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Optimizing impression counts for outdoor advertising

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ITAA: An Intelligent Trajectory-driven Outdoor Advertising Deployment Assistant

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ABSTRACT

In this paper, we demonstrate an Intelligent Trajectory-driven outdoor Advertising deployment Assistant (ITAA), which assists users to find an optimal strategy for outdoor advertising (ad) deployment. The challenge is how to measure the influence to the moving trajectories of ads, and how to optimize the placement of ads among billboards that maximize the influence has been proven NP-hard. Therefore, we develop a framework based on two trajectory-driven influence models. ITAA is built upon this framework with a user-friendly UI. It serves both ad companies and their customers. We enhance the interpretability to improve the user's understanding of the influence of ads. The interactive function of ITAA is made interpretable and easy to engage.

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1. INTRODUCTION

Outdoor advertising (ad) has been a market worth 29 billion dollars since 2017 and its value is expected to reach 33 billion dollars by 2021 [1]. More importantly, the cost of deploying outdoor ads is not cheap. For example, the average cost of renting one billboard to deploy one ad is $14,000 for four weeks in New York [2]; the total cost of 500 billboards is $7,000,000 per month. If we can improve the influence by 5%, we can save up about $350,000 per month for one advertiser by renting less billboards.

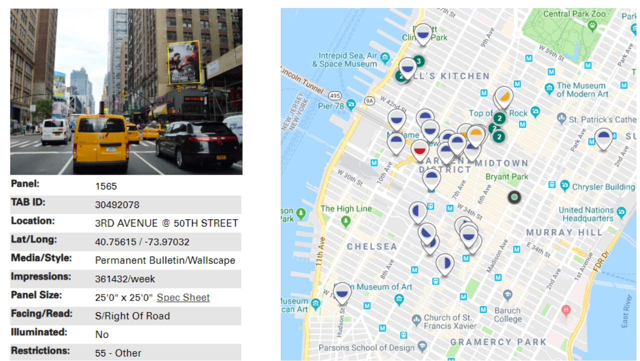

Figure 1: The Screenshot of LAMAR (The Biggest Advertisement Company in The USA)

To this end, the primary goal is to find the near optimal billboard deployment strategy. To the best of our knowledge, ad companies only provide the basic billboard information. For example, LAMAR, the biggest ad company in the USA only shows the information of each billboard such as the location, size and traffic volume (Figure 1). However, they do not provide the service of helping users to find an ideal ad deployment strategy. Existing work on facility deployment [1, 2] are different from our problem in three aspects. First, they assume that each person is associated with a fixed location, which does not consider the movement. In reality, the audience can meet more than one billboard while moving along a trajectory. Second, they assume that the price of each potential location is uniform. In contrast, we consider the non-uniform cost of billboards. Third, in our problem, the cardinality of the solution is uncertain, since it is constrained by a user input budget, and the costs of billboards are non-uniform. In contrast, the existing work often assumes a pre-determined cardinality. To find an ideal ad deployment strategy, we propose a fine-grained framework by leveraging the user/vehicle trajectory data.

In this paper, we demonstrate an Intelligent Trajectory-driven outdoor Advertising deployment Assistant (ITAA) that we have developed. This system is a valuable complement of companies' services in the following aspects.

First, ITAA provides a complete pipeline of finding the optimal billboard deployment strategy. It accepts the user's input with several requirements (i.e., constraints), and re-

*Zhifeng Bao is the corresponding author.
Songsong Mo was visiting student at RMIT when this work was done.
[1]https://www.marketing-interactive.com/ooh-advertising-spend-to-soar-to-us33-billion-by-2021
[2]http://apps.lamar.com

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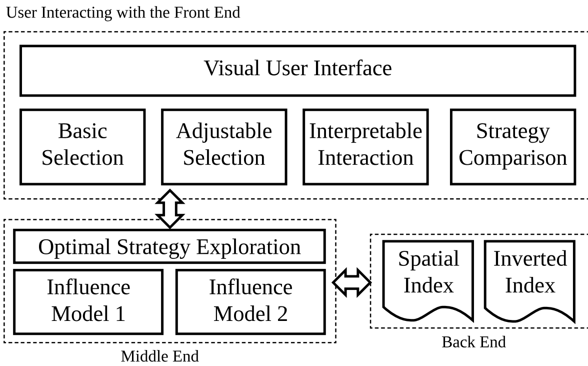


Figure 2: System Architecture

turns a feasible billboard set. In order to improve usability, ITAA supports different explorations with a varying number of constraints. For example, for a user who does not have a clear deployment plan, the only required input is a budget constraint. Based on the budget, ITAA will return a near optimal strategy that can maximize the effectiveness of billboards under the default setting. For a user who has a more definite plan to deploy ads, ITAA provides an adjustable selection function. While exploring the optimal strategy, ITAA allows the user to choose a set of billboards which have to be included in or excluded from the result. After returning the deployment strategy from ITAA, the user is able to adjust the strategy based on the demand. The most sophisticated exploring method supports adjusting parameters such as the query ranges, influence models and influence ratio of a billboard. It is for the domain expert.

Second, to improve the user's understanding of the effectiveness of billboard influence, ITAA is dependent on the concept of interpretable interaction, which is presented to users through the interacting of the UI. For example, by clicking the billboard icons on the map view, the UI not only displays the basic information of this billboard (i.e., cost, influence) but also shows the trajectories influenced by this billboard on the map view.

Third, ITAA provides users with a strategy comparison function, which helps users in comparing different strategies. For example, after generating one feasible strategy, the user can save this strategy as one candidate, and compare these candidates through the map view, tables and charts.

Last but not least, ITAA is able to find the potential billboard location by checking the coverage of trajectories on ITAA. We recommend these locations that have a large traffic volume but have not been deployed any billboard station. A demo video [3] and prototype are available online [4].

2. SYSTEM OVERVIEW

Figure 2 shows the system architecture. At the front end, the UI presents all information such as the map view, query parameters and strategy information. The middle end is responsible for finding the near optimal strategy based on the user's input. In the back end, we build a hybrid index structure including two indexes, which is used to optimize the effectiveness of ITAA.

Front End. The front end provides users with an interactable UI that supports four sub-functions. It is responsible for transferring the user's request to the middle end and presenting the result on the map view. The basic selection function and adjustable selection function are used to find the optimal strategy through the algorithms in the middle end. The interpretability is not a simple function, but a concept running through the system represented by an interactive way. It is built to help users in making strategies. For example, when the user clicks a billboard icon, the UI will not only show the basic information such as the price, and the numerical influence but also highlight the trajectories that are influenced by this billboard on the map view. Analogously, when the billboards in a strategy result are displayed on the map view, all of the influenced trajectories will be highlighted. Besides, by selecting one trajectory, all billboards that can influence this trajectory will be highlighted. ITAA also enables users to compare their deployment strategies so that they can make an insightful decision.

Middle End. Based on different demands, the optimal strategy exploration either invokes the related algorithms to find the optimal deployment strategy or retrieves the two indexes to react to users' operation. More details will be introduced in Section 3.

Back End. The back end contains a spatial index and an inverted index. In the spatial index, the key is a billboard, whereas the value is set of tuples consisting of the trajectory that is influenced by this billboard and the distance between them. In contrast, the key of the inverted index is a trajectory, whereas the value is set of tuples consisting a billboard that can influence this trajectory and the distance between them. Based on these two indexes, we can retrieve which billboards can influence a trajectory, vice versa.

3. FINDING THE OPTIMAL PLACEMENT

In this section, we introduce the back end techniques. Please refer to our work [4, 5] for details. Our goal is to find an optimal ad deployment strategy, that maximizes the influence of ads. Without loss of generality, we adopt two influence models with two respective goals.

Goals. The *first goal* is to maximize the number of distinct users influenced by the deployed ads. We assume that a one-time influence of the billboard to a user is enough. Therefore, we aim to influence as many people as possible for one time. It will be counted as an overlap if a user is influenced by more than one billboard. Based on the above characteristic, we build the One Touch Influence Model [4], which is called OTIM. The *second goal* is to maximize the influence based on the intuition that the effectiveness of ad repetition varies from one person to another. This assumption has been widely adopted in the ad market and the effectiveness of ad repetition should be measured as an S-shaped function [3]. Therefore, we build an Impression Count Influence Model [5] based on the logistic function, which makes the influence model non-submodular. It is called ICIM.

Preliminaries. Given a trajectory database $\mathcal{T} = \{t_1, ..., t_{|\mathcal{T}|}\}$, where each trajectory $t = \{p_1, ..., p_{|t|}\}$ is a set of points generated from the trajectory of a user. Point p consists of the latitude lat and longitude lng. Given a billboard database $\mathcal{U} = \{o_1, ..., o_{|\mathcal{U}|}\}$, each billboard o is a tuple $\{loc, w\}$, where loc is also a coordinate with latitude lat and longitude lng, and w is the cost of billboard.

Definition 3.1. *We define that o influences t, denoted as $I(o, t) = 1$, if $\exists t.p_i$, such that $dist(t.p_i, o.loc) \le \lambda$, where $dist(\cdot)$ computes the Euclidean distance between p_i and $o.loc$, λ is a given distance threshold.*

[3] https://www.youtube.com/watch?v=tE3dEbgHDUY
[4] http://47.75.79.142:8081/AdDeployment/

3.1 Influence Models

OTIM. Let $pr(o_i, t_j)$ denote the influence of o_i to t_j. Let $pr(S, t_j)$ denote the influence of a billboard set S to t_j. It is worth nothing that $pr(S, t_j)$ cannot be computed as $\Sigma_{o_i \in S} pr(o_i, t_j)$, because different billboards in S may have overlaps when they influence t_j. We use the following equation to compute the influence of S to t_j.

$$pr(S, t_j) = 1 - \prod_{o_i \in S} (1 - pr(o_i, t_j)) \tag{1}$$

ICIM. To simplify the equation, let $l(\cdot)$ denote the logistic function. We use the following equation to compute the influence of a billboard set S to a trajectory t:

$$pr(S, t_j) = \begin{cases} l(I(o_i, t_j)) & if\ \exists o_i \in S\ I(o_i, t_j) = 1 \\ 0 & otherwise \end{cases} \tag{2}$$

3.2 Problem Formulation and Methodology

Problem Formulation. Let $I(S) = \sum_{t \in T} p(S, t)$ denote the influence of S to a trajectory set T. We introduce the problem definition as follows:

DEFINITION 3.2. *Given a billboard database $\mathcal{U}$, a trajectory database $\mathcal{T}$, a budget constraint B and the influence model $I(S)$, we aim to find a subset $S \subseteq \mathcal{U}$ that maximizes the overall influence of S such that the total cost of S does not exceed B, i.e.,* $\operatorname{argmax} I(S)$, *where* $cost(S) \leq B$.

Methodology. Based on the given budget, ITAA will find the near optimal billboard deployment strategy that can maximize the influence of the selected billboards under an influence model. As aforementioned, we have two influence models, OTIM and ICIM. We introduce them respectively.

OTIM. The basic greedy algorithm is applicable because OTIM is submodular. However, without a guaranteed approximation ratio, the result could be unexpectedly worse. Therefore, we propose a θ-partition based framework which achieves a $\frac{1}{2}^{\lceil log_{1+1/\theta} m \rceil}$ approximation ratio. θ is an influence overlap threshold which is used to control the cardinality of partitioned clusters. By varying θ, we can trade off the time complexity and the approximation guarantee. This framework contains three steps. First, we partition all billboards into a set of clusters according to their influence overlap. Second, for each of the cluster, an enumeration greedy algorithm will find the local optimal deployment strategy. Third, based on a dynamic programming algorithm, we aggregate these local optimal strategies from clusters to obtain the global solution. Please refer to [4].

ICIM. According to Equation 2, we can show that the objective function of $I(S)$ is not submodular, which means a greedy-based approach is not able to find the solutions with constant approximate ratio. In order to address this challenge, we propose an upper bound estimation method that tightly upper bounds the logistic function value, by means of a tangent line that intersects with the logistic S-curve. Based on the upper bound estimation method, we propose a branch-and-bound framework which achieves $\frac{1}{2}(1-1/e-\epsilon)$ approximation ratio. It explores branches, which represent respective feasible billboard sets that have not yet exhausted the budget and can be filled with more billboards. In particular, we propose a novel bound estimation technique for each branch under exploration by setting a submodular function to tightly upper bound $p(S, t)\ \forall t \in \mathcal{T}$. The estimation technique will obtain a candidate solution (i.e. the billboard set which cannot be further expanded due to the budget constraint) when calculating the upper bound score of a branch.

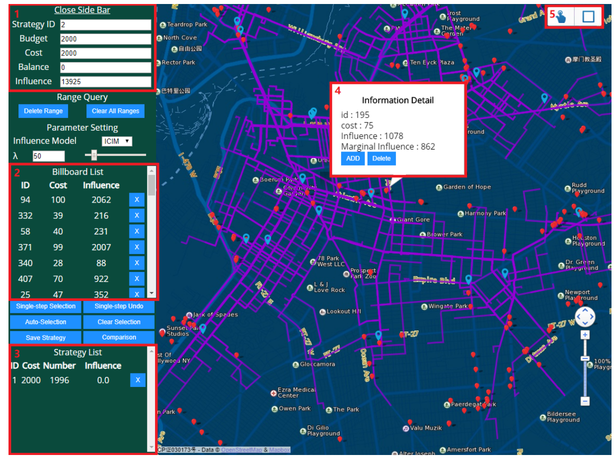


Figure 3: User Interface

The exploration terminates when the upper bound of all remaining branches does not exceed the influence value of the best candidate solution. Please refer to [5].

4. DEMONSTRATION OVERVIEW

In NYC, we collect five hundred thousand taxi trips from TLC trip record[5]. Each trip record includes the pick-up and drop-off locations, time and trip distances. Similar to [4], we use Google Maps API to generate the trajectories.

4.1 User Interface Overview

The user interface is shown in Figure 3. Billboards are displayed on the map view with various icons. A user can zoom in or zoom out the map view to explore different levels of details. By clicking a specific billboard icon, the trajectories influenced by this billboard will be highlighted with green lines. The left sidebar shows the different selection conditions and strategies. The influence model is pre-defined in the drop-down menu, and can be changed by users. All basic information such as the budget, total cost, balance, and influence are shown in rectangle 1. The default budget has been set in the input. It can be reset by the user as an integer that is greater than zero.

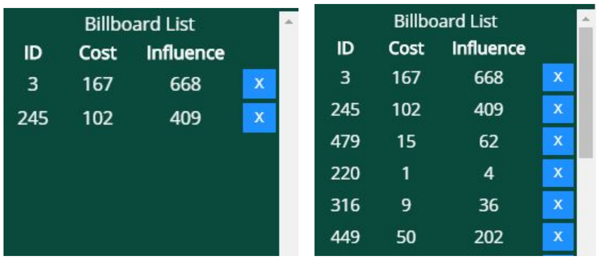
After setting the budget, the user can click a billboard icon to select it manually. As shown in the red rectangle 4, the detail of this billboard will be displayed in the floating menu. In this menu, the "Marginal Influence" is updated based on the selected billboards set. All selected billboards are shown in the list in the red rectangle 2. Clicking the "X" button will delete the selected billboard.

The "Auto Selection" button is used to find the billboard deployment strategy automatically. It can start with an arbitrary size of selected billboards. For example, the user can start with an empty list or a billboard set that needs to be included or excluded in the final result. The algorithm will complete the selected billboards set based on the current selection under the budget constraint.

4.2 Demonstration Scenarios

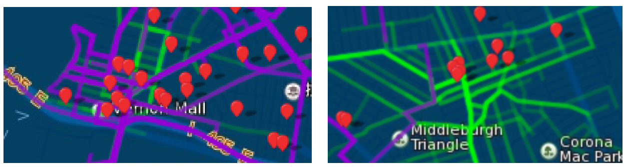
Lydia is working in the marketing department of a company. She is charging for promoting the newest products in the market in NYC by deploying the advertisement on outdoor billboards. She has a limited budget, but it is flexible. It could be a little bit more or less.

[5]https://www1.nyc.gov/



(a) Initial Strategy (b) Returned Strategy

Figure 4: Incremental Selection



(a) (b)

Figure 5: Billboard Influence

Basic Selection. Lydia accesses our system on a browser. The first thing that she notices is the map view. By moving, zoom-in and zoom-out, she can locate NYC on the map view. The default range of deploying ads is the range of the current displaying map view. Next, she needs to input the budget. If necessary, she changes the influence model and the influence range of a billboard (i.e., λ). Then, all she needs to do is to click the "Auto-Selection" button. Based on the budget and deploying range, ITAA will find an ideal deployment strategy consisted of a set of selected billboards. As shown in Figure 3, the map view displays all selected billboards as a blue balloon and the trajectories that have been influenced by these billboards as purple lines. In the sidebar, Lydia can get the numerical details such as the cost, balance, total influence of these billboards (red rectangle 1), and a list of the selected billboards (red rectangle 2).

Adjustable Selection. Lydia does not satisfy with this strategy. For example, some locations have been chosen by her competitors, but not in the strategy. In this case, because the budget is exhausted, she has two options. She could ignore the alarm of over budget, and continue to add the essential billboards. Alternatively, she can remove the current strategy by clicking the "Clear Selection" button first, Next, she adds the essential billboards, and clicks the "Auto-Selection" button. In both options, she will get the deployment strategy containing all essential billboards without exceeding the budget constraint.

Interpretable Interaction. After manually adjusting the strategy, the total influence of billboards decreases compared with the auto-generated strategy. It means that the essential locations have a negative effect of influence. Lydia wants to keep these locations as much as possible, meanwhile increases the total influence of billboards. Therefore, she has to remove a few of them, which requires a full understanding of the billboard influence It is one of the primary purposes of the interpretable interaction supported by ITAA.

For example, the colours of a trajectory influenced by the different states of billboards are different. As shown in Figure 3, the trajectories influenced by the selected billboards are highlighted with purple lines. By clicking the icon of an unselected billboard, the trajectories that are influenced by this billboard will be highlighted with green lines. The more green lines there are, the higher marginal influence this billboard has. For example, in Figure 5, the range of green trajectories in Figure 5b is larger than the range in Figure 5a. It is because that the purple trajectories overlap the green trajectories in Figure 5a.

Furthermore, the incremental selection function explains how ITAA selects billboards to achieve the optimal strategy. By clicking the "Single-step Selection", in each step, ITAA sequentially adds one billboard of the optimal strategy, then updates all relevant information and the map view. Depending on the influence model, ITAA shows how to avoid the influence overlap or enhance impression counts.

Region-Based Selection. The Staten Island of NYC is not the target market. Lydia needs to avoid to deploy any ad at there. For users who want to deploy ads in specific regions only, ITAA allows users to set the deployment ranges. She can click the rectangle icon in rectangle 5, and draw multiple rectangles containing regions except Staten Island. Then, similar to the previous actions, by clicking the "Auto Selection" button, the optimal strategy will be returned and displayed at the sidebar.

Strategy Comparison. Finally, Lydia has several ideal strategies. For making the decision, she needs to know the differences and which one is better. She has already saved the strategies by clicking the "Save Strategy" button before. As shown in Figure 3, in rectangle 5, stored records are saved in the strategy list. Lydia can easily explore the previous result by clicking one of them. The selected billboards of this strategy will be displayed, as well as the related information. Moreover, by clicking "Comparison" button, all the detail information such as the budget, cost, influence, billboard list will be displayed in a new webpage. ITAA will compare each strategy through tables and charts.

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