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Determining the Location of a Milk Condensing Plant in Tennessee

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Determining the Location of a Milk Condensing Plant in Tennessee

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ABSTRACT

Given the increasing popularity of local foods and the desire to reduce shipping costs and carbon footprint, Tennessee-based dairy product producers are showing interest in sourcing fluid milk locally. Based on dairy farmer surveys, discussions with industry leaders, shipping distances, and transportation costs estimates, a mixed integer linear programming model is used to determine the optimal location of an in-state milk condensing plant. The objective is to minimize the total transportation costs of shipments of fluid milk from farms to the condensing plant plus the transportation cost of shipments of condensing plant products to further in-state processing. Twelve scenarios of the model were analyzed with Rutherford County consistently being found as the optimal, transportation cost-minimizing location.

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CHAPTER ONE

INTRODUCTION AND GENERAL INFORMATION

Several value-added dairy production plants are located in Tennessee (Moss et al., 2012). Several of these plants use differing combinations of nonfat dry milk (powdered skim 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 producers, milk shipped from locations outside of Tennessee may have relatively high transportation costs as compared to a possible in-state supply source. Further, many food processors are becoming more interested in shorter supply chains because of consumer interest in local foods and perceptions regarding carbon footprint (Hughes and Boys, 2015). With declining revenues and increasing production costs, Tennessee dairy farmers could have a need for markets generating higher returns or they may be forced to cease production. As shown in Figure 1.1, shrinking profit margins continue to lead to a decline in the number of dairy operations in the state (Hughes et al., 2016).

The research presented here is in response to a perceived need from the viewpoint of value added dairy producers and state dairy farmers. Assuming this perceived need is acted upon, a milk condensing plant would have to be built in Tennessee. To best serve all parties involved in the Tennessee dairy industry, a location has to be found for the milk condensing plant.[1] The goal here is to determine the transportation cost minimizing location of a Tennessee milk condensing plant, where milk is converted to useable outputs for the value-added producers (nonfat dry milk and cream). Achievement of this goal could potentially create a new market for Tennessee dairy producers. Analysis of this topic has multiple factors, including deciding on possible locations for the condensing plant, determining the supply of liquid milk in Tennessee, determining the demand for nonfat dry milk at a yogurt production plant, and determining the demand for cream at an ice cream production plant. Key parameters in the analysis include distance from sources of supply to the potential locations for the milk condensing plant, liquid milk transportation costs, cream transportation costs, powdered milk transportation costs, and conversions from liquid milk to powdered milk and cream.

Decreasing the haul distance of fluid and processed milk can have a potential secondary benefit of a smaller carbon footprint. The possible reduction of input costs and possible higher profits for these firms could ultimately increase the demand for local Tennessee milk, giving Tennessee dairy farmers a new milk market. Value-added dairy producers can also market products as local, not only to Tennessee consumers, but also to consumers elsewhere (for example, consumers in other locations might like the idea of producers using inputs from local farmers). Finally, the condensing plant would generate jobs and income for local residents in the area.

To achieve the objective, the distances from farms to the processing facility should be considered along with distances from the processing facility to the value-added

[1] This study assumes that one condensing plant as opposed to multiple plants would be profit maximizing. This point is further discussed in Chapter Five.

facilities. If the distance to the processing facility is too far from a farm, that farmer might not be interested in supplying milk. Transportation costs to ship fluid milk could become prohibitive if the facility is too distant. In addition, farmers would likely demand a price premium to send their milk to a new buyer, as there is no incentive to stop selling milk to an established buyer.

Different scenarios will be analyzed here. Analyzed scenarios include a base scenario (where milk supply can come from 43 Tennessee counties, 5 Alabama counties, and 16 Kentucky counties) and a scenario favoring Tennessee milk producers over those in surrounding states. In an additional scenario, a location favoring the ice cream production plant and cream transportation over the yogurt production plant and nonfat dry milk transportation is analyzed. A set of seven scenarios accounting for variations in shipping costs are analyzed. Finally, a road closure scenario is also analyzed.

Initially presented in Chapter Two is a discussion of the relevant literature with an emphasis on mixed integer programming models (the tool employed in the analysis). This initial discussion is followed by a discussion of the conceptual model and its implementation in Chapter Three. The discussion of the model is followed by a discussion of the results in Chapter Four. Finally, conclusions and recommendations are discussed in Chapter Five.

CHAPTER TWO

LITERATURE REVIEW

A diverse selection of previous studies are relevant to this research. A few studies use a mixed-integer linear programming to find an optimal location for a processor and a number of them focus on dairy processing. In this chapter, studies that use relevant location programming will be analyzed as well as technical information relating to milk condensing.

Location Theory Literature

Edwards (2007) outlines basic theories regarding location and regional economies including Von Thunen's concentric rings theory, central place theory, agglomeration theory, and industrial location theory. The following discussion briefly covers these concepts.

The concentric rings theory determines where industries should locate in relation to the central marketplace, and assumes production costs are equal everywhere and the market is a central location. The theory is based on transportation costs and gives value to pieces of land by proving their worth for an industry (Edwards, 2007).

The central place theory finds the optimal types of retailers and locations of retailers based on where shoppers are located. The theory assumes shoppers travel to retail locations from all residential locations and frequent those retail locations closest to their residential location. Retailers have demand cones that represent the consumers they serve and the maximum distance these consumers are from the retailer. Different commodities have different levels of effective (threshold) demand, meaning different levels of populations (consumers) are needed to support the provision of different types of goods and services. Accordingly there is a hierarchy among places based on central location, with higher-ordered cities providing goods and services not found in smaller places, such as towns (Edwards, 2007).

Agglomeration theory describes the effect of clusters of firms. When firms locate near each other, a specialized labor force is created and new firms can tap into this labor force. Also, firms can cluster near sources of inputs, reducing the transportation costs of inputs. Groups of interconnected firms can also benefit from knowledge transfers and by influencing the provision of publicly provided goods, both based on regional networks. For retail oriented sectors, firms located near other firms may give consumers reason to shop in an area. These clustered firms can benefit from spillover of consumers (Edwards, 2007).

Industrial location theory seeks a location that minimizes production and transportation costs. Transportation costs can be reduced by locating a facility near the output market and sourcing inputs from a distance. Also, transportation costs can be reduced by locating a facility close to the inputs and shipping the outputs from a distance. A common tradeoff of industrial location is land costs versus labor availability. When locating a facility in a rural area, land costs are reduced but finding skilled labor can be challenging. When locating a facility in an urban area, skilled labor may be readily available but land costs are greater. Facilities with automated processes can reduce land costs by locating in a rural area as there is less demand for skilled labor (Edwards, 2007).

Shaffer et al. (2004) describes a location decision as an "economic transaction with a spatial dimension." Location theory "explains how spatially separated economic units interact among themselves and their input and output markets" and "provides insight into how location decisions are made" (pages 38-42). One aspect of location theory discussed by Shaffer et al. is the least cost approach. The least cost approach finds an optimal location then adds additional costs to decide whether or not the optimal location is affected (Shaffer et al., 2004). This thesis implements the first step of the least cost approach of location theory by finding an optimal location without implementing additional costs.

The least cost (or cost minimization) approach has six assumptions.

1. The firm is in a perfectly competitive environment and cannot gain monopolistic power by locating in a specific location.

2. The demand for the firm's output is perfectly elastic and not affected by its location.

3. The firm's buyers are separate locations with given sizes.

4. The geographic locations of the firm's inputs are given and the supply is perfectly elastic.

5. There is an unlimited supply of labor at any of the firm's potential locations.

6. There are no institutional factors (taxes, politics, insurance, culture, etc.) at any of the firm's potential locations (Shaffer et al., 2004). These assumptions are implicitly implemented in the empirical model discussed in Chapter Three.

In the work described here, optimal location is based on the transportation cost of an input versus the output.

Milk Processing Literature

An important aspect of this research is the conversion of fluid milk to other products when processed in a milk condensing plant. In the situation of the proposed Tennessee condensing plant, after being pasteurized, fluid milk will go through a skimming process and a condensing process, resulting in nonfat dry milk and cream. Fluid milk is transformed into skim milk and cream using a cream separator (Lampert, 1975). The resulting skim milk has a water content of 91%. This water will be removed in the condensing and drying process, leaving the remaining 9% of solids. The resulting nonfat dry milk is either packaged in plastic bags or bins for transportation and protection from moisture (Pearce, 2017).

The information applies to this thesis as this is the process that will occur in the proposed milk condensing plant. The information is used in Chapter Three to create conversion constraints that represent the processing fluid milk will endure.

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), maintains nutritional value longer, 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 (2013) notes 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 to sufficiently fulfill the supply needs of the plant. Given the consistent demand, it is assumed the milk plant will have stable production, with revenues exclusively affected by world prices.

Optimal Location Literature

Literature examining the location and cost minimization of processing plants is relevant (Hilger et al., 1977; Faminow and Sarhan, 1983; Tembo et al., 1999; Wu et al., 2010; 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; 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 supplying the newly constructed sub-terminals chosen by the model would require expanding the capacity of local elevators.

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

Tembo et al. (1999) use a mixed integer model to analyze the potential for expanding the flour milling industry in Oklahoma. The authors minimized all relevant costs—including fixed costs, transportation costs, and processing 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 determined the Oklahoma flour-milling industry could expand by 23 percent.

Wu, Sperow, and Wang (2010) use a mixed integer model to maximize net present value (NPV) of a woody biomass-based ethanol facility. In this case, NPV is an annualized function of revenue, feedstock cost, operating and maintenance cost, income taxes, principal and interest payments, and initial equity. The study looks at a confined area (Central Appalachia) that contains a supply and a demand. The supply locations were represented by the most geographically central town in each county. The authors found the factor that most affects the location decision was distance and the cost of delivering the inputs to the plant.

Griffith et al. (2014) implement a mixed integer programming model to maximize the NPV of a biorefinery in Oklahoma. NPV here consists of costs associated with on-farm production, transportation, and the biorefinery. Included on-farm production costs are fertilizer costs and harvesting costs. Included biorefinery costs are return from products, establishment costs, land rents, operating costs, storage costs, and investment costs. The supply for the model includes all 77 counties in Oklahoma. The optimal biorefinery location is selected from 11 potential counties in Oklahoma. The authors found the optimal location for the biorefinery is Blaine County. The optimal solution held under a scenario where fuel prices were doubled and a scenario where land prices were doubled.

Garcia-Flores et al. (2015) use 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 the optimal plant was located closest to the largest whey production region, showing the location of the supply was the strongest factor in the decision. The authors found the solution is not significantly changed when there are changes in the cost of transportation. Garcia-Flores et al. (2015) also analyze and make 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 produced will enter the supply chain and all processed whey must be concentrated. The facility type constraint ensures only one facility of any type can be located at a site. A maximum plant capacity constraint regarding the amount of whey processed is also imposed. The budget constraint ensures the budget includes estate, equipment, construction, and utilities expenses. The finished production constraint states the total product produced is equal to the conversion ratio (converting input to output) times the total input used.

Kloth and Blakley (1971) use a cost minimization model to find the least-cost locations for dairy plants in the United States. 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. Kloth and Blakley aggregate the milk supply to a central location in a supply area and omit the cost of transporting milk from individual farms to that central location.

Beck and Goodin (1980) use a cost minimization model to find the optimal number of and locations for manufacturing milk plants in Kentucky. 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. The authors found that as there were fewer processing plants, the plant size was larger; processing costs decreased while transportation costs increased. When there were more processing plants, each plant size was smaller; processing costs increased while transportation costs decreased. The changes in processing costs were always a higher magnitude than the changes in transportation costs.

Wouda et al. (2002) use a mixed integer programming model to minimize the production and transportation costs of Nutricia's (a Hungarian dairy company) 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 when one location (instead of multiple locations) is a model requirement, the plant is located between the largest milk supplier and the largest market. When there is product specialization, production costs decrease. When fewer milk processing locations are opened, they have larger capacities. With larger capacities, milk reception costs decrease, yet milk transportation costs increase by a larger degree. The optimum locations are subject to change with small adjustments in transportation costs. Wouda et al. (2002) also account for milk byproducts (whey, buttermilk, permeate, and cream) in their optimization model. 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. Specifics regarding the results were not reported due to proprietary information.

The major factor influencing the results of the aforementioned location studies is transportation costs. When input transportation costs are higher than output transportation costs, the optimal location moves to minimize the distance from the suppliers of the input. When output transportation costs are higher than input transportation costs, the optimal location moves to minimize the distance to the buyers of the output. This knowledge is implemented in Chapter Three when determining potential locations for a milk condensing plant in Tennessee.

While the previously mentioned studies explore many different areas of dairy processing and optimal location programming, none directly apply to the dairy industry in the State of Tennessee. Considering the lack of literature concerning a milk condensing plant in Tennessee, this study uses insights from the previously discussed literature to find an optimal location for a milk condensing plant in Tennessee.

CHAPTER THREE
MATERIALS AND METHODS

This study is concerned with finding the optimal location for a milk condensing plant. This chapter contains fourteen sections discussed as follows: an analysis of the technical process of converting fluid milk to nonfat, the conceptual model, potential locations, demand of nonfat dry milk and cream, supply of whole fluid milk, shipping costs, shipping distances, the objective model, constraints, and five sections regarding different scenarios.

Milk Conversion Process

The condensing plant uses fluid milk as an input. Fluid milk is supplied by Tennessee dairies and dairies from the surrounding region of Southern Kentucky and Northern Alabama. Fluid milk goes through a pasteurization process, a cream separation process, and an evaporation and drying process (Pearce, 2017). The outputs from the entire process are nonfat dry milk (also known as powdered skim milk) and cream. It is assumed a processing plant producing yogurt will be the buyer of the nonfat dry milk. This producer is located in Murfreesboro, Tennessee. It is assumed a processing plant producing ice cream will be the buyer of the cream. This producer is located in Covington, Tennessee.

Conceptual Model

It is assumed the goal of the producer is to maximize profits (Nicholson, 2005). Cost minimization is necessary, but not the only condition required for profit maximization. This study isolates one part of cost minimization, specifically transportation costs. Here, cost minimization is a function of unit costs and distances of shipping inputs (fluid milk) to and outputs (nonfat dry milk and cream) from a milk condensing plant. The function is shown below:

$$Min\ Costs = Costs(C_{fm}, K_{fm}, C_{mg}, K_{mg}, C_{mu}, K_{mu}, d)$$

where the cost per pound per mile in dollars to transport fluid milk from each supplying county *f* to each potential condensing plant *m* is represented by C_{fm}. The number of miles from each supplying county *f* to each potential condensing plant *m* is represented by K_{fm}. The cost per pound per mile in dollars to transport nonfat dry milk from each potential condensing plant to the yogurt processing plant *g* is represented by C_{mg}. The number of miles from each potential condensing plant to the yogurt processing plant *g* is represented by K_{mg}. The cost per pound in dollars to transport cream from each potential condensing plant to the ice cream processing plant *u* is represented by C_{mu}. The number of miles from each potential condensing plant to the ice cream processing plant *u* is represented by K_{mu}. And *d* is a distance variable in miles.

Empirical Model

A mixed integer programming model is used to determine an optimal location for the middleman (milk condensing plant, in this case) in the transshipment problem (Ragsdale, 2012). This model allows for a binary decision variable to be included when deciding which possible location for the condensing plant minimizes shipping costs. Alongside the binary decision variable, continuous decision variables determine the optimal amount of milk that will be shipped from each dairy producing county to the condensing plant, while the amount of nonfat dry milk and cream sent to each of the value-added producers has been determined by an estimate of the demand held by each producer (yogurt and ice cream).

A mixed integer programming model is implemented to solve for the location of the milk condensing plant that minimizes transportation costs of fluid milk as the primary input and nonfat dry milk and cream as the primary outputs. As previously indicated, milk will be supplied from a potential set of counties in Tennessee, Alabama, and Kentucky. Also previously discussed, the outputs of the condensing plant will be shipped to a yogurt processing plant in Murfreesboro, TN and an ice cream processing plant in Covington, TN. For the program to decide between the potential condensing plants, binary decision variables are used to represent each of the 18 potential Tennessee condensing plant location sites in the model. These binary variables activate for the condensing plant that minimizes shipping costs. The model is a transshipment problem with nodes for the supply, the condensing plants, and the value-added processing plants.

The supply nodes representing counties supplying milk to the condensing plant have a negative net flow (as milk will be leaving those nodes), the condensing plants have a zero net flow (as each unit of milk coming into the node will be leaving the node as either nonfat dry milk or cream), and the value-added processing nodes representing the yogurt and ice cream plants have a positive net flow (as nonfat dry milk or cream will be only entering those nodes). The objective function sums 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 plants:

(1) $$Min\ Shipping\ Costs = \sum_{f=1}^{64}\sum_{m=1}^{18} C_{fm}K_{fm}z_m x_{fm} + \sum_{m=1}^{18} C_{mg}K_{mg}z_m y_{mg} + \sum_{m=1}^{18} C_{mu}K_{mu}z_m w_{mu}$$

where the subscript f represents each of the 64 counties that supply fluid milk and the subscript m represents each of the potential 18 condensing plants which will receive and process the fluid milk. (The number of counties supplying fluid milk to the condensing plant is subject to change based on the scenario being modeled.) The yogurt processing plant is represented by the subscript g and the subscript u represents the ice cream processing plant. The cost per pound per mile in dollars to transport fluid milk from each supplying county f to each potential condensing plant m is represented by C_{fm}. The number of miles from each supplying county f to each potential condensing plant m is represented by K_{fm}. The cost per pound per mile in dollars to transport nonfat dry milk from each potential condensing plant to the yogurt processing plant g is represented by

C_{mg}. The number of miles from each potential condensing plant to the yogurt processing plant g is represented by K_{mg}. The cost per pound in dollars to transport cream from each potential condensing plant to the ice cream processing plant u is represented by C_{mu}. The number of miles from each potential condensing plant to the ice cream processing plant u is represented by K_{mu}. The binary variables representing each potential condensing plant are represented by z_m. By definition, the binary variable z_m can either have a value of 0 or 1. The continuous variable representing the amount of fluid milk in pounds sent from each supplying county to each potential condensing plant is represented by x_{fm}. By definition, the continuous variable x_{fm} can have any positive value. The continuous variable representing the amount of nonfat dry milk in pounds sent from each potential condensing plant to the yogurt processing plant is represented by y_{mg}. By definition, the continuous variable y_{mg} can have any positive value. The continuous variable representing the amount of cream in pounds sent from each potential condensing plant to the ice cream processing plant is represented by w_{mu}. By definition, the continuous variable w_{mu} can have any positive value.

Constraints

The objective function is subjected to the following set of constraints as represented in Equation 2 through Equation 7. The continuous variable measuring the amount of fluid milk sent from a county to the 18 potential condensing plant locations cannot exceed each county's supply of fluid milk. The equation representing this set of relationships is shown as follows:

(2) $$\sum_{m=1}^{18} x_{fm} \leq S_f \;\; for\ all\ f$$

where S_f represents the supply of fluid milk in pounds from each supplying county *f*. This constraint holds for all 64 counties and each of the 18 potential condensing plant locations.

The continuous variable measuring the amount of nonfat dry milk sent from the potential condensing plants to the yogurt processing plant must exceed or meet the yogurt producers demand for nonfat dry milk. The equation representing this relationship is shown as follows:

(3) $$\sum_{m=1}^{18} y_{mg} \geq D_g$$

where D_g represents the yogurt producer's demand for nonfat dry milk in pounds and y_{mg} is as previously defined.

After milk enters the condensing plant, it is processed into skim milk and further processed into powdered form (nonfat dry milk). Based on prior discussion, the skim milk process is modeled by multiplying the total amount of milk sent from the supplying counties (represented by x_{fm}) to the chosen condensing plant (represented by z_m) by the conversion coefficient of 0.824, represented by α (i.e., the coefficient that converts whole milk to skim milk). The drying process resulting in nonfat dry milk is modeled by multiplying the resulting amount of skim milk from the previous conversion by the conversion coefficient 0.09, represented by β (i.e., the coefficient that converts skim milk to nonfat dry milk). Or as shown in Equation 4:

$$(4) \qquad \sum_{m=1}^{18} y_{mg} = \left[\alpha * \left(\sum_{f=1}^{64} \sum_{m=1}^{18} x_{fm} z_m\right)\right] * \beta.$$

When whole milk is converted to skim milk, the byproduct of cream remains. This cream is sent from the condensing plant to the ice cream producer. Mathematically, this conversion is represented by multiplying the total amount of milk sent from the supplying counties to the chosen condensing plant by one minus the skim milk conversion coefficient of 0.824 (represented by α). Or as shown in Equation 5 below (with w_{mu} previously defined):

$$(5) \qquad \sum_{m=1}^{18} w_{mu} = (1 - \alpha) * \left(\sum_{f=1}^{64} \sum_{m=1}^{18} x_{fm} z_m\right).$$

A binary variable, z_m, is used to represent which potential condensing plant is chosen to be the optimal location. The value of z_m can either be 0 or 1. Since only one potential condensing plant can exist in this model, the sum of all 18 binary variables (z_m) must equal one. Or as shown in Equation 6 below:

$$(6) \qquad \sum_{m=1}^{18} z_m = 1.$$

A linking constraint must be implemented to connect the binary variables (z_m) and the continuous variables (x_{fm}). The other continuous variables (y_{mg}; w_{mu}) are not included in the linking constraint as they are already connected to the continuous variable x_{fm} in the conversion constraints (Equation 4 and Equation 5). The Big M method is used to create a link between the continuous and binary decision variables, where M is a constant equal to the upper bound on x_{fm} (Ragsdale, 2012). The total pounds of milk sent from the supplying counties is less than or equal to the total supply of fluid milk (M) multiplied by the binary decision variable z_m. When a potential condensing plant is not chosen, the binary and continuous decision variables are equal to zero; the constraint is satisfied. When a potential condensing plant is chosen, the binary variable is equal to one and the continuous variables are a value that will never exceed M; the constraint is satisfied. The equation is shown below:

(7) $$\sum_{f=1}^{64} x_{fm} \leq M z_m \; for\ each\ m$$

where M is the representation of Big M and is equal to $\sum_{f=1}^{64} S_f$.

Potential Locations

Selections for possible condensing plant locations are limited to appropriate industrial parks in the state of Tennessee (Menard, 2016). The locations must be a reasonable distance away from an interstate, have access to utilities, and have sufficient land for building a condensing plant. According to a study by Dalton et al. (2002), a minimum of 8 acres is required.

Possible locations have been found using nonlinear location programming models. All of the supply and demand nodes were weighted by their supply and demand to find possible central locations for the condensing plant. GPS coordinates—which locate points on a map with pinpoint accuracy—of the nodes were used to determine the straight-line distances between all supply and demand nodes, and the model found a location that minimizes the total distance. Central points, found by the simple nonlinear model, are used as possible condensing plant locations.

Further condensing plant locations have been found based on knowledge of the state dairy and milk processing industry. There are potential plants located near the value-added producers, some near the heart of fluid milk supply in Tennessee, and some are located between the heart of supply and the value-added producers. A map of the 18 potential locations evaluated is shown in Figure 3.1.

Demand

The condensing plant transforms fluid milk to nonfat dry milk and cream. The cream is separated from the fluid milk, resulting in cream and skim milk. Fluid milk consists of 27.6% cream and 72.4% skim milk. These percentages were found by applying the ratio of water to solids in cream to the percentage of solids in whole milk (Webb and Whittier, 1970). The resulting percentage of water transferred from the whole milk to the cream was calculated to be 15% and was added to the percentage of solids in cream (12.6%), yielding the percentage of cream in milk. The skim milk is then dried. The drying process results in a nonfat milk powder that is 9% of the weight of the skim milk (Pearce, 2017).

The demand for nonfat dry milk is set at 44,100,000 pounds, which is equivalent to 490,000,000 pounds of fluid skim milk. The demand for cream is the total amount of resulting cream from the separation process.

Estimates for milk demand held by the condensing plant were based on published values for 2016 Yoplait yogurt sales by demand along with their number of Yoplait yogurt plants (four) (Statista, 2017). Additionally, the estimates are based on the demand held by condensing plants for milk on a percentage per dollar of shipment basis as found in the national IMPLAN model data for 2013 (IMPLAN sector 87, Dry, condensed, and evaporated dairy product manufacturing) (Minnesota IMPLAN Group Inc., 2000). Finally, included is the price per pound of milk based on an annual average by the Appalachian Marketing region (Griffith, 2016). These calculations lead to an annual demand of 492.8 million pounds, which were rounded to 490 million pounds for purposes of this analysis. Estimates for cream supplied for the plant were calculated as a derivative based on the number of pounds flowing into the yogurt plant. Given the size of the operation–reportedly one of the largest ice cream plants in the world (WREG, 2013)–it was assessed the ice cream plant would be able to absorb all of the cream produced by the condensing plant for any of the examined scenarios.

Supply

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 the distance, whether directly or indirectly, they would be willing to haul their milk.

The supply of milk was determined from the results of the survey (Hughes et al., 2016) and data from the most recent U.S. Census of Agriculture (2012) for county milk supply in Tennessee, 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 desired price premiums reported in Hughes et al. (2016) 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 from 2012 (to stay consistent with the 2012 Ag Census data), changing the supply unit to pounds. Then price premiums from the survey were introduced. For example, at a 10.0 - 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 would be determined to be the fluid milk supply in that county. County milk supply estimates from Alabama and Kentucky were found using the same method and also based on the price premiums indicated by Tennessee dairy farmers.

When modeling Tennessee supplies including the surrounding region previously mentioned, the supply estimates given a 10.0 - 12.5% price premium fulfill the demand of the value-added producers. For scenarios where Tennessee and the surrounding region are supplying fluid milk, this price premium will be used (Figure 3.2).

Since this model is location based, aggregate supplies are assumed to be located in the county seat of each county. The county seats are ideal locations for supply nodes as they are in a central location and are near highways. Aggregate supplies for the counties and accompanying county seats in Tennessee are provided in Table 3.1.

Shipping Costs

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 yogurt plant. Fluid dairy products require specialized trailers with the ability to keep the fluid dairy cold (Lampert, 1975). Over the road fluid milk transportation cost is assumed to be $3 per mile per a loaded 50,000 pound capacity tanker (Griffith, 2016; Lampert, 1975). That can be rewritten as a cost of $0.00006 per mile per pound of fluid milk or as a cost of $0.006 per mile per hundredweight of fluid milk. Hauling costs for a loaded 50,000 pound truck carrying powdered milk is assumed to be $1.65 (DAT Solutions, 2016). That can be rewritten as a cost of $0.000033 per mile per pound of nonfat dry milk or as a cost of $0.0033 per mile per hundredweight of nonfat dry milk. Due to cream being a fluid product, the per mile per pound cost of transporting cream to the ice cream plant is assumed to be the same rate as was calculated for fluid milk.

Shipping Distances

Distances in miles have been found from each county seat listed in Table 3.2 to each potential condensing plant. 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. The means, standard deviations, and coefficients of variation related to the distances from each county seat to each potential condensing plant are shown in Table 3.3.

The DeKalb County location has the lowest mean (118.78 miles) and standard deviation (59.84 miles) of the 18 potential plant locations in Table 3.3. The Dyer County location has the highest mean (258.08 miles) and standard deviation (103.43 miles). The Rutherford County location has the highest coefficient of variation (0.56), showing that it has the most variability relative to its mean among the 18 potential plant locations. Three locations, Haywood County, Crockett County, and Dyer County, have the lowest coefficients of variation (0.40), showing they have the least variability relative to their means. The Meigs County location has a mean (143.23 miles) closer to the average among all 18 potential plant locations. The Meigs County standard deviation is 73.11 miles, and the coefficient of variation is 0.51.

The same Google Maps based approach was employed to find distances from the potential condensing plants to the value-added processing plants (Table 3.4). The means, standard deviations, and coefficients of variation related to the distances from each potential condensing plant location to each value-added processing plant are shown in Table 3.5.

Given their adjacency to the ice cream and yogurt processing plants, respectively, the Haywood (103.2 miles) and Rutherford (104.5 miles) County locations have the lowest means of the 18 potential plant locations in Table 3.5. The two Blount County locations have the highest means (275 miles each). The Humphreys County location has the lowest standard deviation (18.05 miles) of the 18 potential plant locations. The Rhea County location has the highest standard deviation (109.5 miles). The Humphreys County location also has the highest coefficient of variation (0.96), showing it had the least variability relative to its mean among the 18 potential plant locations. The Rutherford County location had the lowest coefficient of variation (0.16), showing it had the most variability relative to its mean. The DeKalb County location has a mean (144.3 miles) closer to the average among all 18 potential plant locations. The DeKalb County standard deviation is 98.7 miles, and the coefficient of variation is 0.68.

Base Scenario

The base scenario considers counties in Tennessee and the surrounding region as potential suppliers of fluid milk to the condensing plant. Supply estimates are based on a price premium of 10.0-12.5%. Fluid milk enters the condensing plant and is converted to nonfat dry milk and cream. Nonfat dry milk is sent to the yogurt processing plant and cream is sent to the ice cream processing plant. Fluid milk and cream are assumed to have a shipping cost of $3 per mile per 50,000 pounds. Nonfat dry milk is assumed to have a shipping cost of $1.65 per mile per 50,000 pounds.

Tennessee First Scenario

The Tennessee first scenario first considers counties in Tennessee as potential suppliers of fluid milk to the condensing plant, then after Tennessee supply is exhausted, counties in the surrounding region are considered. Supply estimates are based on a price premium of 10.0-12.5%. Fluid milk enters the condensing plant and is converted to nonfat dry milk and cream. Nonfat dry milk is sent to the yogurt processing plant and cream is sent to the ice cream processing plant. Fluid milk and cream are assumed to have a shipping cost of $3 per mile per 50,000 pounds. Nonfat dry milk is assumed to have a shipping cost of $1.65 per mile per 50,000 pounds.

Close to Covington Scenario

The close to Covington scenario is a modification of the base scenario. In this scenario, the milk condensing plant location is constrained to be at most 50 miles from the ice cream plant in Covington. A hard constraint is added to the base model that forces the optimal condensing plant location to be less than or equal to 50 miles from the ice cream plant. The supply estimates and shipping costs are the same as those from the base scenario.

Scenarios with Changing Transportation Unit Costs

Seven scenarios were analyzed from the base scenario with the only change being transportation costs. These scenarios replicate a sensitivity analysis and show how the optimal solution withstands changes in transportation unit costs. The first and second scenarios analyze when the cost of shipping fluid milk and cream increases by 50% ($4.50 per mile per 50,000 pounds) and decreases by 50% ($1.50 per mile per 50,000 pounds). The third and fourth scenarios analyze when the cost of shipping nonfat dry milk increases by 50% ($2.48 per mile per 50,000 pounds) and decreases by 50% ($0.83 per mile per 50,000 pounds). The fifth scenario analyzes when the cost of shipping fluid milk and cream increases by 50% ($4.50 per mile per 50,000 pounds) and the cost of shipping nonfat dry milk decreases by 50% ($0.83 per mile per 50,000 pounds). The sixth scenario analyzes when the cost of shipping fluid milk and cream decreases by 50% ($1.50 per mile per 50,000 pounds) and the cost of shipping nonfat dry milk increases by 50% ($2.48 per mile per 50,000 pounds).

The seventh scenario analyzes when all costs of shipping are increased by 140%. From 2000 to 2017, at its highest point, the price of gasoline was 1.4 times its price in 2000 (Figure 3.3). Accounting for a similar situation, this scenario measures what the total transportation costs might be if gasoline again increases by 140%.

East Tennessee Traffic Scenario

Another way of replicating a sensitivity analysis is by evaluating the model with respect to changes in the transportation network. In this scenario, the base scenario is modified to represent potential road closures and hence changes in traffic patterns in the east region of Tennessee. (The fluid milk supplying counties located in this east region of Tennessee are Blount, Bradley, Carter, Cocke, Grainger, Greene, Hamblen, Jefferson, Johnson, Loudon, McMinn, Meigs, Monroe, Polk, Roane, and Sullivan Counties.) The potential milk supply for each of these counties is found in Figure 3.2. Distances from these East Tennessee counties are doubled in this scenario as a proxy for potential transportation network issues.

CHAPTER FOUR
RESULTS AND DISCUSSION

Results for the twelve scenarios described in Chapter Three are presented and discussed in this chapter. The Base Scenario section discusses results when all 64 potential supplying counties (43 in Tennessee, 5 in Alabama, and 16 in Kentucky) can supply fluid milk to the condensing plant. The Tennessee First Scenario section discusses results when Tennessee's potential fluid milk supply must be exhausted before fluid milk can be sourced from counties in Alabama or Kentucky. The Close to Covington scenario section discusses results when the potential condensing plant locations are limited to those within 50 miles of the ice cream producer in Covington, TN. The Scenarios with Changing Transportation Unit Costs section discusses results when the per pound per mile unit costs of shipping fluid milk, cream, and nonfat dry milk are increased and decreased in different combinations by 50%. Additionally, there is one scenario where all unit costs are increased by 140%. There are seven scenarios measuring changes in unit costs in that section. Finally, the East Tennessee Traffic Scenario discusses results when counties in the eastern region of Tennessee experience road closures and traffic issues forcing the distance traveled from supplying counties to potential condensing plants to be doubled.

Base Scenario

The base scenario allows all 64 potential fluid milk supplying counties (Figure 3.2) in Tennessee, Alabama, and Kentucky to supply milk to the condensing plant. After running the model representing the potential supply from counties in Tennessee and surrounding counties in Alabama and Kentucky, Rutherford County was found to be the cost minimizing location for the milk condensing plant, with total shipping costs of $6,181,829. The Rutherford County location is located 4 miles from the yogurt producer in Murfreesboro, and 205 miles from the ice cream producer in Covington. The cost to ship all 676,795,580 pounds of fluid milk from supplying counties to the Rutherford County condensing plant location is $3,878,422, 62.7% of the total cost. The cost to ship all 44,100,000 pounds of nonfat dry milk from the condensing plant to the yogurt processing plant is $5,821, 0.1% of the total cost. The cost to ship all 186,795,580 pounds of cream from the condensing plant to the ice cream processing plant is $2,297,586, 37.2% of the total cost.

The twenty-nine Tennessee counties supplying milk to the condensing plant (out of forty-three potential supplying Tennessee counties) are shown in Figure 4.1. The three Alabama counties out of five potential Alabama counties supplying milk are shown in Figure 4.1. The eleven Kentucky counties supplying milk out of sixteen potential Kentucky milk supplying counties are shown in Figure 4.1.

The amount of fluid milk sent from each county to the Rutherford potential condensing plant is shown in Table 4.1. The county supplying the most fluid milk to the

Rutherford County location is Barren County, Kentucky with 95,896,321 pounds of milk sent, 14% of all whole fluid milk sent to the condensing plant. The Tennessee county supplying the most fluid milk to the Rutherford County location is McMinn County with 41,965,103 pounds of milk sent, 6% of all whole fluid milk sent to the condensing plant.

The base scenario was run for each potential condensing plant location to create a ranking of the 18 potential locations (Table 4.2). The possible plant locations in seven other counties with total shipping costs under $8 million in order of least cost are Maury, DeKalb, Humphreys, Coffee, Warren, Cumberland, and Grundy Counties.

The total transportation costs for each potential condensing location are separated into fluid milk, nonfat dry milk, and cream shipping costs (Table 4.3). While Rutherford County has the lowest total transportation costs, DeKalb County has the lowest cost of transporting fluid milk. It costs $3,745,417 to transport fluid milk to DeKalb County, while it costs $3,878,422 to transport fluid milk to Rutherford County. Rutherford County has the lowest cost of transporting nonfat dry milk to the yogurt producer, $5,821, as the product is only being shipped four miles. Compare that result to Coffee County, with the next lowest cost of transporting nonfat dry milk to the yogurt producer at $56,029. Haywood County has the lowest cost of transporting cream to the ice cream producer at $295,884, as it is only 26 miles from the ice cream producer. The next lowest cost of transporting cream to the ice cream producer is Crockett County at $431,498.

While DeKalb County has the lowest shipping cost for fluid milk, Cumberland County has the lowest fluid milk shipping cost as a percentage of total transportation costs at 54%, equal to $3,950,083 (Table 4.3). Cumberland County also has the highest cream shipping cost as a percentage of total transportation cost at 44%, equal to $3,216,620. On the other hand, Haywood County has the highest fluid milk shipping cost as a percentage of total transportation costs at 94% ($8,508,791), and the lowest cream shipping cost percentage at 3% ($295,884).

Tennessee First Scenario

The Tennessee First Scenario section discusses results when Tennessee's potential fluid milk supply must be exhausted before fluid milk can be sourced from counties in Alabama and Kentucky.

Rutherford County was also found to be the cost minimizing location for the milk condensing plant under this scenario, with total shipping costs of $6,985,357. This result is an increase of $803,528 or 13% over the base scenario. The Rutherford County location is located 4 miles from the yogurt producer in Murfreesboro, and 205 miles from the ice cream producer in Covington. The cost to ship all 676,795,580 pounds of fluid milk from supplying counties to the Rutherford County condensing plant location is $4,681,950, 67% of the total cost. The cost to ship all 44,100,000 pounds of nonfat dry milk from the condensing plant to the yogurt processing plant is $5,821, 0.1% of the total cost. The cost to ship all 186,795,580 pounds of cream from the condensing plant to the ice cream processing plant is $2,297,586, 32.9% of the total cost. All forty-three potential Tennessee milk supplying counties sent milk to the condensing plant, which leads to a higher cost than the base scenario as many Tennessee dairy producing counties are farther away from the optimal condensing plant location than some dairy producing counties in Alabama and Kentucky. Out of five potential Alabama milk supplying counties, no Alabama county supplies milk. The six Kentucky counties supplying milk out of sixteen potential Kentucky milk supplying counties are shown in Figure 4.2.

The amount of fluid milk sent from each county to the Rutherford potential condensing plant is shown in Table 4.4. The county supplying the most fluid milk to the Rutherford County location is Barren County, Kentucky with 80,264,957 pounds of milk sent, 12% of all whole fluid milk sent to the condensing plant. The Tennessee county supplying the most fluid milk to the Rutherford County location is McMinn County with 43,505,618 pounds of milk sent, 6% of all whole fluid milk sent to the condensing plant.

The Tennessee First scenario was run for each potential condensing plant location to create a ranking of the 18 potential locations (Table 4.5). Locations in seven other counties beside Rutherford County with total estimated shipping costs under $8 million are found in DeKalb, Maury, Cumberland, Warren, Coffee, Humphreys, and Grundy Counties.

The total transportation costs for each potential condensing plant location are separated into fluid milk, nonfat dry milk, and cream shipping costs (Table 4.6). While Rutherford County has the lowest total transportation costs, Cumberland County has the lowest cost of transporting fluid milk. It costs $4,155,610 to transport fluid milk to Cumberland County, while it costs $4,681,950 to transport fluid milk to Rutherford County. The costs of shipping nonfat dry milk and cream to the value-added producers do not differ from the base scenario.

Cumberland County also has the lowest fluid milk shipping cost as a percentage of total transportation costs at 55%, equal to $4,155,610 (Table 4.6). Cumberland County also has the highest cream shipping cost as a percentage of total transportation cost at 43%, equal to $3,216,620. These percentages are a slight change from those found in the Base Scenario. Contrary, Haywood County has the highest fluid milk shipping cost as a percentage of total transportation costs at 95% ($9,747,476), and the lowest cream shipping cost percentage at 3% ($295,884). Here, these percentages are also a slight change from the Base Scenario.

Close to Covington Scenario

This scenario is a constrained optimization. Specifically, only the three locations within 50 miles of the ice cream plant in Covington were candidates for the condensing plant under this scenario. The potential plant in Haywood County was found to be the cost minimizing location within 50 miles of Covington, with total shipping costs of $9,066,791. This result is an increase of $2,884,962 or 47% over the optimal solution from the base scenario. Fluid milk shipping cost increases by $4,630,369 or 119% over the base scenario. Nonfat dry milk shipping cost increases by $256,133 or 440% over the base scenario. Cream shipping cost decreases by $2,001,702 or 87% below the base scenario. The Haywood County location is located 180 miles from the yogurt producer in Murfreesboro, and 26.4 miles from the ice cream producer in Covington. The cost to ship all 676,795,580 pounds of fluid milk from supplying counties to the Haywood County condensing plant location is $8,508,791, 93.8% of the total cost. The cost to ship all 44,100,000 pounds of nonfat dry milk from the condensing plant to the yogurt processing plant is $261,954, 2.9% of the total cost. The cost to ship all 186,795,580 pounds of cream from the condensing plant to the ice cream processing plant is $295,884, 3.3% of the total cost. The twenty-nine Tennessee counties supplying milk to the condensing plant out of forty-three potential Tennessee milk supplying counties are provided in Figure 4.3. All five of the potential Alabama milk supplying counties are supplying milk. The fourteen Kentucky counties supplying milk out of sixteen potential Kentucky milk supplying counties are shown in Figure 4.3.

The amount of fluid milk sent from each county to the Haywood potential condensing plant is shown in Table 4.7. The county supplying the most fluid milk to the Haywood County location is Barren County, Kentucky with 95,896,321 pounds of milk sent, 14% of all whole fluid milk sent to the condensing plant. The Tennessee county supplying the most fluid milk to the Haywood County location is Marshall County with 29,514,670 pounds of milk sent, 4% of all whole fluid milk sent to the condensing plant.

The ranking of these locations based on minimized cost are shown in Table 4.8. As shown in Table 4.9, Haywood County is also the location with the lowest fluid milk shipping cost ($8,508,791), nonfat dry milk shipping cost ($261,954), and cream shipping cost ($295,884).

While Haywood County has the lowest shipping cost for fluid milk, Dyer County has the lowest fluid milk shipping cost as a percentage of total transportation costs at 92%, equal to $9,126,326 (Table 4.9). Dyer County also has the highest cream shipping cost as a percentage of total transportation cost at 5%, equal to $450,551. Haywood County has the highest fluid milk shipping cost as a percentage of total transportation costs at 94% ($8,508,791), and the lowest cream shipping cost percentage at 3% ($295,884). Crockett County has a fluid milk cost percentage of 93% ($8,961,329) and a cream cost percentage of 4% ($431,498).

Scenarios with Changing Transportation Unit Costs

Shadow prices show what change in unit costs force the optimal solution to change in mathematical programming models. In a linear programming model, shadow prices can be used to test the sensitivity of model results to changes in key parameters, such as per mile shipping cost in transportation problems. However, reported shadow prices may not be accurate for a mixed integer model containing binary decision variables (Ragsdale, 2012). Accordingly, following Garcia-Flores et al. (2015), transportation price changes were set at 50% to determine if and how the optimal location of the milk condensing plant would change when unit costs are increased and decreased.

In the first scenario, the cost of shipping fluid milk and cream was increased by 50%. Both costs were adjusted simultaneously as it is assumed they are equal. The total transportation costs increased by 49.95% to $9,269,832; Rutherford County remained the optimal location for a milk condensing plant. In the second scenario, the cost of shipping fluid milk and cream was decreased by 50%. The total transportation costs decreased by 49.95% to $3,093,825; Rutherford County remained the optimal location for a milk condensing plant. In the third scenario, the cost of shipping nonfat dry milk was increased by 50%. The total transportation costs increased by 0.05% to $6,184,739; Rutherford County remained the optimal location for a milk condensing plant. In the fourth scenario, the cost of shipping nonfat dry milk was decreased by 50%. The total transportation costs decreased by 0.05% to $6,178,918; Rutherford County remained the optimal location for a milk condensing plant. In the fifth scenario, the cost of shipping fluid milk and cream was increased by 50% and the cost of shipping nonfat dry milk was decreased by 50%. The total transportation costs increased by 49.91% to $9,266,922; Rutherford County remained the optimal location for a milk condensing plant. In the sixth scenario, the cost of shipping fluid milk and cream was decreased by 50% and the cost of shipping nonfat dry milk was increased by 50%. The total transportations costs decreased by 49.91% to $3,096,736; Rutherford County remained the optimal location for a milk condensing plant.

In the seventh scenario, all transportation unit costs were increased by 140%. The total transportation cost increased by 140% to $8,654,561; Rutherford County remained the optimal location for a milk condensing plant.

None of the changes in fluid and dry shipping unit costs to the base scenario changed the optimal location of the milk condensing plant. While the total costs changed, the Rutherford County location remained the cost minimizing location.

East Tennessee Traffic Scenario

This scenario represents a change in the fluid milk supply's transportation network. This scenario is a modification of the base scenario, where distances from supplying counties in East Tennessee are doubled to indicate potential road closures and traffic issues.

Rutherford County remains the optimal location for a milk condensing plant under this scenario (i.e., it is the least-cost location). Transportation costs increased by 2.42% above the base scenario to $6,331,449 (Table 4.10). With the increase in distance, fluid milk supply from the East Tennessee region ceased, with Kentucky and Alabama supplying more milk to meet the demand.

The potential condensing plant location with the largest percentage increase in transportation costs is Cumberland County with a 10.4% increase over the costs from the base scenario. Cumberland County is in a location that easily sources milk from all of East Tennessee, so the effect of the distance increase makes sense.

The potential condensing plant location with the smallest percentage increase in transportation costs is Dyer County with a 0.45% increase over the costs from the base scenario. Dyer County is the location farthest from the East Tennessee region and sources very little milk from the region in the base scenario, thus the small change in costs.

Summary of Results

In the base scenario, Rutherford County was chosen as the cost minimizing location for a milk condensing plant in Tennessee. The total cost of shipping fluid milk to the plant and nonfat dry milk and cream from the plant is $6,181,829. Counties in Tennessee supplied 45% of the whole fluid milk input for the condensing plant.

In the Tennessee First scenario, Rutherford County was again chosen as the cost minimizing location for a milk condensing plant in Tennessee. The total cost of shipping fluid milk to the plant and nonfat dry milk and cream from the plant is $6,985,357. Counties in Tennessee supplied 66% of the whole fluid milk input for the condensing plant.

In the Close to Covington scenario, Haywood County was chosen as the cost minimizing location for a milk condensing plant in Tennessee. The total cost of shipping fluid milk to the plant and nonfat dry milk and cream from the plant is $9,065,108. Counties in Tennessee supplied 34% of the whole fluid milk input for the condensing plant.

None of the potential locations in the Base, Tennessee First, or Close to Covington scenarios have a nonfat dry milk cost as a percentage of total transportation cost greater than 3%. Thus, at least 97% of each county's total transportation costs are due to fluid milk and cream transportation. The most influential factor in the location decision is a potential location's balance between distance from the supply of fluid milk and distance to the ice cream producer.

In lieu of shadow prices, seven scenarios were implemented as modifications of the base scenario that adjusted shipping unit costs for fluid milk, dry milk, and cream by individual 50% increases and decreases, combinations of 50% increases and decreases, and a 140% increase in fuel costs. Rutherford County remained the optimal, cost minimizing location for the milk condensing plant in Tennessee for all seven cost-changing scenarios.

A transportation network sensitivity analysis scenario was implemented to find the optimal condensing plant location when East Tennessee supply distances are doubled. Rutherford County remained the cost minimizing location, with a 2.42% increase in transportation costs over the base scenario.

Accordingly, the Rutherford County potential condensing plant location remained the optimal location for all analyzed scenarios except one (the Close to Covington scenario, when it was ruled out as a location). These sets of results indicate the Rutherford County location is the best location under a variety of situations, as the results of the model do not change with large changes in relative shipping costs between inputs and outputs.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

A milk condensing plant with outputs of nonfat dry milk and cream was determined to potentially meet the needs of Tennessee value-added producers and dairy producers, as discussed in Chapter One. Two value-added dairy processing plants (a yogurt producer in Murfreesboro and an ice cream producer in Covington) have shown interest in sourcing inputs (nonfat dry milk and cream) from a dairy processor in Tennessee. Tennessee dairy producers have also shown an interest in a new market for their milk. This study's goal is to determine a transportation cost minimizing location for this potential milk condensing plant.

Previous literature regarding plant location and milk processing was discussed in Chapter Two. The production processes and benefits of powdered milk were discussed (Pearce, 2017; Casey, 2013). The least cost (cost minimizing) approach to location programming was also discussed (Shaffer et al., 2004; Hilger et al., 1977; Faminow and Sarhan, 1983; Tembo et al., 1999; Wu et al., 2010; Garcia-Flores et al., 2015). Specifically, studies regarding milk processing location programming were analyzed in detail (Kloth and Blakley, 1971; Beck and Goodin, 1980; Dalton et al., 2002; Wouda et al., 2002). The major takeaway from these studies is in most cases, transportation costs are the major factors influencing a plant's optimal location. Methods used to find the optimal location for a Tennessee milk condensing plant were discussed in Chapter Three. The conversions fluid milk endures through the skimming, evaporation, and drying processes, as well as the model constraints representing these processes were discussed.

Methods used to estimate supply of fluid milk and demand of nonfat dry milk and cream were presented. Methods used to estimate distances and costs regarding the transportation of fluid milk, dry milk, and cream were also presented. Further, the mixed integer programming model (including relevant constraints) used to find the optimal location, inputs, and outputs of a milk condensing plant was examined. The scenarios introduced to the model representing possible transportation situations with which a milk condensing plant might face are introduced. The results from the different scenarios are summarized below.

Rutherford County is the optimal location for a milk condensing plant in Tennessee, with a total transportation cost of $6,181,829 in the base scenario and $6,985,357 in the Tennessee First Scenario. In the base and Tennessee First scenarios, Rutherford County was the potential location with the lowest total shipping costs (with an increase in total transportation costs of $803,528 or 13% in the Tennessee First scenario compared to the base scenario). The main reason for this result is Rutherford County is a central location in Tennessee and is not too distant from any potential fluid milk supplying counties. The second and strongest reason for this result is the Rutherford County milk condensing plant location and the yogurt processing plant location are both located in Murfreesboro, TN; a short 4 mile drive from each other.

Haywood County is the optimal location for a milk condensing plant in the Close to Covington scenario. The main reason for this result is there are only three potential locations within 50 miles of the ice cream plant and Haywood County is the closest one, resulting in the lowest cost of shipping cream to the ice cream plant. While this location is the most desired by the ice cream processing plant, it would not be the ideal location for the Tennessee dairy industry as a whole.

When shipping unit costs are changed, the optimal milk condensing plant location is identical to the result of the base scenario, Rutherford County. While changes in shipping costs do change the total cost of transporting the inputs and outputs, these changes are not influential enough to move the optimal milk condensing plant location.

When the transportation network for fluid milk supply in East Tennessee (a major source of Tennessee milk production) is affected, Rutherford County remains the optimal condensing plant location. Increased shipment of fluid milk from Alabama and Kentucky replace the supply from East Tennessee, under this scenario.

Given the results of the scenarios in this paper and the interest in this project by the yogurt processing plant, it is recommended that a milk condensing plant should be located in Rutherford County.

A weakness of this study is the omission of real estate, construction costs, and operating costs. Firms interested in a milk condensing plant would evaluate the total costs of production, which would include production costs in addition to transportation costs. Another main weakness regards the supply of fluid milk from producers. Milk condensing plant operators generally purchase Class II or Class III milk and most Tennessee milk is sold as Class I fluid milk. Class II and Class III prices are usually lower than Class I prices. Hence, the potential milk condensing plant operators would almost certainly not offer a price premium of 10.0 - 12.5% over market (Class I) price. In addition, many of the dairy farmers hypothetically supplying milk to the condensing plant in this study are currently participating in other milk markets and might not be interested in supplying to this milk condensing plant. Anecdotal evidence suggests this due to previous experience with the atrophy of new milk markets.

Future Research

Further studies on this topic should include commercial real estate costs, construction costs, and variable costs of production in the model. This model could be expanded by analyzing the possibility of locating multiple milk condensing plants in the state. Instead of one centrally-located condensing plant, multiple plants could be located in different supply hubs. This policy could further minimize transportation costs by reducing the distance fluid milk has to travel from farms to the condensing plant and instead put the transportation burden on the less costly (per mile) shipments nonfat dry milk, although other costs could increase. Additionally, more detailed information regarding the willingness of fluid milk producers to sell their milk to a new buyer is needed. In this regard, analysis could be conducted assessing the possibility of the more efficient Tennessee dairy farmers receiving fee-cost plus contracts with the condensed milk processor. Such dairy producers could be assured of a steady market at a reasonable price and the value-added producers could be assured of at least some local supply, which they could use in promoting their product to final consumers (i.e., yogurt produced with a certain percentage of milk that is obtained through a short supply chain). These additions to the project could result in a more accurate assessment regarding the total costs (construction, production, and transportation) for a potential milk condensing plant in Tennessee. These additions could also move the project closer to becoming a reality.

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APPENDIX

Table 3.1. 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
Bledsoe	Pikeville	4,138,651
Blount	Maryville	6,586,397
Bradley	Cleveland	16,174,498
Carter	Elizabethton	1,561,580
Cocke	Newport	7,828,721
Coffee	Manchester	8,596,968
Fentress	Jamestown	1,333,074
Franklin	Winchester	4,628,352
Gibson	Trenton	3,254,469
Giles	Pulaski	3,019,821
Grainger	Rutledge	2,800,433
Greene	Greeneville	33,768,299
Grundy	Altamont	1,479,304
Hamblen	Morristown	7,301,254
Henry	Paris	18,285,560
Humphreys	Waverly	1,057,618
Jefferson	Dandridge	12,843,128
Johnson	Mountain City	145,747
Lawrence	Lawrenceburg	10,147,687
Lincoln	Fayetteville	6,634,764
Loudon	Loudon	32,033,210
Marion	Jasper	1,041,053
Marshall	Lewisburg	29,514,670
Maury	Columbia	21,233,967
McMinn	Athens	43,505,618
Meigs	Decatur	6,128,334
Monroe	Madisonville	25,967,340
Obion	Union City	367,276
Overton	Livingston	7,015,643
Polk	Benton	26,283,126
Putnam	Cookeville	4,910,610
Roane	Kingston	2,134,159
Robertson	Springfield	20,193,353
Rutherford	Murfreesboro	3,839,390
Smith	Carthage	3,138,846
Sullivan	Blountville	4,233,617
Sumner	Gallatin	5,478,527
Warren	McMinnville	13,959,871
Weakley	Dresden	2,951,807

Table 3.1. Continued

Location (County)	County Seat	Pounds of Milk
White	Sparta	20,125,339
Williamson	Franklin	3,383,696
Wilson	Lebanon	3,876,797
Cullman, AL	Cullman	18,479,400
De Kalb, AL	Fort Payne	2,951,807
Etowah, AL	Gadsden	2,723,960
Franklin, AL	Russellville	680,140
Morgan, AL	Decatur	16,506,995
Adair, KY	Columbia	46,430,978
Allen, KY	Scottsville	3,808,783
Barren, KY	Glasgow	95,896,321
Christian, KY	Hopkinsville	32,687,522
Graves, KY	Mayfield	1,761,562
Laurel, KY	London	614,221
Logan, KY	Russellville	67,303,241
Metcalfe, KY	Edmonton	22,060,337
Monroe, KY	Tompkinsville	27,960,550
Pulaski, KY	Somerset	13,894,592
Russell, KY	Jamestown	18,287,837
Simpson, KY	Franklin	7,848,814
Todd, KY	Elkton	38,472,112
Trigg, KY	Cadiz	5,087,446
Warren, KY	Bowling Green	32,694,323
Wayne, KY	Monticello	1,818,373

Source: 2012 Agricultural Census, NASS and author’s calculations.

Table 3.2. Distances (in miles) from each County to each Potential Condensing Plant

County	Haywood	Humphreys	Maury	Rutherford	Warren	Blount-Alcoa	Blount-Rockford	Cumberland	Loudon
Bedford	177	106	39	27	41	211	211	137	174
Bledsoe	283	210	146	94	61	94	96	35	66
Blount	336	263	218	189	142	3	8	77	40
Bradley	309	224	171	131	112	87	87	75	51
Carter	455	359	332	296	249	130	125	185	148
Cocke	389	293	259	230	183	64	58	119	81
Coffee	210	137	73	33	16	176	155	81	144
Fentress	278	205	159	130	100	87	97	32	96
Franklin	234	148	96	56	37	183	183	97	148
Gibson	36.3	75	140	170	215	331	327	253	316
Giles	156	102	50	76	85	251	251	178	210
Grainger	364	289	244	215	168	50	43	104	66
Greene	411	315	281	252	205	86	80	141	104
Grundy	233	160	96	56	23	141	146	75	113
Hamblen	388	292	258	229	182	63	57	118	81
Henry	85	47	116	146	191	293	294	220	283
Humphreys	101	4	7	100	146	262	258	184	247
Jefferson	362	288	243	214	167	49	42	102	65
Johnson	135	410	365	336	289	171	164	225	188
Lawrence	135	87	48	84	104	260	260	186	249
Lincoln	192	122	65	53	54	215	215	120	180
Loudon	331	235	201	183	127	27	38	64	6
Marion	257	184	120	80	62	133	141	80	105
Marshall	159	98	34	40	63	235	235	149	224
Maury	138	66	12	48	93	224	224	150	213
McMinn	336	236	198	158	103	46	62	61	26
Meigs	313	226	175	123	90	70	70	51	34
Monroe	357	244	219	179	123	30	37	87	25
Obion	72	93	164	194	240	368	362	288	341
Overton	262	167	133	104	73	111	111	37	100
Polk	324	239	187	147	128	60	67	84	50
Putnam	231	157	112	83	55	111	106	32	95
Roane	295	222	179	126	121	42	40	36	29
Robertson	178	78	65	64	109	212	212	138	199
Rutherford	179	106	42	2	47	188	184	110	173
Smith	206	133	88	59	60	144	140	66	129
Sullivan	433	349	315	286	239	120	114	175	138
Sumner	179	105	72	43	89	179	175	101	164
Warren	221	136	83	41	9	130	130	56	119

Table 3.2. Continued

County	Haywood	Humphreys	Maury	Rutherford	Warren	Blount-Alcoa	Blount-Rockford	Cumberland	Loudon
Weakley	64	69	139	169	214	327	327	253	316
White	247	162	102	63	37	103	103	29	92
Williamson	153	60	16	30	78	200	200	126	189
Wilson	201	97	63	34	79	155	155	81	144
Cullman, AL	193	197	121	147	145	233	240	185	205
De Kalb, AL	309	236	172	132	114	159	167	136	131
Etowah, AL	244	239	163	169	150	196	203	173	168
Franklin, AL	144	137	109	166	164	280	288	269	252
Morgan, AL	170	169	93	118	116	232	240	220	204
Adair, KY	280	207	168	161	139	165	181	103	166
Allen, KY	214	141	103	76	103	191	187	113	176
Barren, KY	244	171	132	100	145	181	174	100	163
Christian, KY	156	74	109	103	159	257	253	179	242
Graves, KY	108	89	183	176	222	332	327	253	316
Laurel, KY	354	280	242	235	205	114	108	141	128
Logan, KY	203	81	103	84	130	227	221	147	210
Metcalfe, KY	262	189	151	143	116	185	168	94	157
Monroe, KY	237	164	130	100	95	151	147	74	137
Pulaski, KY	321	248	210	202	146	146	119	98	160
Russell, KY	298	225	186	179	133	155	171	89	153
Simpson, KY	194	120	82	75	121	206	202	128	191
Todd, KY	171	71	106	94	151	249	244	171	234
Trigg, KY	142	68	121	114	171	271	265	191	254
Warren, KY	214	107	102	95	141	214	210	136	199
Wayne, KY	299	226	180	151	121	124	117	71	135

Source: Google Maps

Table 3.2. Continued

County	Rhea	Dyer	Crockett	Grundy	Roane	DeKalb	Coffee	Carroll	Meigs
Bedford	120	212	203	46	171	64	24	162	132
Bledsoe	19	302	294	60	50	55	82	254	33
Blount	85	358	349	170	51	135	163	308	70
Bradley	31	330	321	85	63	121	105	280	34
Carter	192	465	457	278	159	243	271	415	178
Cocke	126	399	391	212	92	176	204	349	111
Coffee	94	231	223	20	115	43	7	181	106
Fentress	77	299	291	122	67	76	121	249	82
Franklin	110	254	246	20	142	62	20	204	122
Gibson	297	27	29	219	287	209	208	38	302
Giles	172	177	169	82	211	116	65	137	184
Grainger	111	384	376	197	77	161	189	334	96
Greene	148	421	413	234	114	198	226	371	133
Grundy	67	254	246	16	99	47	32	205	79
Hamblen	125	398	390	211	92	175	204	348	111
Henry	260	78	79	196	253	176	185	22	269
Humphreys	240	122	114	150	218	140	139	45	233
Jefferson	110	382	374	195	76	160	188	333	95
Johnson	232	505	497	318	198	282	310	455	217
Lawrence	192	157	148	102	219	125	85	116	204
Lincoln	142	236	228	51	174	84	35	186	154
Loudon	51	345	336	136	38	122	157	295	36
Marion	67	278	270	33	99	91	54	229	80
Marshall	142	204	196	77	195	100	46	154	154
Maury	161	159	151	97	183	89	63	109	174
McMinn	26	356	348	111	48	102	131	306	15
Meigs	13	333	325	89	40	87	111	283	1
Monroe	47	367	359	132	61	110	153	317	32
Obion	308	33	41	243	310	233	232	47	326
Overton	81	273	264	95	71	50	94	223	86
Polk	45	345	337	100	71	137	121	295	38
Putnam	76	252	244	77	66	29	77	202	81
Roane	42	316	308	116	10	93	122	266	32
Robertson	180	200	191	109	170	92	98	118	185
Rutherford	110	200	192	51	144	40	40	151	122
Smith	110	228	219	82	100	35	71	179	115
Sullivan	182	455	446	268	148	232	260	405	167
Sumner	145	200	192	92	135	57	82	150	150
Warren	71	242	234	33	90	21	30	192	83
Weakley	310	56	56	218	286	208	208	22	302
White	55	268	260	59	63	20	59	211	71
Williamson	144	168	160	80	160	71	69	118	176
Wilson	125	203	195	84	115	37	75	153	130
Cullman, AL	167	221	213	117	199	188	118	186	179
De Kalb, AL	94	330	322	85	126	143	106	280	106
Etowah, AL	130	273	264	122	162	179	142	283	142
Franklin, AL	215	173	165	136	247	207	137	138	227

Table 3.2. Continued

County	Rhea	Dyer	Crockett	Grundy	Roane	DeKalb	Coffee	Carroll	Meigs
Morgan, AL	166	199	191	88	198	159	89	213	179
Adair, KY	147	301	293	161	137	105	160	251	153
Allen, KY	157	236	227	125	146	78	115	186	162
Barren, KY	144	265	257	149	134	94	139	215	149
Christian, KY	223	151	159	152	213	135	141	93	228
Graves, KY	297	69	76	226	286	209	215	57	302
Laurel, KY	146	375	367	200	114	155	199	325	158
Logan, KY	191	189	197	133	181	103	123	118	196
Metcalfe, KY	138	283	275	167	128	88	157	233	143
Monroe, KY	117	258	250	131	107	67	112	208	123
Pulaski, KY	140	342	334	169	108	123	168	293	138
Russell, KY	134	319	311	155	128	109	154	269	139
Simpson, KY	172	215	207	124	162	84	114	165	177
Todd, KY	214	175	182	143	204	127	133	105	220
Trigg, KY	235	123	131	164	225	147	153	79	240
Warren, KY	180	228	227	145	170	101	134	143	185
Wayne, KY	115	320	312	143	105	97	142	270	121

Source: Google Maps

Table 3.3. Mean, Standard Deviation, and Coefficient of Variation of the Distances (in miles) from each County to each Potential Condensing Plant

Potential Condensing Plant	Mean	Standard Deviation	Coefficient of Variation
DeKalb	118.78	59.84	0.50
Warren	124.91	60.78	0.49
Cumberland	126.18	63.54	0.50
Coffee	127.63	64.79	0.51
Rutherford	128.00	71.66	0.56
Grundy	131.24	66.14	0.50
Rhea	140.04	71.01	0.51
Roane	140.76	68.60	0.49
Maury	143.02	76.43	0.53
Meigs	143.23	73.11	0.51
Loudon	155.43	77.91	0.50
Blount-Rockford	166.06	82.70	0.50
Blount-Alcoa	167.02	83.56	0.50
Humphreys	172.44	85.90	0.50
Carroll	211.34	99.80	0.47
Haywood	236.90	93.87	0.40
Crockett	251.90	100.70	0.40
Dyer	258.08	103.43	0.40

Table 3.4. Distances (in miles) from Potential Condensing Plant to Value-Added Producers

Potential Condensing Plant	Yogurt in Murfreesboro, TN	Ice Cream in Covington, TN
Haywood	180	26
Humphreys	95	131
Maury	42	174
Rutherford	4	205
Warren	44	249
Blount-Alcoa	189	361
Blount-Rockford	189	361
Cumberland	115	287
Loudon	177	350
Rhea	112	331
Dyer	201	40
Crockett	192	39
Grundy	49	254
Roane	143	315
DeKalb	46	243
Coffee	39	244
Carroll	151	92
Meigs	125	336

Source: Google Maps

Table 3.5. Mean, Standard Deviation, and Coefficient of Variation of the Distances (in miles) from Potential Condensing Plant to Value-Added Producers

Potential Condensing Plant	Mean Distance	Standard Deviation	Coefficient of Variation
Haywood	103.20	76.80	0.74
Rutherford	104.50	100.50	0.96
Maury	108.00	66.00	0.61
Humphreys	112.95	18.05	0.16
Crockett	115.25	76.75	0.67
Dyer	120.60	80.40	0.67
Carroll	121.25	29.75	0.25
Coffee	141.25	102.75	0.73
DeKalb	144.30	98.70	0.68
Warren	146.30	102.70	0.70
Grundy	151.35	102.65	0.68
Cumberland	201.00	86.00	0.43
Rhea	221.50	109.50	0.49
Roane	229.00	86.00	0.38
Meigs	230.50	105.50	0.46
Loudon	263.50	86.50	0.33
Blount-Alcoa	275.00	86.00	0.31
Blount-Rockford	275.00	86.00	0.31

Table 4.1. Pounds of Milk Sent to Rutherford County Potential Condensing Plant by Supplying County and County Seat in Base Scenario.

Location (County)	County Seat	Pounds of Milk
Tennessee Counties		
McMinn	Athens	41,965,103
Marshall	Lewisburg	29,514,670
Polk	Benton	26,283,126
Maury	Columbia	21,233,967
Robertson	Springfield	20,193,353
White	Sparta	20,125,340
Henry	Paris	18,285,560
Bradley	Cleveland	16,174,498
Warren	McMinnville	13,959,871
Bedford	Shelbyville	13,500,776
Lawrence	Lawrenceburg	10,147,687
Coffee	Manchester	8,596,968
Overton	Livingston	7,015,643
Lincoln	Fayetteville	6,634,764
Meigs	Decatur	6,128,334
Sumner	Gallatin	5,478,527
Putnam	Cookeville	4,910,610
Franklin	Winchester	4,628,352
Bledsoe	Pikeville	4,138,651
Wilson	Lebanon	3,876,797
Rutherford	Murfreesboro	3,839,390
Williamson	Franklin	3,383,696
Smith	Carthage	3,138,845
Giles	Pulaski	3,019,821
Roane	Kingston	2,134,159
Grundy	Altamont	1,479,304
Fentress	Jamestown	1,333,074
Humphreys	Waverly	1,057,617
Marion	Jasper	1,041,053

Table 4.1. Continued

Location (County)	County Seat	Pounds of Milk
Alabama Counties		
Cullman, AL	Cullman	18,479,400
Morgan, AL	Decatur	16,506,995
De Kalb, AL	Fort Payne	2,951,807
Kentucky Counties		
Barren, KY	Glasgow	95,896,321
Logan, KY	Russellville	67,303,241
Todd, KY	Elkton	38,472,112
Warren, KY	Bowling Green	32,694,324
Christian, KY	Hopkinsville	32,687,522
Monroe, KY	Tompkinsville	27,960,550
Metcalfe, KY	Edmonton	22,060,337
Simpson, KY	Franklin	7,848,814
Trigg, KY	Cadiz	5,087,446
Allen, KY	Scottsville	3,808,783
Wayne, KY	Monticello	1,818,373

Potential milk supplying Tennessee counties that supplied no milk to the Rutherford County location: Blount, Carter, Cocke, Gibson, Grainger, Greene, Hamblen, Jefferson, Johnson, Loudon, Monroe, Obion, Sullivan, and Weakley Counties.

Potential milk supplying Alabama counties that supplied no milk to the Rutherford County location: Etowah and Franklin Counties.

Potential milk supplying Kentucky counties that supplied no milk to the Rutherford County location: Adair, Graves, Laurel, Pulaski, and Russell Counties.

Table 4.2. Ranking of the Possible Milk Condensing Plants When Sourcing from Tennessee and the Surrounding Region in Base Scenario.

Rank	**County**	**Total Shipping Cost (in $)**	**Percent Above Optimal Location (in %)**
1	Rutherford	6,181,829	Optimal
2	Maury	6,438,155	4
3	DeKalb	6,535,259	6
4	Humphreys	7,004,825	13
5	Coffee	7,218,584	17
6	Warren	7,266,386	18
7	Cumberland	7,334,063	19
8	Grundy	7,523,976	22
9	Carroll	8,190,705	32
10	Roane	8,289,635	34
11	Rhea	8,396,103	36
12	Meigs	8,525,868	38
13	Haywood	9,066,630	47
14	Loudon	9,203,448	49
15	Crockett	9,672,244	56
16	Alcoa, Blount	9,810,527	59
17	Rockford, Blount	9,813,813	59
18	Dyer	9,869,392	60

Table 4.3. Fluid Milk, Nonfat Dry Milk, and Cream Transportation Costs of the Possible Milk Condensing Plants When Sourcing from Tennessee and the Surrounding Region in Base Scenario.

County	**Fluid Milk Shipping Cost**		**Nonfat Dry Milk Shipping Cost**		**Cream Shipping Cost**	
	(in $)	(% of total cost)	(in $)	(% of total cost)	(in $)	(% of total cost)
Rutherford	3,878,422	63%	5,821	0%	2,297,586	37%
Maury	4,426,887	69%	61,123	1%	1,950,146	30%
DeKalb	3,745,417	57%	66,362	1%	2,723,480	42%
Humphreys	5,398,504	77%	138,108	2%	1,465,213	21%
Coffee	4,427,868	61%	56,029	1%	2,734,687	38%
Warren	4,412,209	61%	63,451	1%	2,790,726	38%
Cumberland	3,950,083	54%	167,360	2%	3,216,620	44%
Grundy	4,606,339	61%	70,873	1%	2,846,765	38%
Carroll	6,945,447	85%	219,750	3%	1,025,508	13%
Roane	4,551,091	55%	208,108	3%	3,530,436	43%
Rhea	4,523,349	54%	162,994	2%	3,709,760	44%
Meigs	4,578,157	54%	181,913	2%	3,765,799	44%
Haywood	8,508,791	94%	261,954	3%	295,884	3%
Loudon	5,023,153	55%	257,588	3%	3,922,707	43%
Crockett	8,961,329	93%	279,418	3%	431,498	4%
Alcoa, Blount	5,489,483	56%	275,052	3%	4,045,992	41%
Rockford, Blount	5,492,769	56%	275,052	3%	4,045,992	41%
Dyer	9,126,326	92%	292,515	3%	450,551	5%

Table 4.4. Pounds of Milk Sent to Rutherford County Potential Condensing Plant by Supplying County and County Seat in Tennessee First Scenario.

Location (County)	County Seat	Pounds of Milk
Tennessee Counties		
McMinn	Athens	43,505,618
Greene	Greeneville	33,768,299
Loudon	Loudon	32,033,210
Marshall	Lewisburg	29,514,670
Polk	Benton	26,283,126
Monroe	Madisonville	25,967,340
Maury	Columbia	21,233,967
Robertson	Springfield	20,193,353
White	Sparta	20,125,339
Henry	Paris	18,285,560
Bradley	Cleveland	16,174,498
Warren	McMinnville	13,959,871
Bedford	Shelbyville	13,500,776
Jefferson	Dandridge	12,843,128
Lawrence	Lawrenceburg	10,147,687
Coffee	Manchester	8,596,968
Cocke	Newport	7,828,721
Hamblen	Morristown	7,301,254
Overton	Livingston	7,015,643
Lincoln	Fayetteville	6,634,764
Blount	Maryville	6,586,397
Meigs	Decatur	6,128,334
Sumner	Gallatin	5,478,527
Putnam	Cookeville	4,910,610
Franklin	Winchester	4,628,352
Sullivan	Blountville	4,233,617
Bledsoe	Pikeville	4,138,651
Wilson	Lebanon	3,876,797
Rutherford	Murfreesboro	3,839,390
Williamson	Franklin	3,383,696
Gibson	Trenton	3,254,469
Smith	Carthage	3,138,845
Giles	Pulaski	3,019,821
Weakley	Dresden	2,951,807
Grainger	Rutledge	2,800,433
Roane	Kingston	2,134,159
Carter	Elizabethton	1,561,580
Grundy	Altamont	1,479,304
Fentress	Jamestown	1,333,074
Humphreys	Waverly	1,057,617

Table 4.4. Continued

Location (County)	County Seat	Pounds of Milk
Tennessee Counties, continued		
Marion	Jasper	1,041,053
Obion	Union City	367,276
Johnson	Mountain City	145,747
Kentucky Counties		
Barren, KY	Glasgow	80,264,957
Logan, KY	Russellville	67,303,241
Todd, KY	Elkton	38,472,112
Warren, KY	Bowling Green	32,694,324
Simpson, KY	Franklin	7,848,814
Allen, KY	Scottsville	3,808,783

All five potential milk supplying Alabama counties supply no milk to the Rutherford County location.

Potential milk supplying Kentucky counties that supplied no milk to the Rutherford County location: Adair, Christian, Graves, Laurel, Metcalfe, Monroe, Pulaski, Russell, Trigg, and Wayne Counties.

Table 4.5. Ranking of the Possible Milk Condensing Plants When Sourcing from Tennessee and the Surrounding Region in Tennessee First Scenario.

Rank	**County**	**Total Shipping Cost (in $)**	**Percent Above Optimal Location (in %)**
1	Rutherford	6,985,357	Optimal
2	DeKalb	7,025,536	1
3	Maury	7,409,347	6
4	Cumberland	7,539,590	8
5	Warren	7,560,370	8
6	Coffee	7,649,408	10
7	Humphreys	7,922,506	13
8	Grundy	7,925,346	13
9	Roane	8,509,803	22
10	Rhea	8,587,518	23
11	Meigs	8,705,345	25
12	Carroll	9,347,306	34
13	Loudon	9,436,050	35
14	Alcoa, Blount	10,012,546	43
15	Rockford, Blount	10,036,891	44
16	Haywood	10,305,315	47
17	Crockett	10,840,051	55
18	Dyer	11,039,606	58

Table 4.6. Fluid Milk, Nonfat Dry Milk, and Cream Transportation Costs of the Possible Milk Condensing Plants When Sourcing from Tennessee and the Surrounding Region in Tennessee First Scenario.

County	**Fluid Milk Shipping Cost**		**Nonfat Dry Milk Shipping Cost**		**Cream Shipping Cost**	
	(in $)	(% of total cost)	(in $)	(% of total cost)	(in $)	(% of total cost)
Rutherford	4,681,950	67%	5,821	0%	2,297,586	33%
DeKalb	4,235,694	60%	66,362	1%	2,723,480	39%
Maury	5,398,078	73%	61,123	1%	1,950,146	26%
Cumberland	4,155,610	55%	167,360	2%	3,216,620	43%
Warren	4,706,193	62%	63,451	1%	2,790,726	37%
Coffee	4,858,692	64%	56,029	1%	2,734,687	36%
Humphreys	6,316,185	80%	138,108	2%	1,468,213	19%
Grundy	5,007,708	63%	70,873	1%	2,846,765	36%
Roane	4,771,259	56%	208,108	2%	3,530,436	41%
Rhea	4,714,764	55%	162,994	2%	3,709,760	43%
Meigs	4,757,634	55%	181,913	2%	3,765,799	43%
Carroll	8,102,048	87%	219,750	2%	1,025,508	11%
Loudon	5,255,755	56%	257,588	3%	3,922,707	42%
Alcoa, Blount	5,691,502	57%	275,052	3%	4,045,992	40%
Rockford, Blount	5,715,847	57%	275,052	3%	4,045,992	40%
Haywood	9,747,476	95%	261,954	3%	295,884	3%
Crockett	10,129,136	93%	279,418	3%	431,498	4%
Dyer	10,296,540	93%	292,515	3%	450,551	4%

Table 4.7. Pounds of Milk Sent to Haywood County Potential Condensing Plant by Supplying County and County Seat in Close to Covington Scenario.

Location (County)	County Seat	Pounds of Milk
Tennessee Counties		
Marshall	Lewisburg	29,514,670
Maury	Columbia	21,233,967
Robertson	Springfield	20,193,353
White	Sparta	20,125,339
Henry	Paris	18,285,560
Warren	McMinnville	13,959,871
Bradley	Cleveland	14,093,032
Bedford	Shelbyville	13,500,776
Lawrence	Lawrenceburg	10,147,687
Coffee	Manchester	8,596,968
Overton	Livingston	7,015,643
Lincoln	Fayetteville	6,634,764
Sumner	Gallatin	5,478,527
Putnam	Cookeville	4,910,610
Franklin	Winchester	4,628,352
Bledsoe	Pikeville	4,138,651
Wilson	Lebanon	3,876,797
Rutherford	Murfreesboro	3,839,390
Williamson	Franklin	3,383,696
Gibson	Trenton	3,254,469
Smith	Carthage	3,138,845
Giles	Pulaski	3,019,821
Weakley	Dresden	2,951,807
Roane	Kingston	2,134,159
Grundy	Altamont	1,479,304
Fentress	Jamestown	1,333,074
Humphreys	Waverly	1,057,617
Marion	Jasper	1,041,053
Obion	Union City	367,276

Table 4.7. Continued

Location (County)	County Seat	Pounds of Milk
Alabama Counties		
Cullman, AL	Cullman	18,479,400
Morgan, AL	Decatur	16,506,995
De Kalb, AL	Fort Payne	2,951,807
Etowah, AL	Gadsden	2,723,960
Franklin, AL	Russellville	680,140
Kentucky Counties		
Barren, KY	Glasgow	95,896,321
Logan, KY	Russellville	67,303,241
Adair, KY	Columbia	46,430,978
Todd, KY	Elkton	38,472,112
Warren, KY	Bowling Green	32,694,324
Christian, KY	Hopkinsville	32,687,522
Monroe, KY	Tompkinsville	27,960,550
Metcalfe, KY	Edmonton	22,060,337
Russell, KY	Jamestown	18,287,837
Simpson, KY	Franklin	7,848,814
Trigg, KY	Cadiz	5,087,446
Allen, KY	Scottsville	3,808,783
Wayne, KY	Monticello	1,818,373
Graves, KY	Mayfield	1,761,562

Potential milk supplying Tennessee counties that supplied no milk to the Haywood County location: Blount, Carter, Cocke, Grainger, Greene, Hamblen, Jefferson, Loudon, McMinn, Meigs, Monroe, Polk, and Sullivan Counties.

Potential milk supplying Kentucky counties that supplied no milk to the Rutherford County location: Laurel and Pulaski Counties.

Table 4.8. Ranking of the Possible Milk Condensing Plants When Sourcing from Tennessee and the Surrounding Region in Close to Covington Scenario.

Rank	County	Total Shipping Cost (in $)	Percent Above Optimal Location (in %)
1	Haywood	9,066,630	Optimal
2	Crockett	9,672,244	7
3	Dyer	9,869,392	9

Table 4.9. Fluid Milk, Nonfat Dry Milk, and Cream Transportation Costs of the Possible Milk Condensing Plants When Sourcing from Tennessee and the Surrounding Region in Close to Covington Scenario.

County	**Fluid Milk Shipping Cost**		**Nonfat Dry Milk Shipping Cost**		**Cream Shipping Cost**	
	(in $)	(% of total cost)	(in $)	(% of total cost)	(in $)	(% of total cost)
Haywood	8,508,791	94%	261,954	3%	295,884	3%
Crockett	8,961,329	93%	279,418	3%	431,498	4%
Dyer	9,126,326	92%	292,515	3%	450,551	5%

Table 4.10. Ranking of the Possible Milk Condensing Plants When Sourcing from Tennessee and the Surrounding Region in East Tennessee Traffic Scenario.

Rank	County	Total Shipping Cost (in $)	Percent Above Base Scenario (in %)
1	Rutherford	6,331,449	2.42
2	Maury	6,495,809	0.90
3	DeKalb	6,885,838	5.36
4	Humphreys	7,053,982	0.70
5	Coffee	7,500,744	3.91
6	Warren	7,659,748	5.41
7	Grundy	7,977,720	6.03
8	Cumberland	8,096,694	10.40
9	Carroll	8,231,351	0.50
10	Rhea	8,976,084	6.91
11	Meigs	9,078,910	6.49
12	Roane	9,092,965	9.69
13	Haywood	9,109,057	0.48
14	Loudon	9,586,535	7.10
15	Crockett	9,716,982	0.46
16	Dyer	9,913,984	0.45
17	Alcoa, Blount	10,553,315	7.57
18	Rockford, Blount	10,625,468	8.27

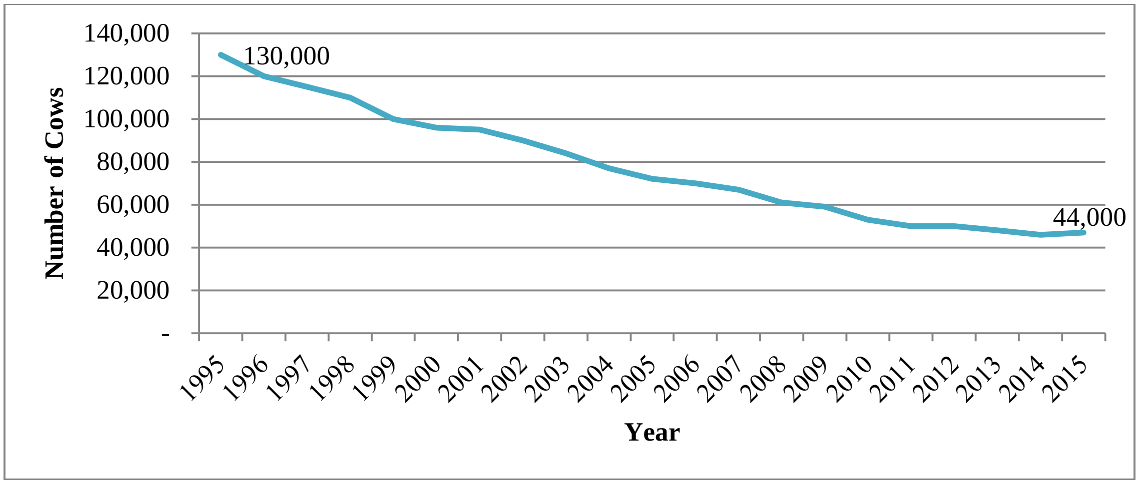

Figure 1.1. Number of Dairy Cows in Tennessee, 1995-2015.

Source: Hughes et al., 2016 based on U.S. Department of Agriculture, National Agricultural Statistical Service, 2016.

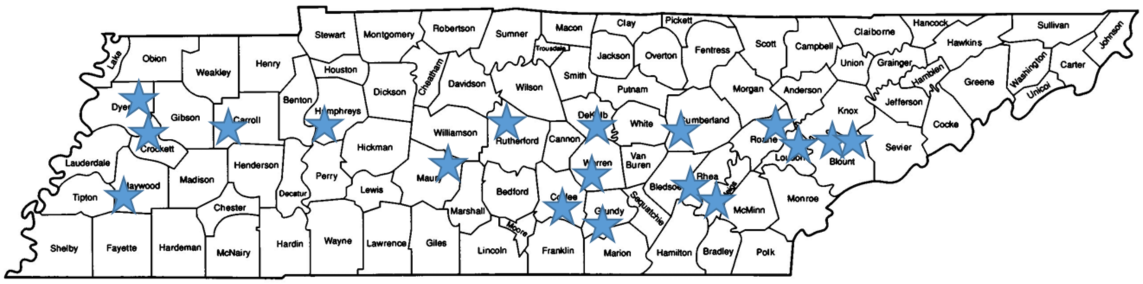

Figure 3.1. Potential Condensing Plant Locations (designated by blue stars)

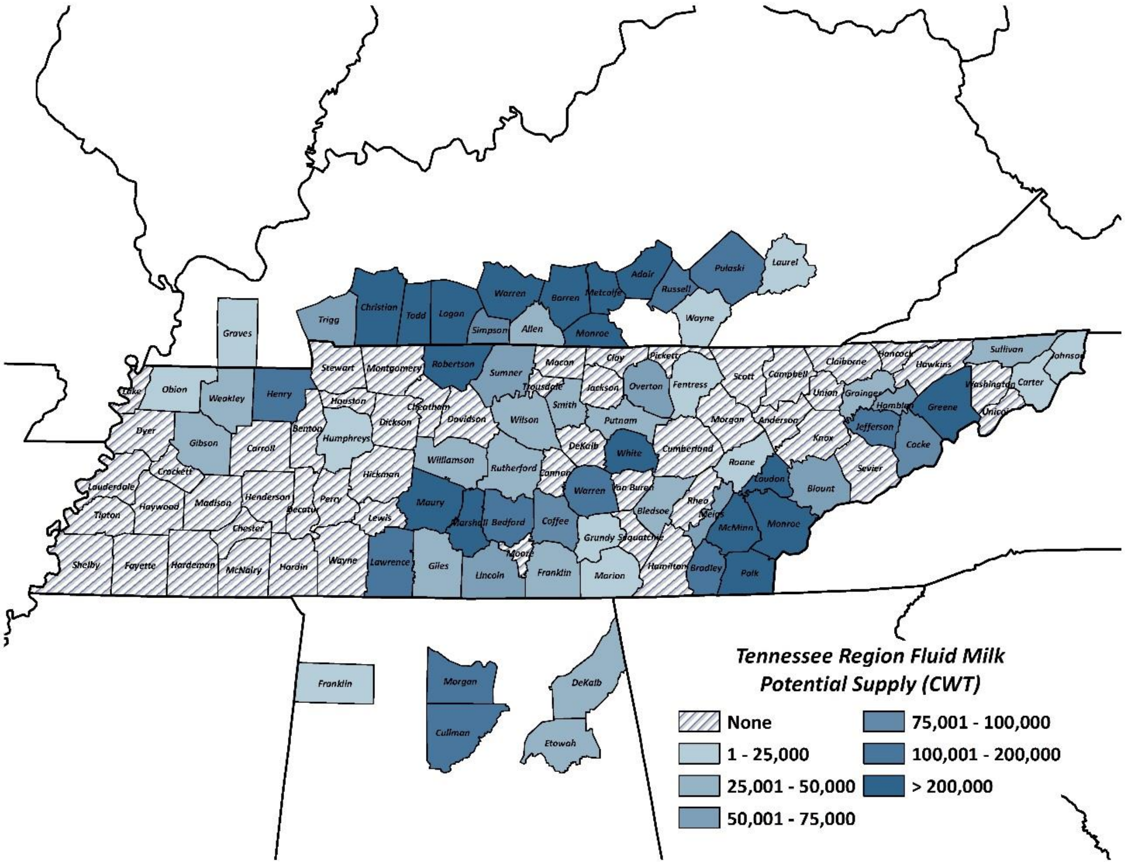

Figure 3.2. Potential Supply of Fluid Milk by County in Tennessee and the Surrounding Region

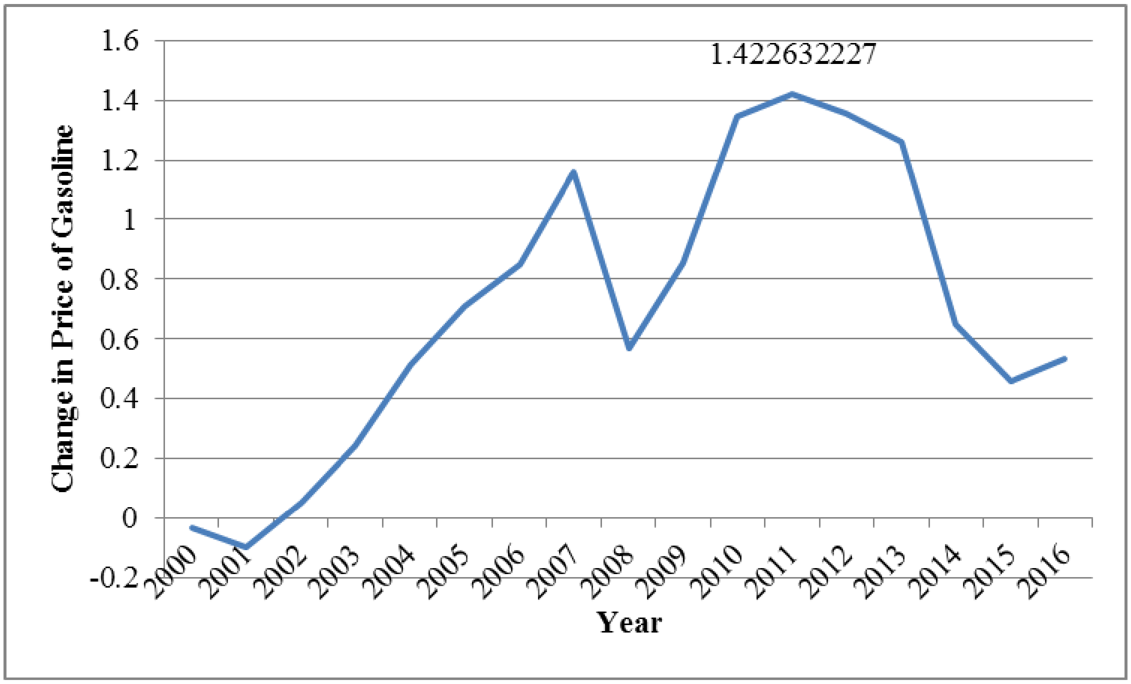

Figure 3.3. Changes in U.S. December Gasoline Prices from 2000 to 2017, Indexed to December 2000

Source: U.S. Bureau of Labor Statistics

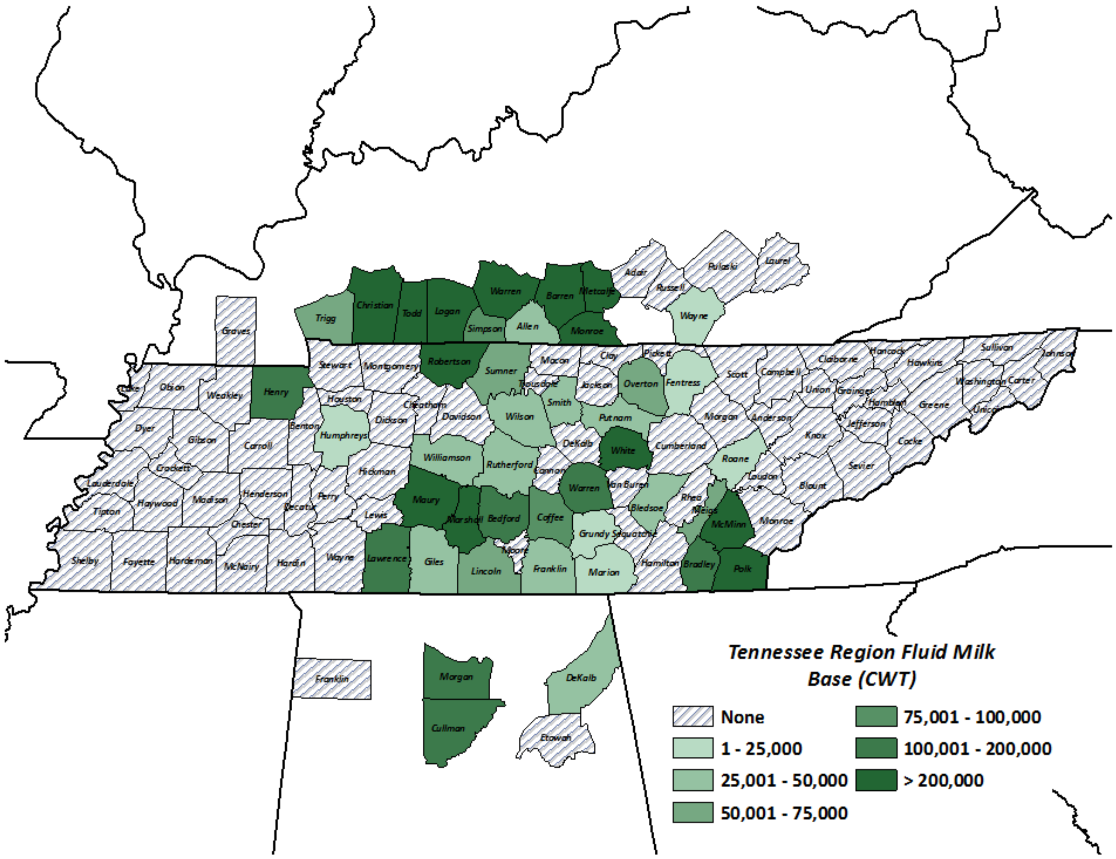

Figure 4.1. Fluid Milk Sent to Rutherford County Potential Condensing Plant under the Base Scenario

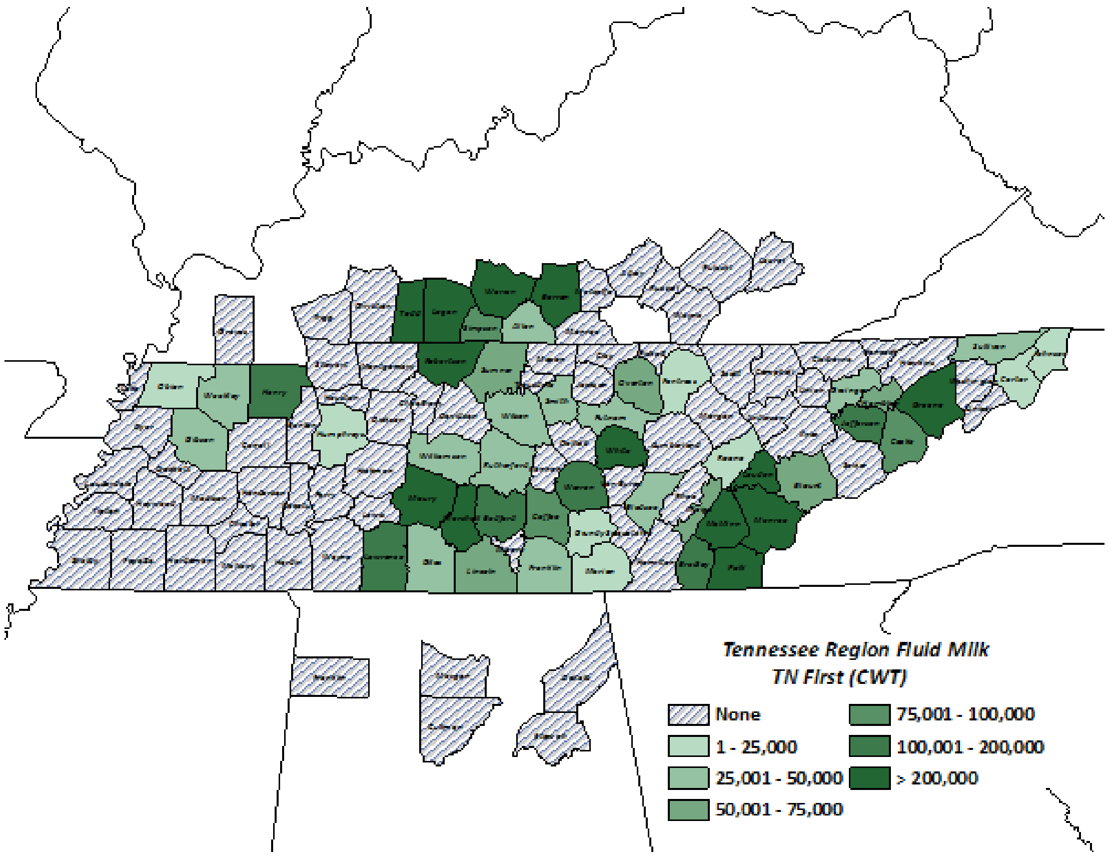

Figure 4.2. Fluid Milk Sent to Rutherford County Potential Condensing Plant under the Tennessee First Scenario

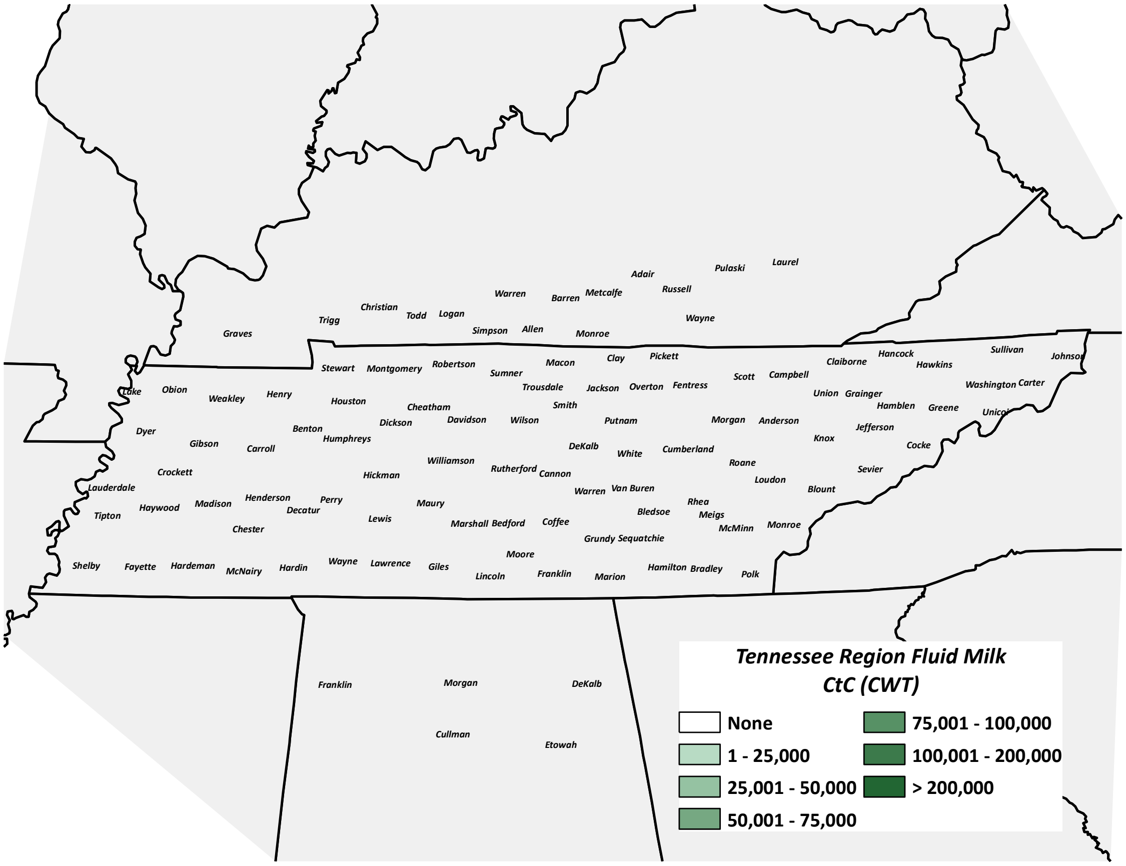

Figure 4.3. Fluid Milk Sent to Rutherford County Potential Condensing Plant under the Close to Covington Scenario

VITA

David Mendez was born on February 24th, 1993 in Voorhees Township, New Jersey. In the Fall of 2011 after completing high school, he began his undergraduate studies at Clemson University in Clemson, South Carolina. In the Spring of 2015, he graduated with a Bachelor of Science degree in Environmental and Natural Resources with a concentration in Economics and Policy and a minor in Business Administration. In the Fall of 2015, he began his graduate studies at the University of Tennessee-Knoxville. He plans to graduate with a Masters of Science degree in Agricultural and Natural Resource Economics with a concentration in Agricultural Economics in the Summer of 2017.