BUSINESS+ COMMUTE OPTIMIZATION SYSTEM: MODEL DEVELOPMENT AND PILOT CASE STUDY

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Mitigating traffic congestion and reducing transportation emissions are among the leading goals of local, regional, national and international planning and transportation agencies. Current strategies include supporting: (1) mixed land-use and transit-oriented developments, (2) multimodal transportation systems, and (3) design of active-transportation friendly environments. While these approaches can successfully contribute to the reduction of transportation related GHG and air pollution emissions, additional innovative opportunities exist. The primary objective of this research is to identify and develop individual-specific commute incentives to optimize business commute footprints. To perform such work a geographical information system (GIS) model was developed and integrated with an optimization model to measure and quantify business commute factors and identify individual-specific commute incentives that can lead to the minimization of business commute footprints. The GIS model outputs include trip attributes (e.g. travel time, travel cost, greenhouse gas emission, and air pollution emissions) associated with every commuting mode from the traveler’s origin to the traveler’s destination. The optimization model uses such data to implement a single-objective function that optimizes travel times, travel costs, emissions, individual-specific commute incentives that target the commute departure time, travel mode (e.g. carpooling, transit, and active transportation) and route choice. To demonstrate the capabilities of the resulting Business+ Commute Optimization System (BCOS), pilot data using student commuters was collected and analyzed. Preliminary results for such a community suggest that GHG emission and air pollution could be reduced by 24% given a 15 minute commute-duration tolerance or that such emissions could be completely eliminated if a 40 minute commute-duration tolerance were permissible. Such results serve as a proof-of-concept for BCOS and highlight the effectiveness of such a new and innovative strategy for minimizing transportation related business emissions and traffic congestion.

Keywords: Business Commute, Commute Alternatives, Commute Footprint, Optimization, Alternative Commute Incentives
1. INTRODUCTION

The United States (US) Environmental Protection Agency (EPA) reported in 2013 that Greenhouse Gas (GHG) Emissions from the transportation sector accounted, nationally, for 27% of total reported GHG, second only to the electricity sector (1, 2). The largest source of transportation-related emissions, accounting for over half of the emissions from this sector, include passenger cars and light-duty trucks such as sport utility vehicles, pickup trucks, and minivans.

Mitigating traffic congestion and reducing transportation emissions are among the leading goals of most local, regional, national and international agencies. Several guidelines which support this goal are currently available by several Departments of Transportation (DOTs). Current strategies rely primarily on strategies that support: (1) mixed land-use and transit-oriented developments, (2) multimodal transportation systems, and (3) design of active-transportation friendly environments. While these approaches have successfully contributed to the reduction of transportation GHG and air pollution emissions, this research presents an innovative system that can add further improvements and provide more effective and individualized action plans. Recent developments related to the traffic analysis propositions of California Environmental Quality Act (CEQA) currently recommend a shift from the reduction of delays to vehicle miles traveled (VMTs). This research presents an innovative system, entitled Business+ Commute Optimization System (BCOS) capable of minimizing GHG and air pollution emissions, and total commute time of a business commute based on various commute alternatives, monetary incentives, commuter tolerance, and individualized action plans.

2. LITERATURE REVIEW

Drive-alone commuting represents a major contributor to peak hour traffic jams, among other implications. Hence, the transportation literature is full of studies exploring different policies tailored towards decreasing modal shares of drive-alone commutes – simultaneously increasing shares of alternative commute modes – and studies aiming to evaluate these policies and assess their impacts.

In spite of traffic jams and the numerous studies, drive-alone has been the predominant mode of transportation for commuting trips for many decades in the USA. In 2000, the average vehicle occupancy for commute trips was 1.08 (3), and in 2010, drive-alone contributed to 76.6% of all commute trips (followed by carpooling 9.7%, transit 4.9%, and work at home 4.3%). Importantly, modal share of drive-alone commute has increased steadily, where it was 64.3% in 1980 (4). While this may be a reflection of the unmatched convenience of the personal automobile, it may also be attributed to an unmatched subsidization of the automobile, especially in terms of parking supply, in comparison to the alternative forms of transportation (5). For instance, the 2015 National Compensation Survey reveals that while most employers provide their employees with free parking at work, only 7% offer subsidies for other travel modes (6).

The effect of employer-provided transportation subsidies (whether parking subsidies for cars, or benefits for other travel modes) on commute mode choice is significant. Numerous Commuter Choice programs exist, which encompass programs such as Parking Cash-Out, Employee Parking Pricing, Travel Allowance, and Transit and Ridership Benefits programs, among others (7, 8). Literature about each of these programs is abundant. Parking Cash-Out programs appear to have received the highest attention, while acceptance of public employee parking pricing has proven to be more challenging (9). The basic paradigm of Parking Cash-Out
programs entails the following cycle: the employer provides employees with benefits for non-
drive-alone commuting options (e.g. monetary benefits), less employees drive-alone to work, the
demand on parking decreases, the employer saves land by reducing the number of parking stalls,
and the employer uses these savings to offer more benefits for non-drive-alone commute options.
Several studies found the impact of these programs to be highly beneficial. As a result, the FTA’s
Commuter Choice programs (10) and California’s Parking Cash-Out Law were established (11).

In general, the literature on commuter mode choice can be classified into two main
groups: 1) the aforementioned Commuter Choice programs, particularly Parking Cash-Out
literature, and 2) Commute Mode Choice Models literature. Publications belonging to the first
group primarily focus on the analysis of the different commute subsidies and assessment of their
impacts. Literature in the second group is more focused on understanding the factors contributing
to individual commute mode choice behavior and modeling individual commute mode choices.

Under the first group, Shoup evaluated the impacts of California’s Parking Cash-Out Law
in eight firms that offered their employees the option to choose cash in lieu of parking subsidies.
The study of 1,694 employees found considerable reductions in drive-alone commutes, vehicle
miles travelled and GHG emissions, and simultaneous increases in carpooling, transit ridership,
and active transportation modal shares (12). Similarly, Mardsen conducted an overview of parking
policies, and concludes that more work should be done to establish how parking restraint could
better supports the economy, the environment and social equity (13). Zhou used a case study to
review the efforts required by a university to establish and sustain a carsharing program. He
concludes that a $1,500 subsidy per vehicle is required to attract a carsharing company and that
reduced carsharing subsidies significantly decrease carsharing demand.

On the other hand, as part of the second group, Hamre and Buehler applied multinomial
logistic regression to revealed preference data of 4,630 commuters in the D.C region and found
that employees that are offered transit benefits, showers or lockers, or bike parking, and had no
free parking were more likely to use transit, walk or cycle to work. However, the existence of free
parking seemed to offset this increase likelihood (14). Similarly, Yang et al. conducted phone
interviews with 1,338 commuters and used multivariate logistic regression models to explore the
impacts of home and worksite neighborhood environments, and worksite support and policies on
commuter mode choices. Their study uncovered significant associations between: a) walking time
from home to transit stops and using worksite incentive for public transit, and commuting by public
transit; b) commuting distance and active commuting; and c) the existence of free or low cost
recreation facilities around the worksite and using bike facilities to lock bikes at the worksite, and
active commuting (15).

Literature is rich with research on commuter mode choices; however, tools that businesses
can utilize to identify optimum policies and incentives and associated benefits are limited. Three
available tools include the Commuter Choice Decision Support Tool (16), CUTR_AVR Model
(17), and Business Benefits Calculator (18). These tools provide businesses with generalized
recommendations for commuting policies and estimates on benefits (e.g. reductions in GHG
emissions). They base their recommendations and estimates on aggregate measures of business
employee commute data, rather than individualized commute information and do not provide
individual-specific incentives that are specifically suitable for individual commuters. Accordingly,
the model presented in this paper addresses this particular limitation.

This research presents the development of a novel and innovative system, entitled the
Business+ Commute Optimization System, or BCOS, which captures disaggregate individual
commute information and provides businesses or similar communities with individualized incentives that are specifically designed to minimize a business’s commute footprint. BCOS is flexible, allowing businesses to specify their desired optimization function; whether to separately or collectively minimize travel times, GHG emissions, and air pollution emissions.

This paper is organized as follows: first, the research objectives and methods are presented including the process model of BCOS; next, BCOS’s components including GIS and Optimization models are presented in detail; next, a pilot case study implementation is documented with results providing proof-of-concept for BCOS; finally, conclusions and future work are discussed.

3. RESEARCH OBJECTIVE AND METHODS

The primary objective of this research is to develop an innovative optimization system for minimizing GHG and air pollution emissions associated with a business’s commute behavior. The Business+ notation in the name, Business+ Commute Optimization System, symbolizes and extends the potential application of such a system to any community that shares a commuting destination (e.g., academic institutions, governmental agencies, community developments, and businesses). Commute information involving individuals’ commute origins and departure times, durations and modes of transportation, and destination location and arrival times, serve as the basis of the optimization system. Such commute information is input into a geographical information system (GIS) model which generates data regarding route and commute mode alternatives as well as corresponding GHG emissions. The output from the GIS model is fed into an optimization model to measure and quantify business commute factors and identify individual-specific commute incentives. The optimization model implements a single-objective function that includes travel times, travel costs, emissions, and the individual-specific commute incentives target the commute departure time, travel mode (e.g. carpooling, transit, and active transportation) and route choice. Finally, the BCOS generates recommendations for an action plan to change individuals’ commuting behavior by way of carpooling, public transportation, efficient routes and departure times. The steps of BCOS are depicted in Figure 1.

![FIGURE 1 Business+ Commute Optimization System Process Diagram.](image-url)
Such an optimization system can aid decision-makers in identifying the optimal selection of a business’ commute alternatives while complying with limited incentive budgets, maximizing convenience, and minimizing environmental impacts. Such results may prove critical for businesses seeking to minimize transportation-related emissions, and improve local and regional air quality.

### 3.1 Geographical Information System (GIS) Model

The objective of the first component of BCOS is to calculate different performance measures (trip attributes) associated with different commuting alternatives. As further explained in Integrated Components section, inputs for the GIS model include the origins and destinations of the commuters, as well as the available transportation network in the city. Outputs of the GIS model include five trip attributes (e.g. trip time, distance, cost, and GHG and air pollution emissions) associated with every commuting alternative from the traveler’s origin to the traveler’s destination. Esri’s ArcGIS software was used in this work.

### 3.2 Optimization Model

The objective of the second component of BCOS is to identify the optimal selection of commute alternatives to simultaneously minimize GHG emissions, air pollution, and commute time of a business commute plan. Such optimization can support businesses in ongoing efforts to minimize the negative environmental impacts and commute time of their commute systems while providing monetary incentives for commuters. The optimization model component is developed in two main phases (1) formulation phase which formulates the model decision variables, objective functions, and constraints; and (2) implementation phase which performs the model computations and specifies the model input and output data. The following section describes in greater detail the development and capabilities of both the GIS and optimization model components of BCOS.

### 4. INTEGRATED COMPONENTS OF BUSINESS+ COMMUTE OPTIMIZATION SYSTEM

#### 4.1 GIS Model for Commute Attribute Calculations

Figure 2 presents a flowchart that depicts the structure of the GIS model component of BCOS. The component is divided into three parts: GIS model inputs, GIS model, and GIS model outputs. The following sections explain each of these three parts in greater detail.

**GIS Model Inputs**

The BCOS’s GIS model component requires four inputs:

1) Commuters’ Origins and Destinations. While a business’ human resources office typically keeps records of employee home addresses and office locations, ideally a travel survey can be used to capture up to date information.

2) Existing Transportation Network in the city. In the USA, transportation network systems are typically available in GIS shapefile or geodatabase formats from the cities, local municipalities or the metropolitan planning organizations (MPOs).
Commute Choice Set. This set includes all commuting alternatives that the business desires to model (e.g. carpooling, public transportation options, and carpooling). Eight commuting alternatives were modeled in this paper. They are listed in the top row of Figure 2. It is worth noting that these eight alternative commuting options encompass only five major transportation modes. These five modes are listed in the left column of Table 1.

Performance Attributes Set. This set includes the performance attributes that the business desires in optimizing or measuring (e.g. travel times, travel costs, and GHG emissions). Six trip attributes (performance measures) were modeled in this research. They are listed in the top row of Table 1.

GIS Model

The GIS model involves five steps:

1) Geocoding origins and destinations. This step entails transforming the surveyed origins and destinations (usually in text format) into geo-referenced data points in the GIS model.

2) Editing the transportation network files. This step entails ensuring the connectivity between the different components of the transportation system. For example, it entails:
   a. Modeling of one-way street segments (e.g. freeway ramps).
   b. Modeling of appropriate connections between different highway segments (since not all intersecting highway links are necessarily connected; e.g. freeways passing over local street segments).
   c. Ensuring that all bus stops are connected with highway segments and with bus lines.

3) Identifying the attribute parameters and developing the attributes functions. As mentioned earlier, six attributes were calculated to optimize (and measure) the performance of the business commuting plan (listed in the top row of Table 1) based on eight commuting alternatives encompassing five major transportation modes (listed in the left column of Table 1).

4) Building the Transportation Network Dataset. This step entails building the ArcGIS Network Dataset using the Edited Transportation Network Files (Step 2) and the developed attribute functions (Step 3). The transportation network datasets enables the calculation of the performance attributes values as a function of the attribute functions and the existing transportation system. The network dataset was built using Esri’s ArcGIS Network Analyst Extension.

5) Coding the GIS Model. A GIS model was coded to calculate the attribute values for all commuters from their respective origins to destinations using all identified commuting alternatives. ESRI’s ArcGIS ModelBuilder was used to code two different models:
   a. One model that loops through all commuters and calculates their commute attributes as a function of all identified commuting alternatives (except carpooling), i.e. seven commuting alternatives.
b. Another model that loops through all possible combinations of carpooling pairs and calculates the attributes associated with this particular commuting alternative.

**GIS Model Outputs**

The GIS model outputs calculate attribute values for every possible commuter-commute mode combination. A sample of the GIS model output is provided at the bottom of Figure 2.

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**FIGURE 2 GIS Model Structure.**

Where: Wt: Walk, Bk: Bike, Sk: Skateboard, B: Bus, CA: Car Alone, C+1: Carpool (1 driver + 1 passenger)
<table>
<thead>
<tr>
<th>Mode</th>
<th>Travel Time</th>
<th>CO2 Emissions</th>
<th>NOx Emissions</th>
<th>VOCs Emissions</th>
<th>Travel Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk</td>
<td>Distance 3 mph</td>
<td>Trip Origin to Destination</td>
<td>0.0</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Bike</td>
<td>Distance 10 mph</td>
<td>Trip Origin to Destination</td>
<td>0.0</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Skateboard</td>
<td>Distance 8 mph</td>
<td>Trip Origin to Destination</td>
<td>0.0</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Bus</td>
<td>Distance 30 mph</td>
<td>Trip Origin to Destination</td>
<td>294.6</td>
<td>1.643</td>
<td>0.039</td>
</tr>
<tr>
<td>Car</td>
<td>∑ Link Lengths Speed Limits</td>
<td>Trip Origin to Destination</td>
<td>368.4</td>
<td>0.693</td>
<td>1.034</td>
</tr>
</tbody>
</table>

* p-mi is passenger mile and gge is gasoline gallon equivalent

### 4.2 Optimization Model to Identify Commute Alternatives Optimums

The optimization model component of BCOS includes two main parts: model formulation, and model implementation. The following sections explain each of these parts in greater detail.

#### Model Formulation

The decision variables of the optimization model component of BCOS represent commuting alternatives for commuters which impact GHG emissions, air pollutions, and commute time. These transportation alternatives, include existing vehicle, public transit and walking, public transit and biking, public transit and skateboarding, walk, bike, and skateboard, as shown across the top row of Figure 3. Each of these commuting chain alternatives is modeled with a binary decision variable representing the primary mode of transport a commuter utilizes to travel from the origin of the commute trip to the final destination. It should be noted that, the optimization model considers only one route for each transportation alternative, which represents the shortest travel time to transport a commuter from the origin of the commute trip to the final destination.

The objective function of the optimization component of BCOS is designed to quantify and minimize GHG emissions, air pollutions, and commute time of community members (i.e., employees, students, residents) that commute to a specified destination. GHG emissions, air pollutions, and commute time are quantified and combined into a single-objective function based on (1) total CO2, NOx, and VOCs emissions of all commuters; (2) total commute time of all commuters; (3) monetary values of GHG emissions, air pollution, and commute time; and (4) selected commute alternatives, as shown in Equation (1). This single-objective function is designed to identify the optimal selection of commute alternatives that minimizes the environmental impacts of a business commute system using the constraints discussed below.
FIGURE 3 Optimization Model Decision Variables.

Minimize: \( TEC = \)

\[
\sum_{m=1}^{M} \sum_{n=1}^{N} X_{m,n} \left[ CE_{m,n} \ast CEC + NE_{m,n} \ast NEC + VE_{m,n} \ast VEC + CT_{m,n} \ast CTC \right] \\
+ \sum_{m=1}^{M} \sum_{n=1}^{N} C_{m,n} \left[ CCE_{m,n} \ast CEC + CNE_{m,n} \ast NEC + CVE_{m,n} \ast VEC + CCT_{m,n} \ast CTC \right]
\]  

(1)

Where: TEC is total equivalent cost of negative environmental impacts and commute time of the commute system based on the selected commute alternatives; \( X_{m,n} \) is binary decision variable for commuter \( m \) to travel from the origin of the commute trip to the final destination using transportation mode \( n \) as shown in Figure 3; \( CE_{m,n} \) is carbon emissions of commuter \( m \) using transportation mode \( n \) in grams; \( CEC \) is equivalent social cost of carbon emissions (\( 4 \times 10^{-5} \) according to Environmental Protection Agency in 2014 (27)); \( NE_{m,n} \) is nitrogen oxide emissions of commuter \( m \) using transportation mode \( n \) in grams; \( NEC \) is equivalent social cost of nitrogen oxide emissions (\( 10.293 \times 10^{-3} \) according to Victoria Transport Policy Institute in 2013 (28)); \( VE_{m,n} \) is volatile organic compounds emissions of commuter \( m \) using transportation mode \( n \) in grams; \( VEC \) is equivalent social cost of volatile organic compound emissions (\( 2.392 \times 10^{-3} \) according to Victoria Transport Policy Institute in 2013 (28)); \( CT_{m,n} \) is commute time of commuter \( m \) using transportation mode \( n \) in minutes; \( CTC \) is equivalent social cost of commute time ($0.2 per minute according to U.S. Department of Transportation in 2009 (29)); \( C_{m,n} \) is carpool binary decision variable for commuter \( m \) picked up by commuter \( n \) as shown in Figure 3; and \( CCE_{m,n}, CNE_{m,n},CVE_{m,n} \) and \( CCT_{m,n} \) are carpool carbon emissions, nitrogen oxide emissions, volatile organic compounds, and commute time of commuter \( m \) picked up by commuter \( n \), respectively.

The optimization model integrates a number of constraints to ensure the practicality of the results. The model integrates four types of constraints (1) commuter constraint, (2) carpool constraint, (3) commute-duration tolerance constraint, and (4) incentives constraint. The commuter constraint is designed to limit the optimization model to select only one alternative for each commuter. For example, the model can elect for commuter # 1 to use public transportation and walking to get from the origin of his/her commute trip to the final destination. The carpool constraint currently allows a maximum of two commuters to commute from their trip origin to the specified destination. In this case, the model assumes that one commuter will pick up the other commuter and drive to the final destination. Therefore, if two commuters are commuting together, they cannot carpool with other commuters. The commute-duration tolerance constraints, which...
can be customized by individual, limit the time allowed for extending commute duration per trip. For example, the model will only recommend commute alternatives that do not extend the commute time for an individual more than a specified duration (in minutes). In addition, the model will only provide a recommendation that two commuters carpool together for commuters whose difference in arrival time do not exceed the specified duration (in minutes). Finally, the model integrates constraints that limit the total amount of monetary incentives that can be provided to all commuters in a network to a specified budget. Monetary incentives are calculated and allocated based on commuter hourly rates (individually) and the difference in duration between the existing commute mode and recommended alternative.

Model Implementation

The present model is implemented in three main steps: (1) develop the model computations using Mixed-Integer Programing (MIP) solver (30), (2) specify the model input data from the GIS model, and (3) generate an action report that provide recommendation for each commuter based on the optimization results.

The optimization computations are executed in the model using MIP due to its capability of guaranteeing a global optimal solution of the transportation network problem in a short computational time. The input data are designed to include output data from GIS model, including commute time, GHG in terms of carbon emissions and air pollution of nitrogen oxide and volatile organic compounds, and travel distance for each transportation alternative of a commuter. The optimization model also includes additional input data from the GIS model in the aforementioned categories for each commuter carpooling with another commuter in the network. Furthermore, the optimization model requires commuter specific information such as arrival time in the morning, departure time in the afternoon, parking cost, hourly rate, and existing method of the commuter to transport to the final destination in the morning and afternoon. Finally, the developed optimization model is designed to provide detailed results of the identified optimal solution. The model generates an action report that includes recommendations for each commuter, resulting changes in commute time difference, and individualized incentives.

The following section presents a pilot implementation of BCOS to illustrate its capabilities and evaluate its performance.

5. PILOT CASE STUDY: STUDENT COMMUTERS AT CALIFORNIA STATE UNIVERSITY, FRESNO

To demonstrate and test BCOS’s capabilities, pilot data was collected using an on-line survey instrument developed by the authors. The data documented real-world commute behavior for 21 undergraduate engineering students as they commuted to/from California State University, Fresno on a single, representative school day in spring 2015. Input data included information about transportation mode choice, arrival and departure times, and commute origin and destination. Survey participants were selected using a convenience sampling method. Therefore, response rate is not recorded.

Case Study Implementation

Commuters’ origins and destinations data were input into the GIS model component of BCOS. Integrating City of Fresno transportation system data, the GIS model generated route and commute trip attribute (GHG emissions, air pollution, and commute time and cost) for every
commuter using possible commuting alternatives in Fresno (sample output presented in Table 2B). Individual commute departure and arrival times and primary mode of transportation information for all case study participants (presented in Table 2A) along with the GIS component output (Table 2B) represent input data for the Optimization model component of BCOS.

Based on this data, the optimization model component calculated GHG emissions and air pollution of the existing commute plan and evaluated individual-specific commute incentives that would lead to reduction of the business commute footprints. As previously noted, the optimization model requires additional input data to set the commute-duration tolerances, commuter hourly rates, and available daily incentives that can be spend to incentivize commuter to implement the recommended commute alternatives. Assumptions and simplifications used in BCOS during the case study implementation are presented in the following section.

### TABLE 2 Commute Information Input for Optimization Model

#### TABLE 2A Commuter departure and arrival times and transportation modes of 21 students at California State University, Fresno

<table>
<thead>
<tr>
<th>Commuter</th>
<th>Morning Commute</th>
<th>Afternoon Commute</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Departure time</td>
<td>Primary Transportation mode</td>
</tr>
<tr>
<td>1</td>
<td>9:01 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>2</td>
<td>8:23 AM</td>
<td>Ride bike</td>
</tr>
<tr>
<td>3</td>
<td>9:46 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>4</td>
<td>8:16 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>5</td>
<td>12:07 PM</td>
<td>Drive car</td>
</tr>
<tr>
<td>6</td>
<td>8:39 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>7</td>
<td>8:11 AM</td>
<td>Walk</td>
</tr>
<tr>
<td>8</td>
<td>7:34 AM</td>
<td>Carpool</td>
</tr>
<tr>
<td>9</td>
<td>8:52 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>10</td>
<td>8:11 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>11</td>
<td>7:37 AM</td>
<td>Ride bike</td>
</tr>
<tr>
<td>12</td>
<td>8:05 AM</td>
<td>Carpool</td>
</tr>
<tr>
<td>13</td>
<td>7:35 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>14</td>
<td>7:57 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>15</td>
<td>8:51 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>16</td>
<td>9:59 AM</td>
<td>Walk</td>
</tr>
<tr>
<td>17</td>
<td>6:10 PM</td>
<td>Drive car</td>
</tr>
<tr>
<td>18</td>
<td>4:30 PM</td>
<td>Walk</td>
</tr>
<tr>
<td>19</td>
<td>9:43 AM</td>
<td>Drive car</td>
</tr>
<tr>
<td>20</td>
<td>10:59 AM</td>
<td>Walk</td>
</tr>
<tr>
<td>21</td>
<td>8:08 AM</td>
<td>Drive car</td>
</tr>
</tbody>
</table>
### TABLE 2B Values of trip attributes for all possible commuting alternatives in Fresno

(Sample GIS Model output for Commuter #1)

<table>
<thead>
<tr>
<th>Commute Options</th>
<th>Vehicle/bus/ train time</th>
<th>Walk/bike skateboard</th>
<th>Total travel time</th>
<th>Carpool commute time to destination</th>
<th>Travel distance</th>
<th>Travel distance for carpooling after pickup</th>
<th>Emissions</th>
<th>Carpool emissions after pickup</th>
<th>Commute cost</th>
<th>Carpool commute cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing vehicle</td>
<td>3.0</td>
<td>0.0</td>
<td>3.0</td>
<td>0.0</td>
<td>1.8</td>
<td>0.0</td>
<td>0.0</td>
<td>1.9</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Public transit 1</td>
<td>2.4</td>
<td>12.6</td>
<td>15.0</td>
<td>0.0</td>
<td>1.9</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Public transit 2</td>
<td>2.4</td>
<td>4.0</td>
<td>6.5</td>
<td>0.0</td>
<td>1.9</td>
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**Case Study Simplifications and Assumptions**

Several simplifications and assumptions were used in the calculation of the commute attributes for the case study. Following is a list of the prevailing ones:

- Route choice behavior: minimum travel time paths were assumed for each respective commute alternative.
- Congestion: average static travel times were assumed for all commute trips, i.e. travel times were not calculated as a function of increased route congestion.
- Existing vehicles: as presented in Table 1, national US fleet averages (rather than commuter-vehicle-specific values) were assumed for the different attribute parameters utilized in this model.
Parking: attribute values were calculated from commuters’ origins to destinations. Parking locations and availability of parking spaces were not included in the model.

Life cycle costs: trip costs were calculated as a function of only vehicle operation costs. Other vehicle lifecycle costs (e.g. costs of vehicles) were not included.

Value of time: valued of student time was assumed at the rate of $18 per hour. This rate was based on the average university hourly pay rate for undergraduate students.

Business budget for incentives: case study implementation set the maximum available monetary incentive at $200/day.

Student commuters: case study is based on student commuters. Student schedules are typically more flexible than those of employees, since most employees work 8 am – 5 pm shifts and have more responsibilities (e.g. picking kids from school).

Sample size: the presented case study includes only 21 commuters. A larger number of commuters would allow for increased carpooling possibilities.

Carpooling: modeled carpooling scenarios are based on only 2-person carpools (a driver and a passenger). Higher numbers of carpools would increase the estimated benefits of the identified optimum commute plans.

It should be noted that the stated simplifications are not an intrinsic characteristic of the modeling framework presented in this paper. As mentioned later in this paper, future extensions of this work will involve overcoming these limitations.

Case Study Results

BCOS was used to identify the optimal selection of commute alternatives that minimizes the environmental impacts and total commute time for the case study commute system using the assumptions discussed. The objective function used in the present optimization model component of BCOS is designed to allow the flexibility regarding whether to focus on GHG emissions, air pollution, and commute time, separately and/or collectively. For example, the objective function of the model can minimize only GHG emissions by setting zero rates for the air pollution (\(NEC = 0\)) and commute time (\(CTC = 0\)). In this case, the optimization model is able to identify the optimal selection of commute alternatives to minimize GHG emissions, as shown in Figure 4A in the solution listed for “GHG emissions only” (column 3).

In the “GHG emissions only” solution (Figure 4A), the optimization model component identified a system solution (optimum commute plan) where one commuter drives an existing vehicle, three commuters use public transit and biking, one commuter uses public transit and skateboarding, and 14 commuters bike. Similarly, the model identified different optimal solutions of commute alternatives: minimizing only NO\(_x\) emissions, only VOC emissions, and only commute times (Figure 4A). In addition, the model identified the optimal solution of commute alternatives for minimizing all combined emission costs and for minimizing combined costs of all emissions and commute times, as shown in Figure 4A. It should be noted that, in all the analyzed scenarios, the model eliminated several carpooling options due to the difference in arrival and departure times of the (small sample of) students. The optimization model allowed carpooling only for commuters who did not have differences in their arrival times in the morning commute and departure times in the afternoon commute greater than 30 minutes.

Next, the optimization model was used to analyze another set of scenarios to minimize all negative environmental impacts of the transportation network with varying tolerance to commute-duration for all individuals ranging from 0 minute to 40 minutes in five minute increments (Figure
Case study results demonstrate that, as the commuters tolerate more time to changes in their commute, the model recommends the use of commute alternatives associated with lower emissions such as walking, biking, and skateboarding in order to minimize the negative environmental impacts of the transportation network. For example, in the solution of 0 minute tolerance, the model identified 15 commuters to drive their existing vehicle and 6 commuters to ride their bikes to the destination. It should be noted that the equivalent cost of the existing transportation network is less than the solution of 0 minute tolerance, as the original network has two commuters carpooling, as reported in the survey. The carpooling details of those commuters were not reported in the survey and accordingly the emissions of these carpooling commuters were
calculated based on half of the emissions using existing vehicles. During the optimization computations, those two commuters were modeled as driving their existing vehicle which resulted in slightly higher emissions as shown in the solution of zero minute tolerance. It should also be noted that, the model does not prioritize one commuter alternative over the other if they lead to the same negative environmental impact. For example, in the solution of 5 minute tolerance, the optimization model recommends 5 commuters to drive their own cars, 7 commuters to use public transit and biking, 2 commuters to walk, 5 commuters to bike, and 2 commuters to skateboard. The model could have recommended 9 commuters to bike instead of 2 commuters to walk, 5 commuters to bike, and 2 commuters to skateboard and provide the same results of negative environmental impacts while complying with the model constraints. By increasing each commuter tolerance to 40 minutes, the model recommended all commuters to ride their bikes and eliminate all negative environmental impacts, as shown in Figure 4B in the solution listed for “tolerance 40 min. The optimization model is designed to generate a commute plan which includes individual-specific commute recommendations, difference in commute times, and available incentives, as shown in Table 3 in the 10 minute tolerance solution. The results of this solution show negative values for the difference in commute time of commuter 7, 16, 18, and 20. These negative values resulted because commuters originally reported that they walked and the model recommended biking which resulted in shorter commute time.

**TABLE 3 Selected commute alternatives and their difference in commute time and incentives for 10 minutes tolerance solution**

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<th>Commuters</th>
<th>Morning and afternoon commute method</th>
<th>Morning difference in commute time (min)</th>
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6. CONCLUSIONS AND FUTURE WORK

In addition to traffic congestion, fatalities and injuries, as well as other negative impacts, the transportation sector is responsible for a significant share of greenhouse gas and air pollution emissions. Substantial proportions of these impacts are attributed to the high modal share of single occupant (drive-alone) automobile trips. Accordingly, research and policy efforts directed towards increasing vehicle occupancy and increasing modal shares of alternative forms of transportation (e.g. active transportation and transit) are abundant. Given the high volume of commute travel, efforts that focus on commute travel are of a particularly high interest. This is evident by existence of the FTA’s Commuter Choice programs and California’s Parking Cash-Out Law. Such programs encourage businesses to offer employees monetary incentives for commute alternatives other than drive-alone. Businesses, in general, may be willing to offer employees with such commute incentives; however, identifying the optimum set of incentives and being able to quantify the resulting benefits is an important, enabling factor from a business’ perspective.

This paper presents a novel system, Business+ Commute Optimization System (BCOS), designed to enable businesses reduce their commute footprints. This system: a) identifies the optimum employee commute plan and associated set of employee-specific personalized incentives, and b) quantifies the resulting benefits, while taking into account individual employees travel limitations (e.g. desired departure times), as well as business budget constraints. The developed BCOS is composed of two components: a GIS model and an optimization mode. Given employee specific origins and destinations, desired travel plans (departure and arrival times), and the existing transportation system in the city, the GIS model calculates the travel attributes (e.g. travel time, cost, and emissions) of every individual employee associated with every possible commuting alternative in the city (e.g. walk, transit and carpool). Then, the optimization model utilizes these attributes; along with business incentives budget constraints to identify the optimum employees commute plan associated with minimizing a business-specified objective function (e.g. minimizing commute emissions, travel times, or a combination of different attributes). The paper also presents a pilot case study where the developed model was applied to 21 students commuting to and from California State University, Fresno. Students commute information was gathered for a regular school day in spring 2015 using a travel survey designed by the authors. The gathered information included students travel schedules (commute trip start times, and arrival times), and mode choices. The collected information revealed that most students commuted by driving alone.

The paper also presented a pilot case study where the developed model was applied to a real-life case of 21 students commuting to and from California State University, Fresno. Using a travel survey designed by the authors, students commute information was gathered for a regular school day in spring 2015. The gathered information included students travel schedules (commute trip start times, and arrival times), and mode choices. The collected information revealed that most students commuted by driving alone. Assuming a limited incentives budget of $200/day, the CBOS model was run six different times to identify and compare between six different optimum commute plans and resulting commute footprints. Each one of the runs was associated with a different business objective function. The model identified the optimum commute plans to minimize: CO₂ emissions, NOₓ emissions, VOC emissions, total cost of emissions (CO₂, NOₓ, and VOCs), travel times, and total cost of travel time and emissions. Additionally, the CBOS model was run to identify and compare between optimum commute plans and resulting commute footprints associated with different values of commuter travel schedule tolerance, i.e. tolerance in desired departure and arrival times. Examples of the results for such a community suggest that GHG emission and air pollution could be reduced for by 24% given a 15 minute travel schedule tolerance.
or that such emissions could be completely eliminated if a 40 minute travel schedule tolerance were permissible. These results serve as a proof-of-concept for BCOS and highlight the effectiveness of such a new strategy for minimizing traffic congestion and transportation related business emissions.

While the results of this work demonstrate that the developed system can serve as a valuable tool for identifying optimum businesses employee commute plans and for quantifying benefits associated with employee-specific alternative commuting incentives, several possible extensions are possible. A few examples of these extensions include: addressing the assumptions and simplifications mentioned in the paper including extending the model to more robustly address parking (i.e., cost and convenience) implications, implementing the developed model for a case with business employees rather than students including extending the model to more robustly address additional commuting constraints (i.e., childcare pick-up/drop-off requirements), integrating the willingness of individual commuters to receive incentives and change their commuting mode, and integrate individual commuters commuting mode preferences.

**AUTHOR CONTRIBUTION**

Authors at University of Colorado Denver and California State University, Fresno collaborated on this research. The originality of the business optimization systems is presented by Dr. Abdallah. The contribution of the research development is listed as follows:

1. The review of literature was performed by Dr. Tawfik
2. GIS model was developed and written by Dr. Tawfik and Ms. Adame
3. Optimization model was developed and written by Dr. Abdallah
4. Case study data collection was initiated and developed by Dr. Clevenger
5. Case study GIS analysis was performed by Dr. Tawfik and Ms. Adame
6. Case study optimization analysis and results were conducted by Dr. Abdallah
7. Case study was written by Dr. Abdallah and Dr. Clevenger
8. Conclusion was written by Dr. Tawfik
9. Future research directions were identified by all the authors

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25. US EPA Office of Transportatoin and Air Quality. Average In-Use Emissions from Urban Buses and School Buses.
26. U.S. DOT Burea of Transportation Statistics. Table 3-17: Average Cost of Owning and Operating an Automobile(a) (Assuming 15,000 Vehicle-Miles per Year).