Developing a Spatial Transport Model to Determine Optimal Routes When Delivering Unprocessed Milk

Sunday Nanosi Ndovi, Patrick Albert Chikumba

Abstract**—**In Malawi, smallholder dairy farmers transport unprocessed milk to sell at Milk Bulking Groups (MBGs). MBGs store and chill the milk while awaiting collection by processors. The farmers deliver milk using various modes of transportation such as foot, bicycle, and motorcycle. As a perishable food, milk requires timely transportation to avoid deterioration. In other instances, some farmers bypass nearest MBGs for facilities located further. Untimely delivery worsens quality and results in rejection at MBG. Subsequently, these rejections lead to revenue losses for dairy farmers. Therefore, the objective of this study was to optimize routes when transporting milk by selecting the shortest route using time as a cost attribute in Geographic Information Systems (GIS). A spatially organized transport system impedes milk deterioration while promoting profitability to dairy farmers. A transportation system was modeled using Route Analysis and Closest Facility network extensions. The final output was to find quickest routes and identify nearest milk facilities from incidents. Face-to-face interviews targeted leaders from all 48 MBGs in the study area and 50 farmers from Namahoya MBG. During field interviews, coordinates were captured in order to create maps. Subsequently, maps supported selection of optimal routes based on least travel times. Questionnaire targeted 200 respondents. Out of the total, 182 respondents were available. Findings showed that out of the 50 sampled farmers that supplied milk to Namahoya, only 8% were nearest to the facility while 92% were closest to 9 different MBGs. Delivering milk to nearest MBGs would minimize travel time and distance by 14.67 hours and 73.37 km respectively.

Keywords**—**Closest facility, milk, route analysis, spatial transport.

I. Introduction

PERISHABLE foods must be transported to the processing plant in the fastest time possible due to deterioration that is triggered by room temperature and delivery time [1]. To deliver the raw food on time, one has to select the optimal route that generally reduces travel distance [2]. Subsequently, the deterioration of foods is minimized leading to positive payoffs to stakeholders particularly dairy farmers within the supply chain. To achieve timely delivery, [3] asserts that modelling a road network in GIS supports decision-making in selecting the shortest route.

Malawian dairy industry is an important investment subsector for the Government of Malawi [4]. It plays a vital role in social economic development of smallholder dairy farmers by providing food, revenue, jobs, and social security [5]. Milk and Milk Product Act Cap. 67:05, Laws of Malawi stipulate that the transportation of milk and milk products is the sole responsibility of dairy farmers, MBGs, and processors. Furthermore, it states that the Government shall not subsidize costs related to transporting. That necessitated optimization of routes using GIS in the transport network.

Milk is transported between two or more geographical locations by one or mixed modes of transport to reach the destination. Related studies focused on milk transportation problems between collection centers and processing plants. Some of these studies include those conducted by [6] and [7]. However, this study focused on the milk transportation problem between the dairy farms and the milk collection centers in Malawi.

Decades' worth of studies conducted in Malawi's dairy industry have argued that there are myriad problems in the dairy industry. Some of these which are related to this study include ineffective supply chain [8], poor quality of milk with estimated rejection rate of 17% [8], transport problems [9] and farmers operating outside recommended 8 km radius from milk collection centers [10], [11]. However, there is little evidence to show a solution and implementation to resolve the listed constraints. Therefore, this research sought to contribute actions towards addressing the aforementioned problems, particularly transport problems by optimizing routes using GIS technology.

The main objective of this study was to optimize routes when transporting unprocessed milk from the farms and to the MBGs using GIS. GIS calculated time-taken and distance-covered between farms and MBGs. Subsequently, GIS model selected the shortest route from every farm to its nearest MBG. Eventually, this information would then assist farmers in making informed decisions like estimating transit time while using a specific mode of travel. To address the main aim, it was paramount to develop a spatial transport model to determine optimal routes.

II. Literature Review

A study by [12] in India suggests that introduction of GIS in the dairy industry is crucial. It provides real time information that leads to making informed decisions. GIS offers a set of capabilities in dealing with spatially referenced points, related data and information. Implication is that an efficient and effective logistics system of unprocessed milk requires a better understanding of spatial distribution of milk collection centers in relation to both dairy farms and processing plants. This is possible with the aid of computer-based GIS systems. Similarly, in this study, farms and MBGs are spatially

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referenced features used as nodes in a road network to find shortest path(s) leading to enlightened decisions.

In Mongolia, [13] reveals that the GIS mathematical optimization model reduces travel distance in a milk distribution network. This is achieved by finding quickest routes in a road network. Conversely, route optimization is attained by mapping farms, MBGs and roads. This will help farmers to appreciate shortening of time in relation to distance since maps in GIS offer graphical reports.

In finding strategies for smooth transportation of unprocessed milk to the processor by [14] in Tanzania, the investigator uncovered one milk collection center that had closed due to disproportionality between high running costs of the center and low milk collection. The author argues that closing the facility was necessary due to poor business returns and advised farmers to sell milk in informal markets. Findings and recommendations excluded GIS as a transportation solver to solidify the claims. The GIS based transportation system schedules routes using the Vehicle Routing Problem (VRP) extension that guides how to optimize assignment of vehicle capacity and sequence visits to milk collection centers.

Related studies focused on transportation between the milk collection centers and the processing plants using VRP while disregarding farms in the milk value chain [15], [16]. The farms are the source in the supply chain hence very crucial. The milk transportation problem can only be complete if smallholder dairy farmers and any type of roads involved are incorporated. Therefore, this study modeled a system using Route Analysis and Closest Facility Analysis to solve a transportation problem.

Route Analysis is a routing solver within Network Analyst in ArcMap environment based on Dijkstra's algorithm. It finds the shortest route by factoring in starting point to ending point following a sequence of rules [17]. Likewise, the route consists of a one-way trip from the source to the destination of unprocessed milk. In this study, the route started at the farm and ended at the MBG. Rules were where to turn on junctions, path to follow and closest possible MBGs to deliver milk from a set of options.

Reference [18] highlights that there is direct and substantial impact between transportation, social and economic growth in rural Malawi. However, rural transportation is planned in a disintegrated way coupled with a non-holistic approach. Thyolo district, a location of this study, is classified as a rural area in Malawi. According to [19], the country is predominantly rural based with an estimation of 84 % of the total population living in rural areas.

Reference [20] categorizes roads as main, secondary, tertiary, district and others. Villages that make rural areas connect to the classified roads using unclassified feeder paths. Transportation is concerned with speed that has factors of *distance* and *time*. Speed is the amount of distance traveled divided by time taken. Anecdotally, speed on the roads varies due to volume of traffic, roughness of the road, elevation of the terrain, direction of wind blowing, age-group, torque (for bicycle/motorcycle/car) among others irrespective of mode of transport. In Malawi, speeds in existence are those for classified roads and little evidence on unclassified paths.

Closest Facility measures the impedance between the incident and the facility; and identifies which facilities are nearest from the incident [21]. This infers that dairy farms are source of unprocessed milk while MBGs are destinations. Closest facility determines the nearest facility from the incident. According to [22], this is guided by the following equation

$$r(C) \leq 2 * OPT \tag{1}$$

where r is the radius, C is the cost, 2 is approximated number of solutions and OPT are the Options

To find the nearest facility, the algorithm selects the first center C at random. Then selects the next center at random again whose length from C is greater than 2 by r. The process is repeated for all facilities using all vertices in the data set until all costs are calculated. Subsequently, the least distance is selected as the nearest facility from the incident. Therefore, contextually, (1) selected the middle point of the farm. Then it chose the next center for MBG whose distance was greater than 2 by following a set containing all vertices. Distances were calculated and compared where the shortest length between farm and MBG was selected hence closest milk facility.

Decision Theory underpinned this study as it determined best selection from possible available options where consequences were certainly unpredictable. A transport model was designed to provide information on transit time and distance covered by farmers when delivering milk to MBGs. A model selected the route with least metrics from all candidate routes. This helped solve milk transportation problems from a social economic point of view through four Decision Theory constructs, namely: - acts, events, outcomes and payoffs.

III. Methodology

A. Location of Study

The study area is Thyolo District in Malawi and it involves delivery of unprocessed milk from farms to MBGs on a road network. The district covers an area of 1,666 km² with population density of 433.0/km² [23]. Much of the land is covered with tea, coffee and macadamia estates. It has a population of 587 452 of which the percentage of dairy farmers is unclear.

B. Data Collection

Data collection constituted interviews, questionnaires and capturing of coordinates for farms and MBGs. Semi-structured interviews were conducted in order to understand transportation challenges that smallholders face. The interviewees were those that were presumed influential, knowledgeable, experienced, available and willing to participate. The interview targeted 50 farmers from Namahoya MBG and all leaders from 48 MBGs in the study location. Respondents were physically visited in their natural settings. In the processing, coordinates were captured with the objective of creating thematic maps in GIS.

Smallholder dairy farmers are already clustered in cooperatives known as MBGs. The study questionnaire targeted 50 farmers from each of the four MBGS. The four were Goliati, Nakhwakwe, Namahoya and Okhalhavo totaling 200 farmers as given in Table I.

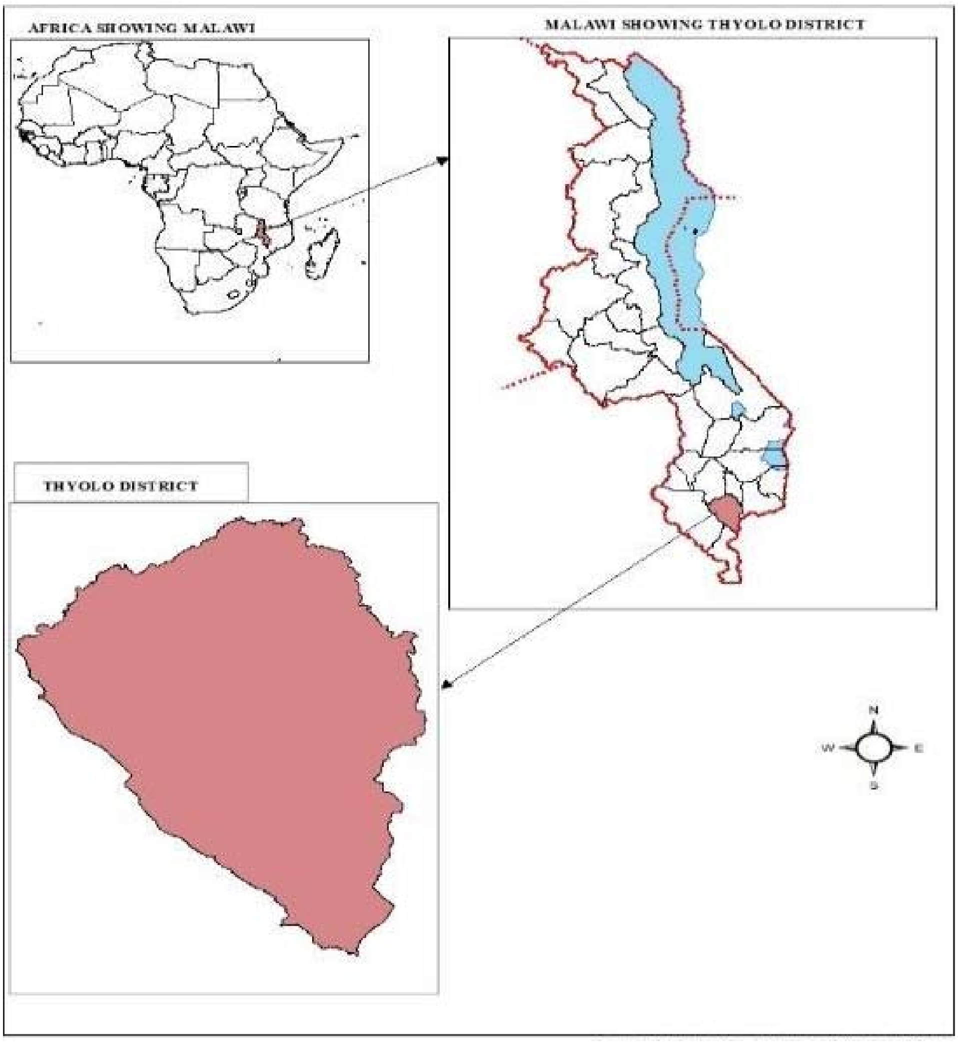

Fig. 1 Map showing location of Thyolo district in Malawi

TABLE I
MBGS AGAINST TARGET POPULATION

MBG Name	Target Population
Goliati	50
Nakhwakwe	50
Namahoya	50
Okhalhavo	50
Total	200

C. Geoprocessing

Cadastral map of Malawi was digitized from satellite imagery using freehand in order to produce layers such as road network, rivers, landcover, landuse, district and international boundaries. The purpose of creating a road network was to connect farms and MBGs through roads. Fig. 2 shows the digitized road network in Thyolo. The resultant shape files were stored in a geodatabase that was created so as to optimize file sharing, compression and updating.

D. Transport Model

A transport model was designed using the collected data such as coordinates, road network, land usage and land coverage. It was achieved by using Route Analysis and Closest Facility Analysis. Fig. 3 shows a design of a transport model in a flow chart format.

IV. Results and Discussion

A. Mode of Transport

The questionnaire interrogated farmers on most used modes of travel and it was categorized into foot, bicycle, motorcycle, ox-cart, vehicle and wheelbarrow. Findings showed that farmers transport milk on foot, by bicycle or by motorcycle. Alternation of the three modes of travel was also observed. For example, on certain days, milk was delivered on foot while on other days by bicycle. In most cases, this happened when the bicycle was dysfunctional. Fig. 4 shows the number of farmers against modes of transport.

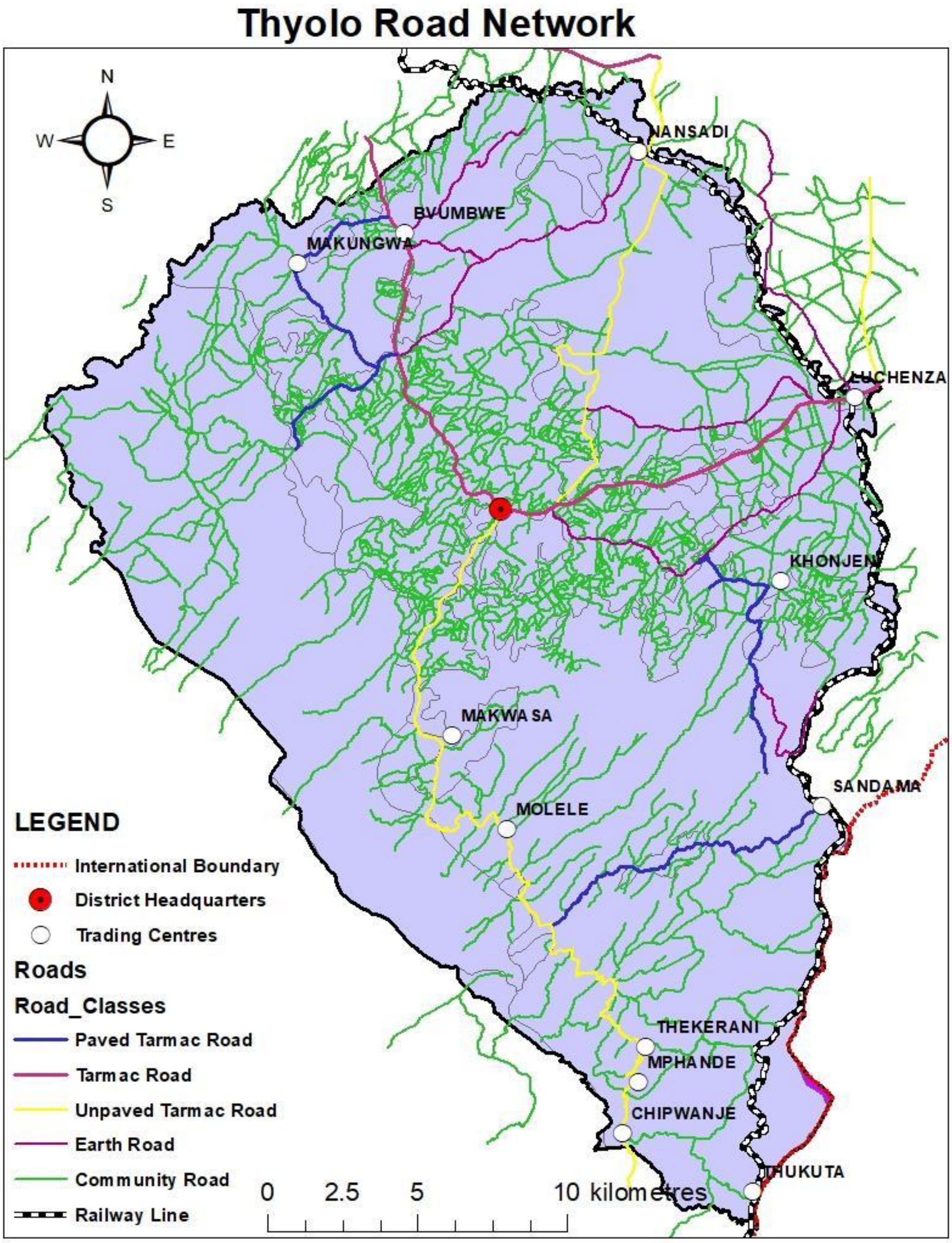

Fig. 2 Thyolo Road network

Findings in Fig. 4 showed that out of 50 farmers, 5 transported milk on bicycles representing 10% while 41 traveled on foot representing 81%. Only 4 used motorcycles representing 8% and no-one transported milk by ox-cart nor vehicle nor wheelbarrow. Results indicated that walking was the most used mode of transport. The revelation is in agreement with findings by [24].

B. Route Analysis

Running a new route using Network Analysis in GIS produced the quickest route between farm and MBG. Therefore, in Fig. 5, the route is marked blue between farm10 and Namahoya MBG. Results estimated that the farmer took 0.86 hours to cover a distance of 4.35 km. Consequently, the model selected the shortest routes and calculated times taken against distances covered from all farms to Namahoya.

Digitized road network in Thyolo is 447.9 kilometers long with an estimated walking time of 89.57 hours at 5 km/hour. Although the study involved other modes of transport such as bicycling, motorcycling among others, route analysis focused on walking because it is the commonest. Therefore, 5 km/hour was the adopted speed for farmers who walked to the MBG.

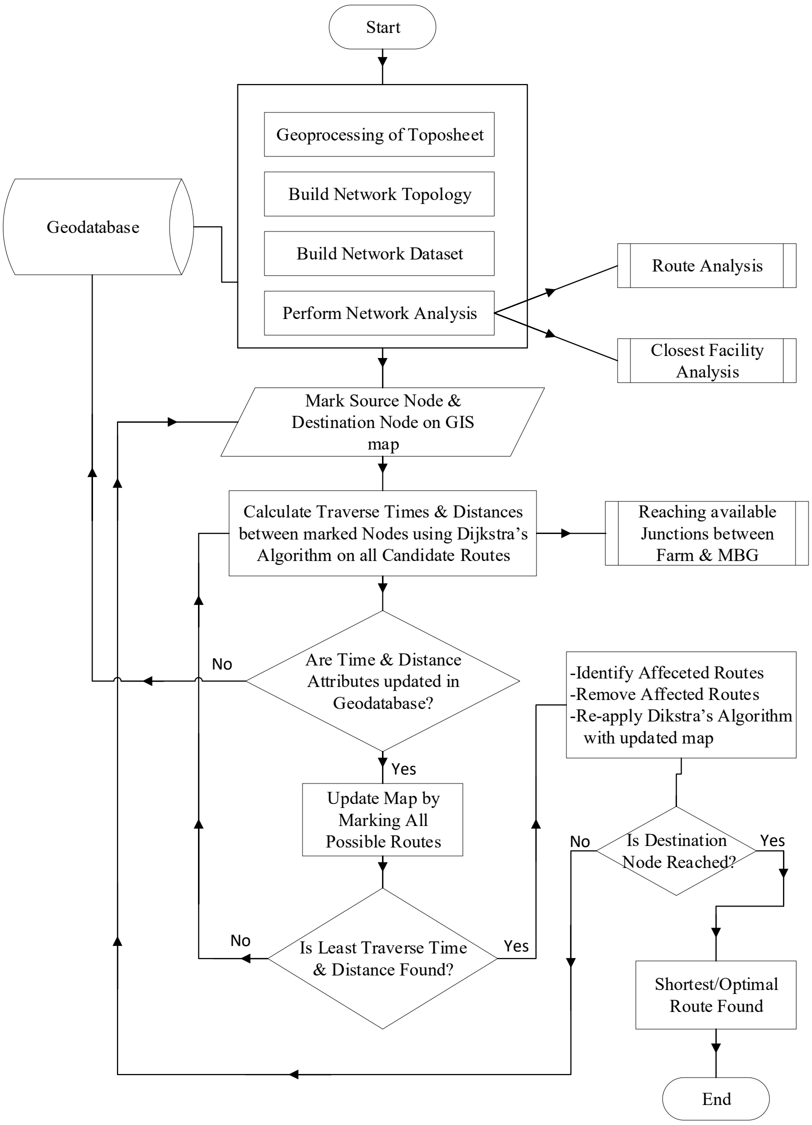

Fig. 3 Transport Model Presented in Flow Chart

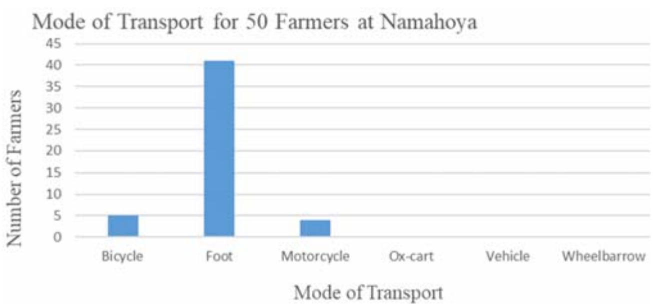

Fig. 4 Number of Farmers Against Mode of Milk Transportation

C. Closest Facility Analysis

Closest Facility Analysis identified nearest MBGs from farms using the road network while considering land cover and land usage. The network layer selected the shortest route and determined the nearest three MBGs. Three was the researcher's preference as it can be any number. The selection of routes and MBGs depended on least impedance. Farms and MBGs were loaded with 8 km search tolerance. 8 km is the recommended radius of transporting unprocessed milk to avoid unacceptable levels of deterioration. In addition, parameter target facility count was set to three. Running *solve* function produced shortest routes to three closest milk facilities as in Fig. 6.

Results in Fig. 6 showed that Closest Facility Analysis searched for three nearest MBGs from every farm based on least travel distances. The map showed that some farmers bypassed their nearest MBGs to transport milk to Namahoya. Relationship between farms to one nearest MBG is represented as a bar graph in Fig. 7 based on least travel distances.

Taking into account incidents to their respective nearest facilities, results from Fig. 7 indicated that 50 farms were nearest to 10 different MBGs and not only Namahoya as it suggests presently. The figure shows that out of 50 farms that were sampled, only 8% were located nearest to the facility and "eligible" to supply milk to Namahoya. 92% of the farms are nearest to other nine different MBGs.

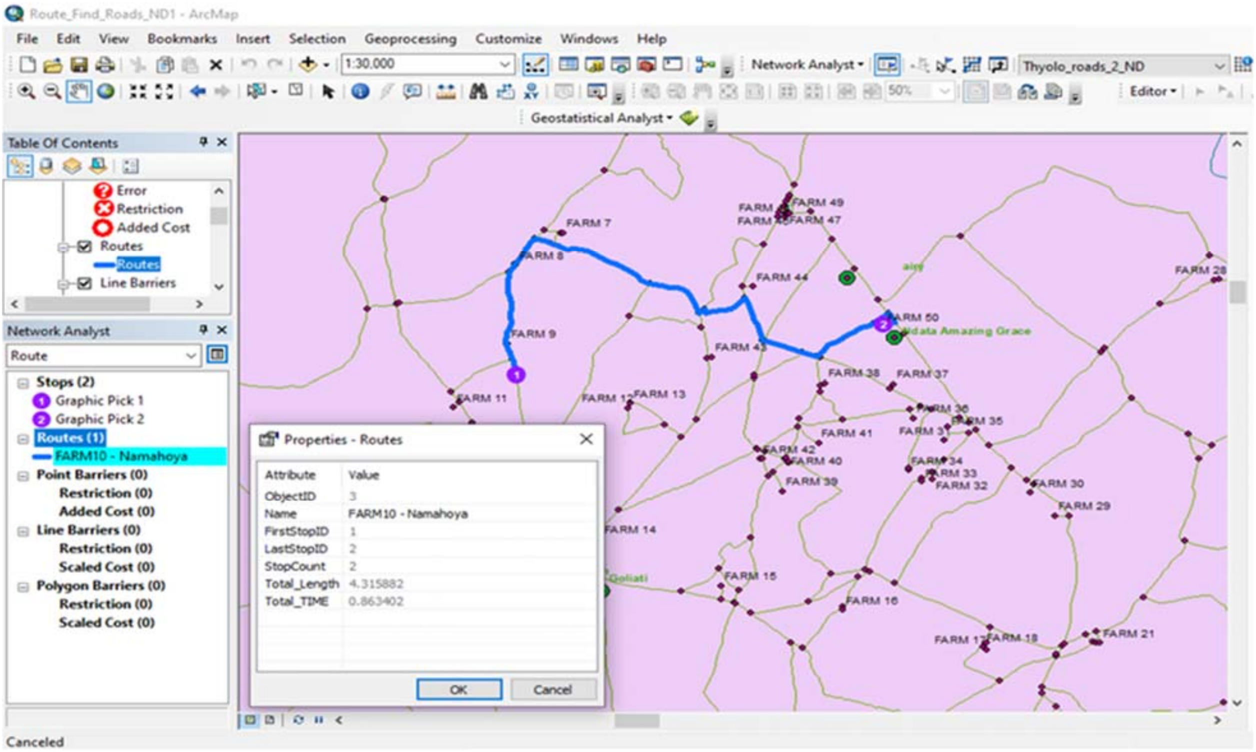

Fig. 5 Map showing Shortest Route between Farm10 and Namahoya

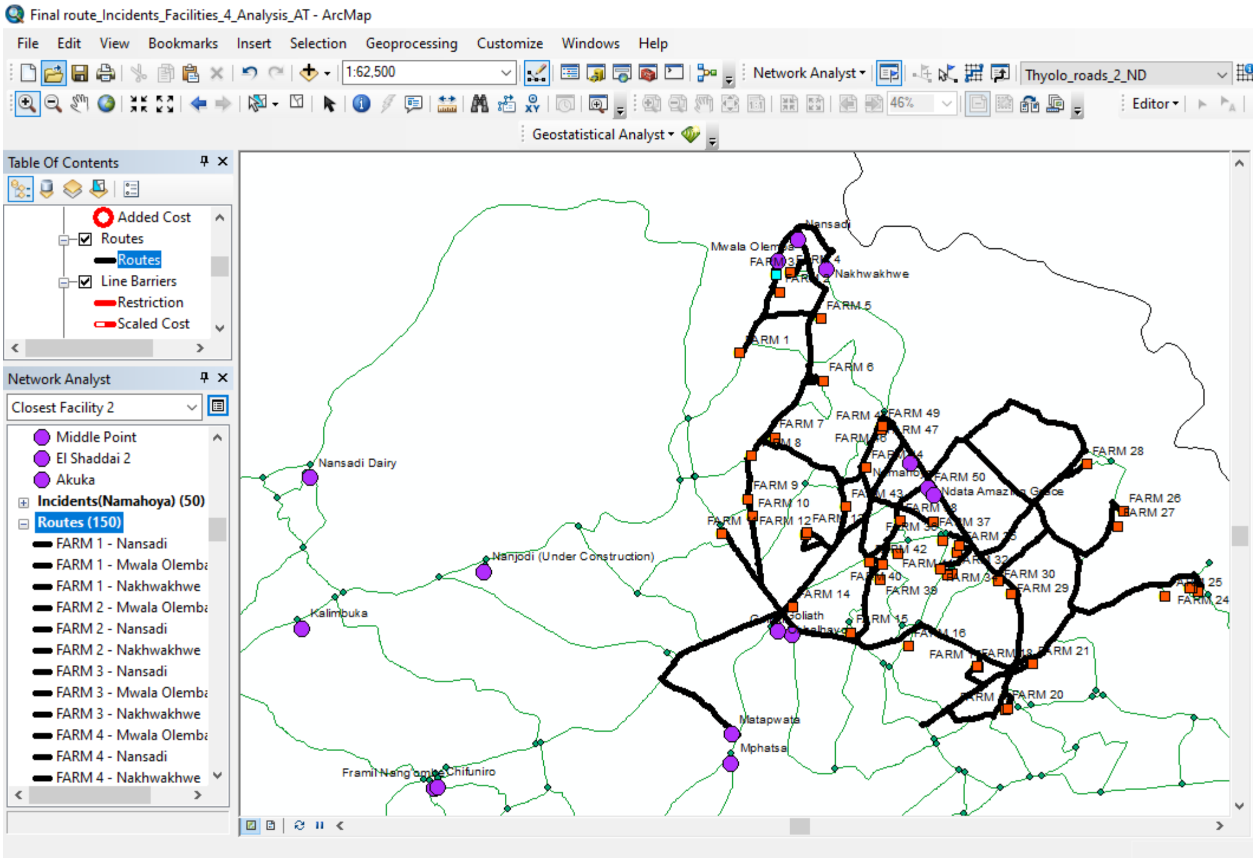

Fig. 6 Search for 3 nearest facilities

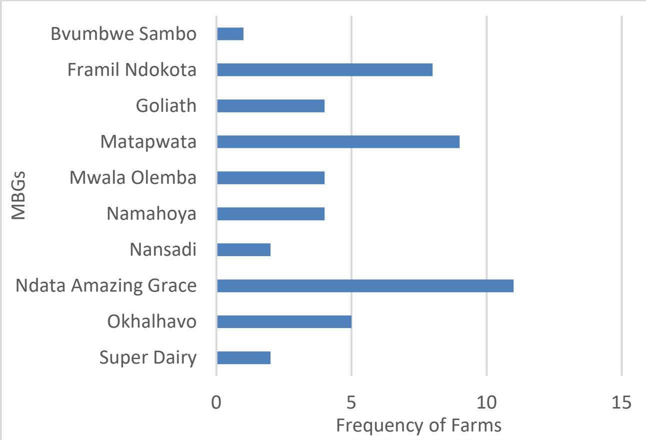

Fig. 7 Frequency of Nearest Farm (s) to MBG

Closest facility analysis confirmed that 4% were supposed to be supplying milk to Super Dairy and another 4% to Nansadi. Bvumbwe Sambo had 2% of farms nearest to it which is the lowest number while Ndata Amazing Grace had the highest number of nearest farms at 22%. Those that bypassed their nearest facility represented 92% against 8% that are in proximity with Namahoya. In the process, transit time was elongated leading to further deterioration of milk.

The total estimated walking time from all 50 incidents to Namahoya was 32.23 hours covering a total distance of 161.13 kilometers. The means for time and distance are 0.64 hours and 3.22 kilometers respectively. However, it was also necessary to estimate walking transit time, travel distances to respective closest MBGs, and then compare the results.

When delivering milk to the nearest facility, findings estimated total walking time to be 17.55 hours covering a total distance of 87.76 km. Averages for time taken and distance covered were 0.35 hours and 1.76 km for 50 smallholders. Therefore, transportation efficiency regarding total travel time and travel distances were compared between all 50 farmers when they deliver milk to Namahoya and when each farmer transports milk to their nearest MBG. The findings were achieved by subtracting Total Travel Time Spent to Deliver Milk to Closest Facility (TTTSDMCF) from Total Travel Time Spent to Delivered Milk to Namahoya (TTTSDMN). Therefore, mathematically the Time Difference (TD) was represented as:

$$TD = TTTSDMN - TTTSDMCF = 32.23 \text{ hours} - 17.56 \text{ hours} = 14.67 \text{ hours}$$

Since travel time varies directly with travel distance, it was necessary to examine differences in travel distances. This was when all farmers deliver milk to Namahoya (X) against each farmer transporting milk to their respective nearest MBGs (Y):

$$\text{Distance Difference} = X - Y = 161.13 \text{ km} - 87.76 \text{ km} = 73.37 \text{ km}$$

The difference in time and distance was a huge saving when milk was transported to the nearest MBG than when shipping to Namahoya. Findings showed that milk farmers took longer transit time and covered longer distances to get to Namahoya than to their closest MBGs. To improve efficiency, farmers can transport milk in lesser time and shorter distances to their nearest MBGs.

V. Conclusion

The Route Analysis tool allowed performing spatial analysis on the Thyolo road network. Particularly finding shortest routes, estimation of transit times and calculations of distances between farms and MBGs. This helped farmers to make informed decisions by deciding what time to depart for delivery since they would estimate traverse time based on shortest distance. On the contrary, Closest Facility Analysis identified the nearest facility based on least time and distance. The tool showed that time and distances were significantly reduced as it revealed that 50 farms were nearest to 10 different MBGs and not to Namahoya MBG. This supported delivery of less deteriorated milk to the MBG. Eventually, the likelihood that the farmer's milk would be accepted was high hence a positive outcome in the form of revenue.

Transport modeling connected farms with MBGs through a road network to solve a real transport problem in the milk supply chain. The model addressed the real world problem. In addition, the model can be used for any travel mode as long as the related average speed is set.

Drawing from the Decision theory, construct *Acts* who were farmers decided farm departure time bearing in mind the mode of transport to get to the MBG. ArcMap calculated the distances from every farm to MBG and estimated transit times per individual farmer. In the event that a farmer faced an eventuality like un-purchasing of milk by the MBG due to some reason, the model provided a second and third option. The uncertainty resulted in delivering milk to the next MBG if the first choice was not servicing. Otherwise, the farmer would get the milk back home for consumption, hence the negative *outcome*.

A. Contributions

The study mapped 48 MBGs in Thyolo district and 50 farms from Namahoya that have since been uploaded on Google Maps platform with the intention of making features public and usable by anyone from any location on earth. Farmers can locate geographical locations of milk facilities. Subsequently, farmers can find the quickest route, calculate travel time and travel distance between point locations.

B. Limitations

In order to get directions and locations of MBGs was a challenge as they were neither signposts nor mappings. We skipped some MBGs unknowingly in the process. This was rectified by visiting the District Animal Health and Livestock Development Officer for Thyolo district who provided a full list of MBGs. Additionally, the officer provided directions that led to locations of "missed" MBGs. Consequently, this led to unbudgeted logistical expenditure.

C. Recommendations

Since the majority of farmer's transport milk on foot while carrying milk loads, the study recommends that farmers should mobilize themselves and benefit from free buffalo bicycles offered by World Bicycle Relief. In Malawi, the organization is already supporting some dairy farmers so that they switch from walking to bicycling hence improving efficiencies. A more affordable and efficient way to transport milk is by bicycling rather than walking. Additionally, this study recommends to the Government of Malawi that it provides soft loans in the form of bicycles so that there is improvement in milk volumes delivery. Increased quantities of milk transported will translate to improved payoffs to farmers hence improving livelihoods.

D. Further Research

This study dwelt on optimizing routes when transporting unprocessed milk. The focus was on finding shortest routes between incidents and facilities and finding the nearest facility for dairy farmers. Therefore, future scholars may attempt to investigate transportation of unprocessed milk by considering impediments such as road turns, time windows, restrictions, historical traffic data and land elevation. This would give a more detailed result.

Acknowledgment

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