ADVERTISING ON TRANSPORTATION NETWORKS

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ABSTRACT

Roadside billboards are the biggest income earners in the Out-of-Home (OOH) advertising industry, where road users are the targeted audience. Those billboards are predominantly owned by local government authorities who lease out the infrastructure while the OOH industry decides which billboards to utilize. This paper aims at maximizing the revenue for governmental agencies on the placement of advertising infrastructure and the profit for advertising companies on selecting the billboards to advertise on. The problem is modelled as two optimization models. The first model informs governmental agencies on how to optimally allocate their budget to select links to develop billboards. The second model helps determine which billboards to advertise on from an advertising campaign perspective. The selection criteria combine the budget constraint with the variables, such as traffic volume and vehicle average speed. The models have been tested and proved to be effective in the Sioux Falls network.

Keywords: Advertising Billboards, Transportation Networks, Optimization

1. INTRODUCTION

Outdoor advertising, or Out-of-Home (OOH) advertising, is one of the most used forms of advertising. Its intended purpose is to reach the target audience when they are on-the-go or outside of home. The outdoor advertising industry over the last seven years has consistently been the second best advertising industry behind online advertising, in terms of return on investment figures (OMA, 2012). The biggest income earner of the outdoor advertising industry is the roadside billboard with a return of $131.1 million in the year 2012 alone (OMA, 2012).

An advertising campaign predominantly consists of a leasing process which is then followed by an advertising campaign. The leasing process involves the billboard owners, having erected the billboards, leasing out the billboards to the OOH advertising companies. The advertising campaign involves clients contacting their respective advertising agencies to develop images and words to be put on the billboards. The agencies then contact the OOH advertising companies whose billboards' audiences match the target audience of the advertisement. The target audiences of roadside billboard are road users, primarily motor vehicle travellers including drivers or riders, and their passengers, and the pricing of these billboards depends on the demographics and number of road users. Therefore, a complete data of travellers on roads where certain billboards are located is needed by OOH advertising companies to design a targeted advertising campaign. Regarding the demographics data of road users, the members of Outdoor Media Association (OMA) in Australia has developed an outdoor audience measurement, i.e. Measurement of Outdoor Visibility and Exposure (MOVE) (MOVE, 2009 and MOVE, 2009). This system enables the stakeholders to analyze the demographics of people that travel on the roads where billboards exist. However, apart from the evaluation process there is no comprehensive framework to optimize the road advertising system. This study develops an optimization model to optimally allocate advertising budget on a transport network.

There are three main agencies involved in OOH advertising, the owners of the advertising infrastructure which predominantly are government agencies, the leasing agency and the advertising agency. As discussed earlier that predominantly most of the tools are utilized at the advertising end of the spectrum, and no systematic method exists to help inform governmental agencies on the placement of advertising infrastructure that would provide them maximum revenue. The main contribution of this paper is to address this gap by developing two optimization models. The first model informs a governmental agency on how to optimally allocate their budget to develop advertising infrastructure, so that the governmental agency can maximize their revenue. The second optimization model is from an advertising campaign perspective, where the company has to determine which billboards to advertise on. To the best of our knowledge, this is the first study addressing the gap of advertising on a transport infrastructure.

The remainder of this paper is organized as follows. In section 2, we first briefly describe the data used in this research, followed by establishing the relationship between billboard exposure and traffic network factors. Then we formulates two models to allocate the budget into the links that will generate maximum exposure and assign the number of billboards to each link based on the associated cost. Section 3 presents and discusses the results of link selection and billboard number optimization. Ultimately, conclusions and suggestions for future studies are outlined in Section 4.

2. METHODOLOGY

2.1 Input Data

The research proceeds using the available test network data of Sioux Falls, South Dakota, USA, developed by Bar-Gera (2012). The Sioux Falls network has 24 nodes and 76 links in total. These links have different length, capacity and traffic volume distribution. These will provide different distribution of exposure in each of the links. With the given data, the Bureau of Public Roads (BPR) travel time function used by Dixit, Gardner, and Waller (2013) in their StrUE Transport Model is employed in this research to work out the travel time in each link, and further calculate the travel speed in each link. The BPR travel time function is shown in Equation (1).

$$T_i(q)=t_f\left[1+\alpha\left(\frac{q_i}{C}\right)^k\right] \tag{1}$$

Where T_i denotes the travel time in link i (measure in hours); t_f is the free-flow travel time (measured in hours); q_i is the traffic volume per hour (measured in vehicles); C represents hourly capacity (measured in vehicles); α and k are two constants with the values of 0.15 and 4, respectively.

2.2 The Relationship between Billboard Exposure and Traffic Network Factors

Evaluating advertising impact on road users hinges on quantifying billboard exposure using transport network data, the relationship between the exposure and the traffic network factors is critical to pin down. It is a common fact that as a drivers' speed increases, his or her attention to the surrounding areas which includes roadside billboards decreases. This is represented through a decreasing exponential function between the driver's probability of viewing a billboard, or likelihood-to-see (LTS) a billboard with the speed. This relationship is shown on Figure 1 below.

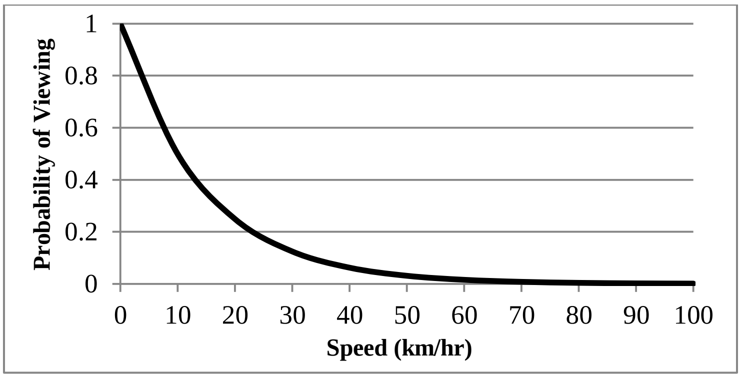

FIGURE 1. Probability of A driver Viewing One Billboard against the Driving Speed

Traffic volume on a particular link determines the exposure of the billboards. The product of the traffic volume and the LTS determines the expected number of viewings of the advertisements or the road users opportunity-to-see (OTS) the billboards In other words, the more vehicles are driving through a link, the higher the potential number of people that could view the billboards located in that particular link. This relationship is shown in Equation (2).

$$Exp_i=P_0e^{-\Omega v_i}q_i \tag{2}$$

Where Exp_i denotes the total billboard exposure in link i (measured in vehicles); P_0 is the probability of the billboard exposure at zero speed, which is assumed to be 1; Ω represents the average glance time of driver, which is set to be 0.57 seconds according to Beijer et al., (2004), v_i is the speed of vehicles in link i (km/hr), and q_i represents the traffic volume of link i (measured in vehicles).

2.3 Link Selection: the First Model

The link selection optimization model was developed to address the problem associated to efficient allocation of advertising infrastructure on a network so as to maximize total exposure and therefore inturn maximize revenue. This problem would be of particular interest to government agencies who are required to make these decisions. The optimization model is presented below. The Sioux Falls network is used as the test network. Also A is a set links indexed by i.

Decision variables:

- $a_i = \begin{cases} 1, & \text{if link i is selected} \\ 0, & \text{otherwise} \end{cases}, \forall i \in A$
- P_i: The revenue related to the exposure of billboard in link i, $\forall i \in A$;

Parameters:

- P_0: Probability of the billboard exposure at zero speed;
- Ω: Average glance time of driver;
- v_i: Speed of vehicles in link i, $\forall i \in A$;
- q_i: Volume of link i, $\forall i \in A$;
- C_i: Capital cost of installing a billboard on link i, $\forall i \in A$;
- γ: Average monetary value for exposure of one driver's glance;
- B: Budget.

Objective function:

$$\text{Max} \sum_{i \in A} a_i P_i \tag{3}$$

Subject to:

$$P_i = (P_0 e^{-\Omega v_i} q_i)\gamma \quad \forall i \in A \tag{4}$$

$$\sum_{i \in A} (a_i C_i) \leq B \quad \forall i \in A \tag{5}$$

$$P_i \geq 0 \quad \forall i \in A \tag{6}$$

$$a_i = (0,1) \quad \forall i \in A \tag{7}$$

The objective function is to maximize the total billboard revenue for a given network (Equation 3). Constraint (4) is incorporated by the previously established relationship in Equation (2). Constraint (5) ensures the total cost of installing billboards on all links will not exceed the budget. Constraint (6) and (7) set the domain for the decision variables. Solutions depend also on the parameters of the model. As discussed in Section 2.2, P_0 equals to 1; Ω is set to be 0.57 seconds. γ is assumed to be \$0.50.

2.4 Profit Maximization: the Second Model

The second model is formulated to maximize profit while acknowledging the cost involved in operating the advertising system. Let X_i be the set of Number of billboards on link i, and is indexed by t and has elements from $1 \ldots T$, where T is the maximum number of billboards on link i.

Decision variables:

- $x_{t,i} = \begin{cases} 1, & \text{if t billboards are selected on link i} \\ 0, & \text{otherwise} \end{cases} \quad \forall i \in A, \forall t \in X_i$

  The variable $x_{t,i}$ indicates whether t billboards were chosen on link i, or not.

Parameters:

- C: Cost of running one billboard.
- t: is the number of billboards on a particular link

Objective function:

$$\text{Max Prof} = \sum_{i \in A} [(P_0 e^{-\Omega v_i} q_i) t x_{t,i} \gamma - C t x_{t,i}] \tag{8}$$

Subject to:

$$\sum_{t \in X} x_{t,i} = 1 \quad \forall t \in X, \forall i \in A \tag{9}$$

$$x_i = (0,1) \quad \forall i \in A \tag{10}$$

The objective function (8) defines the profit of OOH advertising company, i.e. the difference between the utility earned from the exposure of the number of billboards selected on link i and the cost of operating those billboards. Constraint (9) determines the number of billboards selected on link i. Constraint (10) sets the domain for the decision variable.

3. RESULTS

The proposed two models are solved by MATLAB. The first model is solved by the solver binary integer programming (bintprog), and the second model is solved by the solver solving constraint integer program (SCIP). This section discusses the optimization results of both models.

3.1 The Results of Link Selection

The link selection optimization model is run over a range of budget values from \$0 to \$20,000 with an increment of \$100. The model then determines the optimal allocation of the budget to select links for various budget scenarios. The combined results are plotted in Figure 2.

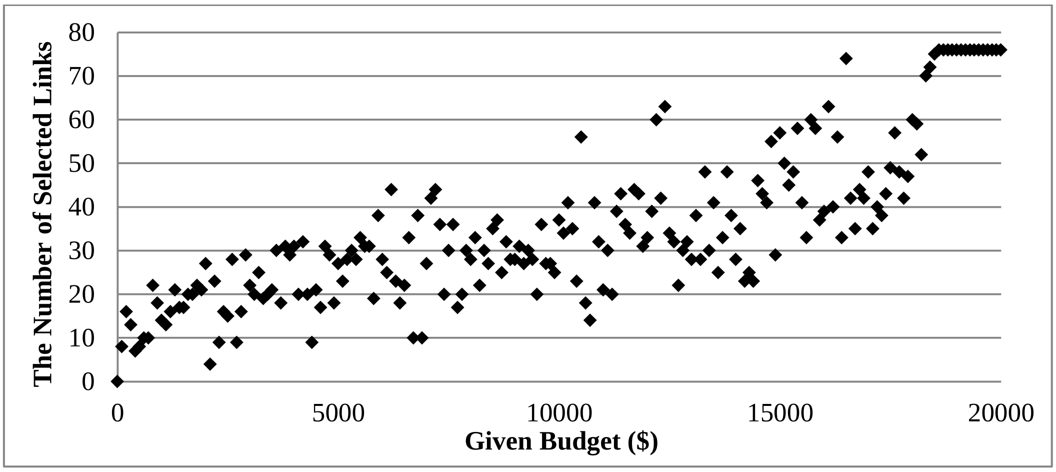

Figure 2. The Number of Selected Links for Given Budget Scenarios

We observe that though on an average the number of links selected based on optimal allocation increases as the budget increases, there is substantial variability, as shown in Figure 2. The links with higher traffic volume and lower average speed obtain higher billboard exposure, making the link more expensive. In contrast, those links possessing lower traffic volume and higher average speed generate lower exposure, which makes the links cheaper as a result. As the budget increases, the simulation can afford to ease its selection criteria and select more links accordingly. This is shown by an upward trend on Figure 2, which continues until it reaches an optimum budget where all the available links can be afforded. The optimum budget in the Sioux Falls case is \$18,595. Any given budget that is above this point will still select the same number of links, which is represented by the straight horizontal line at the top right of the figure.

The value of the objective function in dollar terms for a given budget is shown in Figure 3. Similar to the number of links selected we observe that after the budget reaches \$18,595, no further benefits can be garnered through investing on roadside billboards in Sioux Falls network.

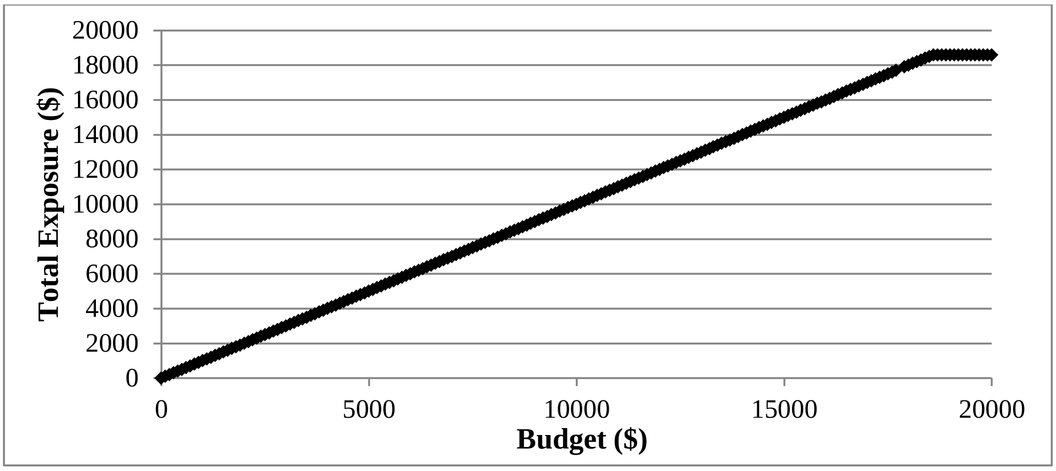

Figure 3. Total Exposure in Dollar Terms for Given Budget Scenarios

3.2 The Results of Billboard Number Optimization

The sensitivity of the model is evaluated over a range of cost values from $0 to $25 with an increment of $5. The model applies the selection criteria that will yield the maximum profit given the cost associated with each billboard. Figure 4 shows the number of billboards assigned to the first 10 links. The number of billboards on each link varies as the cost increases indicating that the model applies the selection criteria to all the links in search of maximum exposure that will yield maximum profit. As the cost increases, it becomes apparent that some links are favoured more than the others as they yield higher exposures than the rest. When cost equals to 0, the model has no need to apply the selection criteria and hence assigns two billboards to each of all the links as it can afford to reach all of the links equally and yield the maximum exposure. When the cost of operating one billboard increases to $5, the model starts to apply the selection criteria and select the links that yield higher exposures than the others to maximize profit. This is when exposures in links number 1, 2, 3, 5, and 7 are deemed too low, and hence, the model prioritize the other links over them. The model assigns four billboards to link 4 and 10, and six billboards to link 6, 8, and 9 as they yield higher exposures and profit. The same criteria are then iterated and applied when the cost of one billboard increases to $10. At this point, the only links that yield enough exposures to maximize the profit are links 4 and 9. When the cost reaches $15 and higher, the exposures in the first 10 links are deemed too low. As a result, the model assigns the billboards to the other links in the network.

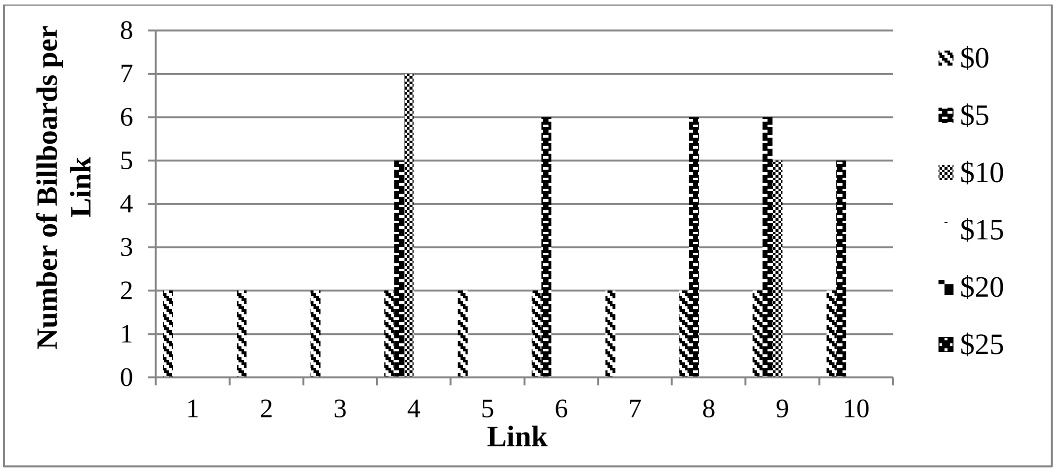

Figure 4. The Number of Billboards on the First 10 Links for the Given Costs

Figure 5 demonstrates the results from a different perspective. It shows the distribution of the number of billboards per link measured by the amount of times those numbers assigned to the links. There are three patterns of distributions observed in the figure. First, when cost equals to 0, all the links are assigned with the same amount of billboards. This confirms that the model runs through all of the available links in its simulation and seeks to have equal distribution of exposures on all of the links. Second, in all cost scenarios, there are several links are allocated with 0 billboard. This is in consistence with the selection criteria of the model that reject some links in favour of assigning more billboards in the other links. Third, no link is assigned with 9 or 10 billboards, which implies that the model abandons the option of assigning high number of billboards to high exposure links in favour of spreading the distribution of exposures among more links.

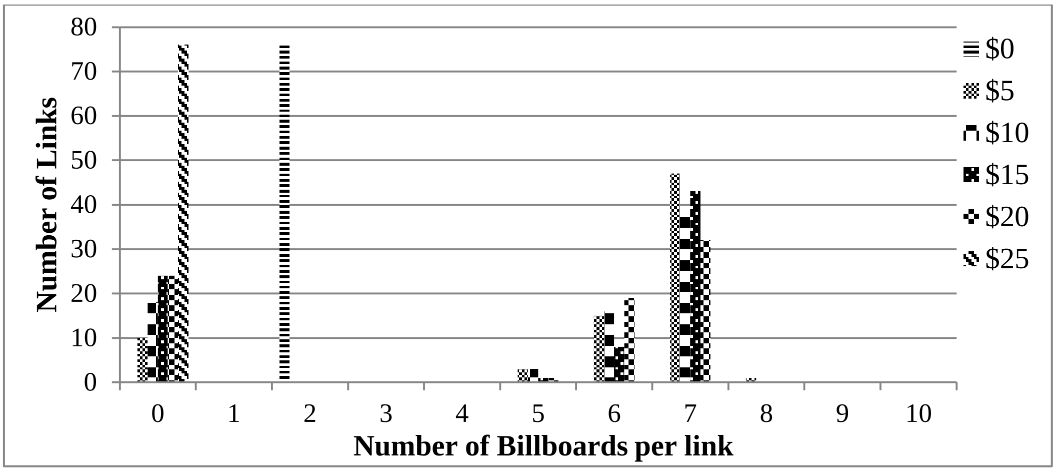

Figure 5. The Number of Links against the Number of Billboards per Link for the Given Costs

The pattern of profit against cost is shown in Figure 6. It can be concluded from the figure that the model converges to a solution. As the cost of running billboards increases to over $25, the total profit decreases to 0. This is consistent with the objective function set up at the beginning of the simulations.

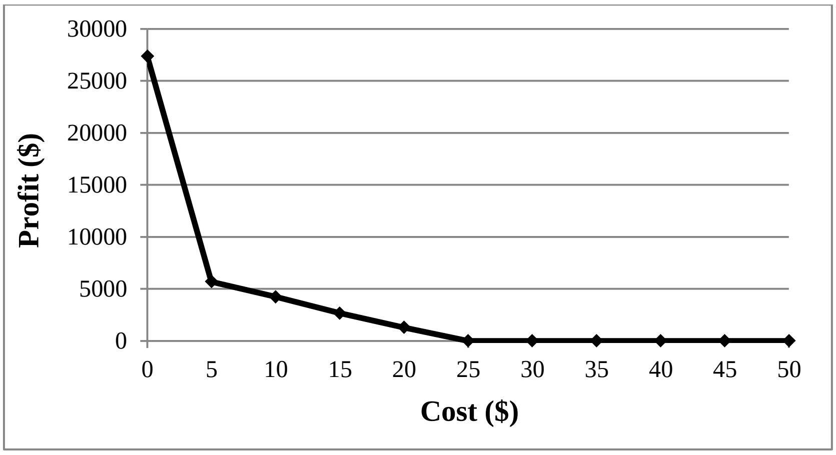

Figure 6. Profit of Running the Billboards for Given Cost Scenarios

4. CONCLUSIONS AND FUTURE STUDY

This research presented the use of transport models to evaluate roadside billboard exposure, and proposed two optimization models to select links and determine the number of billboards assigned to each selected link with the purpose to select links to maximize the exposure of billboards and to maximize profits of the OOH advertising company for given budget and operation cost. Based on the optimization results, we find that links with higher traffic volume and lower average speed yield higher billboard exposure, while those links possessing lower traffic volume and higher average speed obtain lower exposure. As the budget increases, more links will be selected accordingly. The results of the second model indicate that more billboards will be assigned to the links with higher exposure. As the operation cost of billboards increase to a certain value, the model will not allocate any billboards to the links and therefore, the total profit decreases to 0.

The two exposure valuation models can be readily used by OOH advertising companies as well as governmental agencies looking to investigate the feasibility of investing on roadside billboards in a transport network. The traffic network data can be applied to the model. By simulating the budget of the companies and operation cost of the running billboards, the two models can yield results that aid in the decision making and planning processes.

This research has left rooms for future studies which include incorporating the effect of different demographics of audience on the exposure values to yield better approximation of average exposure value per person, incorporating pedestrians and other road users that are not included in the traffic network data to yield a more accurate exposure result.

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