A Stochastic Truck Routing Model for Agricultural Freight

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ABSTRACT

This paper analyzes the routing of agricultural freight from the fields to the elevators. A number of optimization models are built to analyze the effects of truck type restrictions in the truck mix on the overall system cost of delivering from fields to elevators. The models account for both the selection of truck type and load type for deliveries while respecting the load restrictions imposed on the highway network. The estimated origin-destination matrix is assigned on the highway network using a stochastic model. The stochastic model is designed to take into account the different behavior of truck traffic as opposed to passenger vehicle traffic and is implemented using simulation. The models developed here are tested on the highway network of North Dakota.

Keywords: Agricultural Freight, Grain Transportation, Load Restriction, Trucking Cost, Truck Routing, Stochastic

INTRODUCTION AND BACKGROUND

Agriculture accounts for more than $297.2 billion in the U.S. economy. All agricultural products must be transported from farms to elevators and on to final destinations creating the largest demand of freight transportation in the United States and representing approximately 31 percent of all ton-miles of freight movement in 2007 (U.S. Department of Agriculture, 2010). For states like North Dakota, Iowa, Nebraska, Minnesota, Indiana and South Dakota, where agriculture accounts for a significant component of the state economy, maintaining state transportation infrastructure for efficient movement of agricultural commodities is vital for the state’s competitive position in economic development. Estimates of agricultural freight traffic flows are used to determine the demand of transportation services in state and to analyze the impact of various policy changes on the agricultural freight movement. Given the importance of estimating transportation flows, the reliability of the estimates is critical to managing transportation infrastructure. However, challenges exist for estimating agricultural freight flows. For example, truck movement from farms to elevators increases manifold during the harvest season, creating dramatic swings in the agricultural freight flows over time. Further, there are two predominant types of grain movement,
one from farms to elevators and the other from elevators to final destinations. There are also other less predominant movements as well, i.e. from smaller elevators which are called satellite elevators, to bigger elevators known as sub-terminal elevators. These intermediary destinations can account for a significant portion of agricultural freight flows. This makes it necessary to go beyond analyzing only farms and final destinations, flows to and from elevators must also be considered. Finally, axle load restrictions imposed on highways affect the movement of trucks, especially those carrying agricultural commodities as their transportation service is mostly truckload (TL). Depending on the time of year the load restriction on a given road may vary. Hence, estimates of agricultural freight flows must account for the timing of the harvest season for various agricultural products, the flow to and from intermediate destinations, and the seasonal load restrictions on roads.

Though much research exists on traffic flows, comparatively little has been done on agricultural freight flows. Tolliver (1989) did a study on analyzing the impact of grain terminals on rural roads. In this study a linear program was used for optimization of grain flow. Two sets of optimization problems were solved. One modeled the problem from the farm owner’s perspective as a transportation problem and the other modeled the problem from the elevator owner’s perspective as a transshipment problem. A second study consisting of a Kansas state highway planning project was undertaken by Russell et al. (1992) to improve the Kansas Department of Transportation’s ability to manage increasing truck volumes and axle loads on the state highway system. Russell et al. (1992) used secondary data for five major agricultural commodities: wheat, corn, sorghum, soybeans and boxed beef.

Mitra et al. (2007) developed an agriculture freight flow transportation model for the flow of crop freight from the fields to the elevators and from the elevators to the final destinations. To that end they used a transportation model with three steps: trip generation, trip distribution, and trip assignment. The data for the trip generation was developed from satellite imagery of crop layers in the state. In the trip distribution stage a gravity model was used to develop the origin-destination (O-D) matrix $\Theta = \{\theta_{ij}\}$, where $\theta_{ij}$ is the amount of grains in tons, moved from origin $i$, which is the location of the farm to destination $j$, which is the location of the elevator. Primarily four truck types are used to haul crop freight from the field to the elevators. Specifically, two-axle single unit (2A-SU), three-axle single unit (3A-SU), four-axle single unit (4A-SU) and five-axle semi-trailer (3-S2) trucks are used. These configurations are referred to as single axle, tandem axle, tridem axle and semi respectively. In a previous study, by Vachal and Tolliver (2001), a survey was conducted at elevator locations to estimate the percentage of these truck-types in the truck mix which is used for delivering crop at the elevators from the farms. One of the assumptions in the study by Mitra et al. (2007) was that of a fixed ratio between truck types. It was assumed, that for all crop movements from farms to elevators, the ratio between the four truck types within the truck mix remained constant. i.e. $x_1 : x_2 : x_3 : x_4 = A : B : C : D$, where $x_1, x_2, x_3, x_4$ are the numbers of single axle, tandem axle, tridem axle and semi-trucks in the truck mix used for hauling crops for each O-D pair. $A, B, C$ and $D$ are the constants available from the survey results for each crop type. A deterministic cost function for the route choice was assumed. Traffic volume on most highways in the state is below the highway capacity, and the volume-to-capacity ratio is quite low for any traffic speed adjustment. Based on this fact, an all-or-nothing traffic assignment method was developed to assign the truck traffic on the highway. This all-or-nothing traffic assignment methodology incorporated in the model some expected problems. For each O-D pair, all trucks were assigned to the best route while the second best route, which might exceed the best route in cost by only a fraction of a dollar, was not assigned any truck traffic. The outcome of this model when validated with actual ground count,
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