	120	180	142
Loudon	331	235	201	183	127	26.7	38.1	64.6	6.2	50.6
Marion	257	184	120	80.3	61.8	133	141	80.8	105	67.4
Marshall	159	98.3	33.5	40.4	63.1	235	235	149	224	142
Maury	138	66.1	12.3	47.7	92.8	224	224	150	213	161
McMinn	336	236	198	158	103	45.9	62.1	61.7	26.8	26.4
Meigs	313	226	175	123	89.7	70	70	51.3	34.7	13.2
Monroe	357	244	219	179	123	29.6	37.7	87	25.2	46.6
Obion	72.1	92.8	164	194	240	368	362	288	341	308
Overton	262	167	133	104	73.2	111	111	37.2	100	81.1
Polk	324	239	187	147	128	59.8	67.9	84.9	50	45.2
Putnam	231	157	112	82.9	55.4	111	106	32.2	95.2	76.1
Roane	295	222	179	126	121	41.5	40	36.1	29.1	41.8
Robertson	178	77.9	64.9	64.1	109	212	212	138	199	180
Rutherford	179	106	41.5	1.8	47	188	184	110	173	110
Smith	206	133	87.8	58.7	59.8	144	140	66	129	110
Sullivan	433	349	315	286	239	120	114	175	138	182
Sumner	179	105	71.9	42.8	88.6	179	175	101	164	145
Warren	221	136	83.1	41.4	8.9	130	130	56.5	119	71
Weakley	63.7	68.8	139	169	214	327	327	253	316	310
White	247	162	102	62.5	37.2	103	103	29	92	54.9

Williamson	153	60	16.3	30.1	77.6	200	200	126	189	144
Wilson	201	97.3	63.4	34.3	79.3	155	155	81.1	144	125
Cullman, AL	193	197	121	147	145	233	240	185	205	167
De Kalb, AL	309	236	172	132	114	159	167	136	131	93.6
Etowah, AL	244	239	163	169	150	196	203	173	168	130
Franklin, AL	144	137	109	166	164	280	288	269	252	215
Morgan, AL	170	169	92.6	118	116	232	240	220	204	166
Adair, KY	280	207	168	161	139	165	181	103	166	147
Allen, KY	214	141	103	75.7	103	191	187	113	176	157
Barren, KY	244	171	132	99.7	145	181	174	100	163	144
Christian, KY	156	74	109	103	159	257	253	179	242	223
Graves, KY	108	89.1	183	176	222	332	327	253	316	297
Laurel, KY	354	280	242	235	205	114	108	141	128	146
Logan, KY	203	81.3	103	83.8	130	227	221	147	210	191
Metcalfe, KY	262	189	151	143	116	185	168	94.3	157	138
Monroe, KY	237	164	130	100	95	151	147	73.6	137	117
Pulaski, KY	321	248	210	202	146	146	119	97.9	160	140
Russell, KY	298	225	186	179	133	155	171	89.2	153	134
Simpson, KY	194	120	82.1	74.7	121	206	202	128	191	172
Todd, KY	171	70.6	106	94	151	249	244	171	234	214
Trigg, KY	142	67.7	121	114	171	271	265	191	254	235
Warren, KY	214	107	102	95.2	141	214	210	136	199	180
Wayne, KY	299	226	180	151	121	124	117	70.9	135	115

Source: Google Maps

The same strategy was employed to find the distances from the potential condensing plants to the value-added processing plant. The previously mentioned potential condensing plant addresses will be entered into the "from" line and the addresses of the processing plants in the "to" line.

Table 3. Distances (in miles) from Potential Condensing Plant to Value-Added Processor

Potential Condensing Plant	**Distance**
Haywood	180
Humphreys	94.9
Maury	42
Rutherford	4
Warren	43.6
Blount-Alcoa	189
Blount-Rockford	189
Cumberland	115
Loudon	177
Rhea	112

Source: Google Maps

A mixed integer programming model has been implemented to solve for the condensing plant that minimizes cost. In order for the program to decide between the potential condensing plants, binary decision variables will be included. These binary variables will activate for the condensing plant that minimizes shipping costs. The model will be set up as a transshipment problem, with nodes for the supply, the condensing plants, and the value-added processing plant. The problem will be set up so that the supply nodes have a negative net flow (as milk will be leaving those nodes), the condensing plants have zero net flow (as each unit of milk coming into the node will be leaving the node), and the value-added processing nodes will have a positive net flow (as milk will be only entering those nodes). The objective model is shown below in Equation 1:

$$(1) \qquad Min\ \ Shipping\ Costs = \sum_{f=1}^{n}\sum_{m=1}^{10} C_{fm} z_m x_{fm} + \sum_{m=1}^{10}\sum_{p=1}^{1} C_{mp} z_m x_{mp}$$

$where$:

C_{fm}
$= cost\ per\ loaded\ tanker\ of\ fluid\ milk\ from\ each\ county\ to\ each\ condensing\ plant$

C_{mp}
$= cost\ per\ mile\ per\ loaded\ truck\ of\ dry\ milk\ powder\ from\ each\ condensing\ plant\ to\ the\ processor$

x_{fm}
$= loaded\ fluid\ milk\ tankers\ sent\ from\ each\ supplying\ county\ to\ each\ condensing\ plant$

x_{mp}
$= loaded\ trucks\ of\ dry\ milk\ powder\ sent\ from\ each\ condensing\ plant\ to\ the\ processor$

$$z_m = \begin{cases} 0, if\ the\ potential\ condensing\ plant\ location\ is\ not\ chosen \\ 1, if\ the\ potential\ plant\ location\ is\ chosen \end{cases}$$

The objective function sums together the total costs from shipping from suppliers to the chosen condensing plant and the total costs from shipping from the chosen condensing plant to the value-added processing plant.

The objective function is subjected to the following constraints:

$$(2) \qquad x_{fm} \leq S_f\ \ for\ all\ f$$
$$(3) \qquad x_{mp} = D_p\ \ for\ all\ p$$

$where$:

$S_f = total\ supply\ of\ loaded\ milk\ tankers\ from\ each\ supplying\ county\ f$

$D_p = demand\ of loaded\ trucks\ of\ dry\ milk\ powder\ from\ the\ processor\ p$

Constraints (2) and (3) makes sure that the amount of milk sent from a county to the chosen condensing plant do not exceed the county's supply and the number of trucks sent from the condensing plant to the value-added plant does not exceed the demand of the value-added plant, respectively.

$$(4) \qquad \sum_{f=1}^{n} \sum_{m=1}^{10} x_{fm} = \sum_{m=1}^{10} \sum_{p=1}^{1} x_{mp}/0.125$$

Constraint (4) ensures the tankers of milk sent from all the counties to the chosen condensing plant equal the trucks of dry milk powder sent from the condensing plant to the value-added plant. A 0.125 coefficient is assumed to represent the conversion of fluid milk to dry milk powder. This constraint is there to make sure the chosen condensing plant acts as a true middleman and has a net flow of zero tankers of milk.

$$(5) \qquad x_{fm} \leq S_f z_m$$
$$(6) \qquad x_{mp} \leq D_p z_m$$

Constraints (5) and (6) act as linking constraints that force an interaction between the binary variable choosing a condensing plant and the variables that determine how much milk enter and exit the condensing plant.

$$(7) \qquad x_{fm}\ are\ integers\ \ for\ all\ f\ and\ m$$

Constraint (7) guarantees that the decision variables for the amount of milk sent to the chosen condensing plant are integers and that only full tankers are being sent to the condensing plant. Since constraint (2) is an inequality, the supply numbers do not need to be adjusted.

$$(8) \qquad z_m\ are\ binary\ \ for\ all\ m$$
$$(9) \qquad \sum_{m=1}^{10} z_m = 1$$

Constraints (8) and (9) force the condensing plant location decision variable to either be a 0 or 1 one and force the sum of those binary variables to be equal to one. This ensures that only one condensing plant will have a 1 for a z value and thus only one condensing plant location will be chosen.

$$(10) \qquad x_{fm} \geq 0\ \ for\ all\ f\ and\ m$$

$$(11) \quad x_{mp} \geq 0 \ for\ all\ m\ and\ p$$

Constraints (10) and (11) assure that none of the counties can ship negative pounds of milk to the condensing plant and the condensing plant cannot ship negative numbers of trucks to the value-added processing plant.

Results

After running the mixed integer linear programming model, Rutherford County was determined to be the optimal location for a milk condensing plant. The Rutherford location held a $300 thousand advantage over the next least cost location. The rankings of the ten possible locations for a milk condensing plant and their cost differential to the Rutherford County location is listed below in Table 4.

Table 4. Ranking of the Possible Milk Condensing Plants When Sourcing from Tennessee and the Surrounding Region

Rank	**County**	**Cost Above Optimal Location (in millions of dollars)**
1	Rutherford	0
2	Cumberland	+0.3
3	Maury	+0.4
4	Warren	+0.5
5	Rhea	+0.6
6	Loudon	+0.8
7	Humphreys	+0.9
8	Blount-Alcoa	+1
9	Blount-Rockford	+1.1
10	Haywood	+3.2

The model was run a second time using a scenario where fluid milk supply came only from Tennessee farmers. In order for Tennessee farmers to fully supply the demand for whole milk powder, a 12.5 – 15% price premium was assumed when calculating the fluid milk supply. In this scenario, Rhea County was determined to be the optimal location for a milk condensing plant, holding a $100 thousand dollar advantage over the next least cost location.

Conclusions

Rutherford County is the optimal location for a milk condensing plant in Tennessee. The scenario where the surrounding region was taken into account is a more realistic expectation, considering it could be challenging for the new condensing plant to source exclusively from Tennessee in its early years. Yet, if Tennessee was the only source of fluid milk for the condensing plant, the optimal location would shift east from Rutherford towards Rhea County.

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