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TIME-COST-ENVIRONMENT TRADE-OFF ANALYSIS FOR BUSINESS COMMUTING SYSTEMS

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Abstract: Half of transportation related emissions are reported to be from passenger cars and light-duty trucks such as sport utility vehicles, pickup trucks, and minivans. Furthermore, business transportation plans are frequently non optimized; relying instead on mainly on personnel convenience, time, and cost rather than environmental impacts and savings. This paper presents the development of an optimization model that is capable of identifying the optimal selection of individualized business commute alternatives in order to minimize GHG and air pollution emissions, commute time and cost. This model identifies the optimal commute mode for each commuter (e.g. drive car, carpool, use public transit or walk) that minimizes the aggregate negative environmental impacts, time, and cost of businesses while maintaining convenience. The optimization model is integrated with a geographical information system (GIS) to identify business commute attributes such as emissions and commute cost and time of each commute alternative. The performance of the developed optimization model is tested and verified using a case study of student community. Results of the case study are promising and illustrate the capabilities of the optimization model in minimizing business commute emissions, time, and cost.

1 Introduction

The United States (US) Environmental Protection Agency (EPA) reported in 2014 that Greenhouse Gas (GHG) emissions from the transportation sector is 26% of total national GHG emissions, second only to the electricity sector (Environmental Protection Agency 2013; U.S. EPA Office of Policy 2015). Over half of the emissions from the transportation sector are generated from passenger cars and light-duty trucks such as sport utility vehicles, pickup trucks, and minivans. Many local, regional, national and international agencies are actively studying opportunities to mitigate traffic congestion and reduce transportation related emissions. Several guidelines which support these studies and initiatives are currently available by several Departments of Transportation (DOTs). The existing strategies at DOTs rely mainly on: (1) multimodal transportation systems, (2) mixed land-use and transit-oriented developments, and (3) design of active-transportation friendly environments. While these strategies have contributed to the reduction of transportation related emissions and traffic congestion, additional research and innovative models are needed to further reduce transportation emissions as well as time and cost based on individualized action plans.

2 Literature Review

Commuters' mode choices and resultant impacts have received particular attention in the travel behavior literature. Since commute trips represent a significant percentage of morning and evening peak traffic, previous research efforts have focused on understanding reasons behind commuter mode choice behavior, and identifying ways to decrease impacts of morning and evening commutes; primarily by reducing the share of drive-alone commutes. Outcomes of these research efforts have resulted in the development of many policies and programs. Accordingly, another part of the literature focuses on the development and assessment of the subsequent effectiveness of these programs. The following subsections provide brief breakdown of the existing literature.

2.1 Motivation for Commute Modal Shares

Drive alone commute has been the primary mode of transportation in the US for many decades and the trend has been increasing. In 1980 and 2010, the modal share of drive-alone commute was 64.3% and 76.6%, respectively (American Association of State Highway and Transportation Officials 2013; Rossetti A and Eversole S 1993). Several factors appear to contribute to the high modal share of drive-alone commutes in the US. While the relative convenience of the automobile in comparison to other modes is an understandable factor, it does not explain the higher share of drive-alone commute in the US, in contrast to comparable societies in other developed states such as those in Europe and Asia. Several other factors contribute to high drive-alone commuting, such as urban sprawl, relatively lower gas taxes and dependent prices, lower overall (or perceived) quality of public transportation systems, and drive-alone commute subsidies.

Free or highly subsidized employee parking, compounded by the absence of equivalent subsidization for alternative modes of transportation, is believed to be one of the main reasons for the high percentage of drive-alone commutes in the US (Shoup 2005). Several efforts and policies are being developed to increase modals shares of non-drive-alone commutes. Examples of these policies include the 1990 Clean Air Act provision that required employers with more than 100 employees located in ozone nonattainment areas to develop policies that would result in a 25% increase in their employees commute auto occupancy above the area-wide baseline average (Black 2010; Meyer et al. 1999). Other common groups of programs include ones that seek to increase percentages of telecommuting and employee parking cash-out programs where employees can opt to receive the value of a parking space as additional income and arrange their own means of commute transportation. The impacts of these policies, however, remain minimal. In 2015, the National Compensation Survey revealed that most employers offer their employees with free parking at work; yet, only 7% offer subsidies for alternative modes of transportation (National Compensation Survey 2015).

It appears that the generalized nature of these policies represents significant limitations. For example, parking cash-out programs offer all employees the same, flat compensation regardless of their commute footprint. However, it is not uncommon for a single employee with a long commute to cause a footprint that is equivalent to the combined footprint of several employees with shorter commutes. It may be more efficient, therefore, to convince this single employee to switch to an alternative mode of travel; by offering a higher compensation than that offered to employees with shorter commute footprints. Similarly, since different employees have different mode preferences, businesses that offer mode-specific compensations (such as tax-free transit vouchers) may be able achieve higher impacts by individualizing their alternative transportation policies, and associated incentives.

2.2 Commuter Mode Choice Behavior

Many factors contribute to commuter mode choices. Examples of these factors include traveler specific factors such as age, gender, income, and value of time; mode specific factors such travel time and cost; trip specific factors such as trip chaining stops, and urban characteristics of origin and destination; business-related factors such as existence of free parking and incentives for alternative transportation modes; and environmental factors such as temperature and rain.

Examples of this group of literature include the work of Heinen et al. who used longitudinal data for 633 part-time bicycle commuters to investigate day-to-day decisions to commute by bicycles. Their results indicated that workers needing to wear business attire, transport goods, use a car during office hours, commute in the dark, commute facing higher wind speed, commute for a longer duration in rain, or have longer commute distances are less likely to commute by bicycle (Heinen et al. 2011). Chatman used the 1995 Nationwide Personal Transportation Survey (the predecessor name of the National Household Travel Survey, NHTS) to investigate the effect of density and mixed land use at the workplace on commute mode choice. He employed a joint logit-Tobit model and found that employment density at the workplace to be associated with a lower likelihood of automobile commuting (Chatman 2003). Bhat and Sardesai used stated and revealed preference data from a web-based commuter survey in Austin. They applied a mixed logit framework and their results emphasized the effect of commute and midday stop-making on mode choices. Additionally, their results indicated that travel time reliability is an important factor influencing commute mode choices (Bhat and Sardesai 2006).

2.3 Impacts of Commuter Mode Choices

Examples of research efforts focusing on impacts of businesses' alternative transportation programs include the work of Hamre and Buehler. They 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. They also found that the existence of free parking seemed to offset this increase likelihood (Hamre and Buehler 2014). 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 (Yang et al. 2015).

2.4 Tools for Business Alternative Transportation Programs

Literature is rich with research on commuter mode choice behavior; however, tools and applications that businesses can utilize to identify optimum policies and incentives, and associated benefits are limited. Three available tools include the Commuter Choice Decision Support System, CUTR_AVR Model, and Business Benefits Calculator. The Commuter Choice Decision Support System is supported by the U.S. Department of Transportation (USDOT) and the Environmental Protection Agency (US EPA). It is designed to help employers determine the most appropriate types of commuter choice options for [their] worksite (US Federal Highway Adminstration and US Environmental Protection Agency n.d.). The CUTR_AVR Model, developed in 1999 by the Center for Urban Transportation Research (CUTR) at the University of South Florida, is "based on a large, real-world data set" and uses an artificial neural network to predict mode share and average vehicle ridership by inputting attributes of the employer-based TDM program" (Center for Urban Transportation Research (CUTR) 1999). The third tool, Business Benefits Calculator, developed by the US EPA, is a "Web-based Calculator that enables an employer considering Best Workplaces for CommutersSM to estimate the financial, environmental, traffic-related, and other benefits of joining the program" (Damsted 2006).

All three of 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 individual-specific incentives that are specifically suitable for individual commuters. Accordingly, this proposal addresses this particular limitation and significantly extends previous research efforts.

3 Research Objective

The main objective of this research is to develop an optimization system that is capable of simultaneously minimizing GHG and air pollution emissions as well as commute time and cost of businesses. Information of individuals' commute origins and destination, departure times and arrival times as well as modes of transportation serves as the basis of the optimization system. The commute information is input into a geographical information system (GIS) which generates data of route and commute mode alternatives and corresponding emissions. The output data from the GIS is fed into a multi-objective optimization model to identify optimal commute plan for businesses and minimize negative environmental impacts as well as commute time and cost while maintaining commuter convenience. The optimization model is developed in two main phases (1) formulation phase which formulates the model decision variables, objective functions, and constraints; and (2) implementation phase that performs the model computations using linear programming and specifies the model input and output data. A case study of student community at California State University at Fresno is analyzed and optimized using the developed system to verify its performance and illustrate its capabilities.

4 Commute Attribute Calculations

Inputs of the GIS model were collected using a simple travel survey. The travel survey collected information about the commute trip of 21 undergraduate students at California State University, Fresno on two consecutive days during the Spring semester of 2015. The surveyed information included their commute trip origins and destinations including all intermediate stops during the commute, departure and arrival times, their chosen mode of travel, and their willingness to use alternative modes of transportation. Additional information and analysis of the survey results can be found in earlier publications (Clevenger et al. 2016; Tawfik et al. 2016). In order to quantify the footprint of the students' commute trips, the survey information were input into ESRI's ArcGIS and modeled using ESRI's Model Builder and the Network Analyst extension.

Building the ArcGIS multimodal transportation model involved a number of steps. First, GIS files for Fresno's different transportation networks (e.g. streets, bus lines and bus stops) were obtained from the local Metropolitan Planning Organization (Fresno Council of Governments, Fresno COG). Second, these transportation networks were modified to ensure the connectivity between the different elements across the different networks (e.g. connectivity between the streets and bus stops, and between the bus stops and the bus lines). Third, a multimodal network dataset was built to allow for the estimation of the trip characteristics (travel time and travel distance) and footprint attribute values (GHG and air pollution emissions, energy demand, and travel cost) of any trip within the study area. Calculation of the different mode-specific footprint attribute estimates were based on average parameter values that are included in Table 1.

Table 1. Values of Parameters Utilized in Calculations of Footprint Attribute Estimates

Mode \ Attribute	Travel Time	Travel Distance	CO2 Emissions	NOx Emissions	VOC Emissions	Travel Cost
Walk	$\frac{Distance}{3\ mph}$	Trip Origin to Destination	0.0	0.000	0.000	0.0
Bike	$\frac{Distance}{10\ mph}$	Trip Origin to Destination	0.0	0.000	0.000	0.0
Bus	$\frac{Distance}{30\ mph}$	Trip Origin to Destination	294.6 g/p-mi*	1.643 g/p-mi*	0.039 g/p-mi*	0.0
Car	$\sum \frac{Link\ Lengths}{Speed\ Limits}$	Trip Origin to Destination	368.4 g/mi	0.693 g/mi	1.034 g/mi	59.2 ¢/mi

* p-mi is passenger mile (assuming 25% bus occupancy)

Once the multimodal network dataset was created, the students' trip origins and destinations were geocoded into the GIS model. Next, models were created to simulate every student's commute trip using every possible travel mode (walk, bike, bus, car and carpool), and calculate the trip footprint associated with every student-mode combination. The simulation code was created using ESRI's ModelBuilder and Python code. Further elaboration of the GIS model is included in a previous publication (Tawfik et al. 2016). Table 3 presents a sample output from the GIS model, showing the calculated footprint attributes associated with every possible commute mode for one student.

5 Optimization Model

5.1 Formulation

The optimization model's decision variables are designed to model all transportation alternatives for commuters which impact GHG emissions, air pollutions, commute time, and cost. These transportation alternatives, include driving existing vehicle, driving new vehicle, using public transit and walking, using public transit and biking, walking, biking, and carpooling with every commuter separately (HOV 2), as shown in Figure 1. A binary decision variable is used to model each of the commute alternatives representing the primary mode of transport a commuter utilizes to travel from the origin of the commute trip to the final destination. The optimization model considers only one route for each transportation alternative, based on the GIS model which represents the shortest travel time from the origin of the commute trip to the final destination.

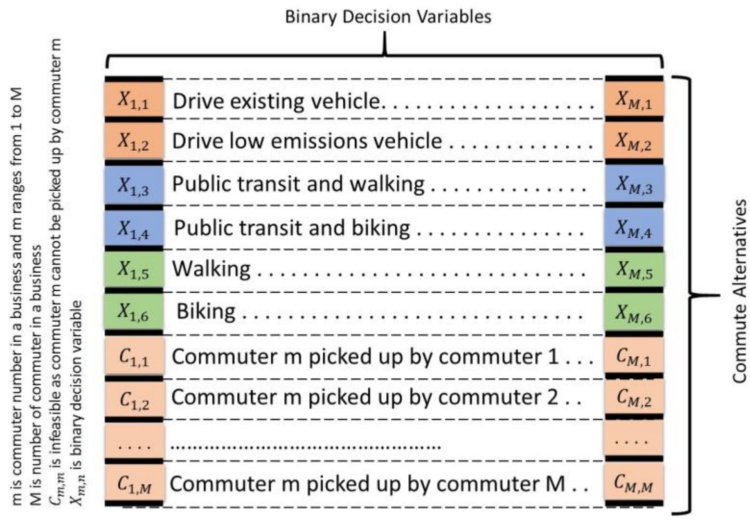

Figure 1. Optimization Model Decision Variables

The objective functions of the optimization model are designed to quantify and minimize (1) GHG and air pollution emissions, and (2) total commute time for a number of commuters that commute to/from a shared destination/origin, and (3) total commute cost for a number of commuters that commute to/from a shared destination/origin. Three objective functions are used to minimize the aforementioned negative environmental impacts and total commute time. GHG and air pollution emissions are qualified and combined based on (1) CO_2, NO_x, and VOC_x emissions, (2) monetary values of GHG and air pollution emissions, and (3) selected commute alternatives. Total commute time of a business is qualified and minimized in the model based on the selected commute alternatives and their commute time from the GIS model. Similarly, total commute cost of a business is quantified and minimized in the model based on the selected commute alternatives and their costs from the GIS model.

The developed model integrates a number of constraints to ensure the practicality of the generated solutions, including (1) commuter constraint, (2) carpool constraint, and (3) tolerance constraint. The commuter constraint is integrated in the model to select only one commute alternative for each commuter. For example, the optimization model can select commuter # 2 to use public transportation and walking to get from the trip origin to destination. The carpool constraint is integrated in the model to allow two commuters to commute from the origin of their commute trip to the specified destination. The model is designed to allow one commuter to pick up another commuter and drive to the specified destination. Furthermore, one two commuters are commuting together, they cannot carpool with other commuters. A tolerance constraint is integrated in the model to limit the recommended commute alternatives of the model based on the flexibility of the commuter and maintain convenience. For example, the model will only recommend commute alternative for a commuter which does not extend the commute time more than a specified commuter tolerance (in minutes). In addition, the developed model allows only two commuters to carpool together if the difference in their arrival time do not exceed a specified commuter tolerance (in minutes).

5.2 Implementation Phase

The developed multi-objective optimization model is implemented in four main steps: (1) specify the model input data from the GIS model, (2) execute the model computations using weighted mixed-integer programing, (3) generate trade-off solutions among the objectives of the optimization model, and (4) generate recommendations for business commuters.

The developed system is designed to receive commute data of all feasible commute alternatives for each commuter from the GIS. Commute data is designed to include commute time and cost; travel distance, environmental impacts in terms of carbon emissions, air pollution of nitrogen oxide, and volatile organic compounds; and fuel consumption for each transportation mode of each commuter as well as carpooling in the business. Furthermore, the optimization model requires additional commuter data such as arrival time in the morning, departure time in the afternoon, parking cost, commuter hourly rate, and existing commute method for each commuter to transport to the destination in the morning and afternoon.

The optimization computations are executed in the model using weighted mixed-integer programing due to its capability to guarantee a global optimal solution of business commuters in a short computational time, and generate trade-offs solutions among the three optimization objectives. The optimization model is designed to generate trade-off solutions among (1) minimizing total negative environmental impacts, (2) minimizing total commute time of business commuters, and (3) minimizing total commute cost of business commuters. These trade-off solutions represent those solutions that are not dominated by any other solution with respect to the aforementioned three optimization objectives. The Pareto optimal solutions can be generated using unique combinations of relative importance weights for the aforementioned three optimization objectives. For example, a trade-off solution can be generated by setting the total equivalent cost of emissions weight to 100% and 0% to the other two optimization objectives. Similarly, two other trade-off solutions can be generated by setting total commute time weight to 100% with 0% to the other two objectives, and setting total commute cost weight to 100% with 0% to the other two objectives. Additional trade-off solutions can be generated by setting unique weights for the three optimization objectives. It should be noted that, the optimization objectives need to be normalized while identifying the trade-off solutions. Finally, detailed results for each trade-off solution is provided by the developed optimization model. An action report is generated which include individualized information on the recommended commute method for each commuter, expected addition/reduction in commute time, cost, and emissions, departure and arrival times, and expected savings.

6 Case Study

A case study of students at California State University at Fresno is analyzed to evaluate the system performance and illustrate its new capabilities. The data of the case study was collected using an online survey developed by the authors. The collected data represents real-world commute behavior of 21 engineering students as they commuted to/from California State University, Fresno campus on a representative school day. Collected data included departure and arrival times, transportation mode choice, and commute origin and destination. The departure and arrival time and primary transportation mode for student commute in the morning and afternoon are summarized and listed in Table 2.

The collected data was then input into the GIS to identify various commute attributes. Based on the integrated City of Fresno transportation system data, the GIS generated attributes of carbon emissions, nitrogen oxide emissions, volatile organic compounds, and commute trip duration and cost for each commute alternative in Fresno. The generated emissions are then converted to social costs based on emission factors discussed in the model formulation section. A sample of the generated data for one of the commuters is summarized and listed as shown in Table 3.

Table 2. Departure and arrival time and primary transportation mode for students' commute

	Morning Commute			Afternoon Commute		
Commuter	Departure time	Transportation Mode	Arrival time	Departure time	Transportation Mode	Arrival time
1	9:46 AM	Drive car	9:55 AM	2:01 PM	Drive car	2:10 PM
2	9:01 AM	Drive car	9:05 AM	5:56 PM	Drive car	6:00 PM
3	8:23 AM	Ride bike	8:25 AM	9:58 AM	Ride bike	10:00 AM
4	8:16 AM	Drive car	8:20 AM	6:25 PM	Drive car	6:30 PM
5	12:07 PM	Drive car	12:23 PM	3:54 PM	Drive car	4:10 PM
6	8:39 AM	Drive car	8:46 AM	10:57 AM	Drive car	11:00 AM
7	8:11 AM	Walk	8:12 AM	2:59 PM	Walk	3:00 PM
8	8:11 AM	Drive car	8:15 AM	8:11 PM	Drive car	8:15 PM
9	7:34 AM	Carpool	7:43 AM	6:22 PM	Carpool	6:30 PM
10	8:52 AM	Drive car	9:00 AM	11:53 AM	Drive car	12:00 PM
11	7:37 AM	Ride bike	7:40 AM	3:58 PM	Ride bike	4:00 PM
12	8:05 AM	Carpool	8:15 AM	10:51 PM	Carpool	11:00 PM
13	7:35 AM	Drive car	7:40 AM	7:36 AM	Drive car	7:40 AM
14	7:57 AM	Drive car	8:01 AM	9:56 AM	Drive car	10:00 AM
15	6:10 PM	Drive car	6:14 PM	7:56 PM	Drive car	8:00 PM
16	8:51 AM	Drive car	9:02 AM	1:55 PM	Drive car	2:00 PM
17	9:59 AM	Walk	10:00 AM	12:08 PM	Walk	12:10 PM
18	4:30 PM	walk	4:32 PM	9:28 PM	Walk	9:30 PM
19	9:43 AM	Drive car	9:55 AM	9:53 PM	Drive car	10:05 PM
20	10:59 AM	walk	11:00 AM	4:59 PM	walk	5:00 PM
21	8:08 AM	Drive car	8:20 AM	4:48 PM	Drive car	5:00 PM

Based on the collected data of the student community, the optimization system calculated total equivalent social cost at $4.61, total commute time at 382 minutes, and total commute cost at $205 as shown as existing scenario in Figure 2 and Figure 3. The optimization model was then used to optimize the commute plan for the student community at Fresno by identifying the optimal selection of commute alternatives that generates optimal trade-offs among the three optimization objectives of (1) minimizing equivalent social cost of negative environmental impacts, (2) minimizing total commute time, and (3) minimizing total commute cost. A commuter tolerance of 25 minutes for depart and arrival times was used in optimizing the students' commute plan to limit the commute time increate for each student by no more than 25 minutes.

The Pareto optimal solutions that are identified by the model for negative environmental impacts and total commute time are shown in Figure 2. Two extreme solutions were identified with minimum possible total commute time as shown in solution (a) in Figure 2 and minimum possible negative environmental impacts as shown in solution (b) in Figure 2. Similarly, the Pareto optimal solutions that are identified by the model for total commute cost and total commute time are shown in Figure 3. A new extreme solution is identified for minimum possible commute cost as shown in solution (c) in Figure 3. It should be noted that solution (a) is the same in both Figure 2 and Figure 3 as they constitute a 3D space of the three optimization objectives. Between the identified extreme solutions, the optimization model identified several trade-off solutions as shown in Figure 2 and Figure 3. Many of the identified solutions outperforms the existing scenario in terms of the three optimization objectives. For example, solution (d) outperforms existing scenario in terms of negative environmental impacts (31% reduction) and total commute time (21% reduction) as shown in Figure 2. Similarly, solution (e) outperforms existing students commute in terms of total commute time (21% reduction), and cost (52% reduction) as shown in Figure 3. This highlights opportunities for identifying optimal commute plans for business not only that maintains commuter convenience but also incentives commuters based on savings in commute time and cost as well as reduction in their daily negative environmental impacts.

Table 3. Sample of commuter 1 trip attributes values for all possible commuting alternatives in Fresno

Commute Options		Vehicle/bus/ train time	Walk/bike skateboard	Total travel time	Carpool commute time to destination	Travel distance	Travel distance for carpooling after pickup	Emissions	carpool emissions after pickup	Commute cost	Carpool commute cost
Existing vehicle		1.8	0.0	1.8	0.0	0.9	0.0	0.0	0.0	1.0	0.0
Public transit 1		1.0	8.2	9.1	0.0	0.9	0.0	0.0	0.0	0.0	0.0
Public transit 2		1.0	3.3	4.3	0.0	0.9	0.0	0.0	0.0	0.0	0.0
Bike		0.0	5.6	5.6	0.0	0.9	0.0	0.0	0.0	0.0	0.0
Walk		0.0	17.4	17.4	0.0	0.9	0.0	0.0	0.0	0.0	0.0
Carpool options	2.1	0.0	2.1	3.0	0.9	1.8	0.0	0.0	1.8	1.1	1.1
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.6
	7.8	0.0	7.8	8.5	4.5	4.1	0.2	0.0	6.8	2.4	2.4
	3.6	0.0	3.6	4.0	2.9	2.4	0.1	0.0	4.2	1.4	1.4
	14.0	0.0	14.0	15.8	8.8	9.7	0.3	0.0	14.1	5.7	5.7
	5.8	0.0	5.8	6.6	5.2	5.1	0.2	0.0	8.0	3.0	3.0
	0.8	0.0	0.8	1.0	0.5	0.4	0.0	0.0	0.8	0.2	0.2
	6.5	0.0	6.5	8.2	5.1	6.0	0.2	0.0	8.4	3.6	3.6
	7.5	0.0	7.5	7.8	6.6	6.0	0.2	0.0	9.9	3.5	3.5
	3.1	0.0	3.1	3.6	2.0	1.9	0.1	0.0	3.1	1.1	1.1
	1.5	0.0	1.5	2.8	1.0	1.3	0.0	0.0	1.7	0.8	0.8
	8.1	0.0	8.1	9.8	6.1	7.0	0.2	0.0	9.9	4.1	4.1
	3.3	0.0	3.3	4.4	2.0	3.2	0.1	0.0	3.8	1.9	1.9
	3.0	0.0	3.0	3.2	2.0	1.9	0.1	0.0	3.1	1.1	1.1
	10.4	0.0	10.4	10.1	7.1	6.3	0.2	0.0	10.6	3.7	3.7
	1.2	0.0	1.2	0.5	0.6	0.4	0.0	0.0	0.8	0.2	0.2
	3.5	0.0	3.5	3.7	2.0	1.9	0.1	0.0	3.1	1.1	1.1
	1.0	0.0	1.0	2.0	0.5	0.9	0.0	0.0	1.0	0.5	0.5
	9.6	0.0	9.6	11.4	9.4	10.3	0.4	0.0	15.0	6.1	6.1
	8.5	0.0	8.5	1.0	5.0	0.4	0.1	0.0	5.4	0.2	0.2
	17.8	0.0	17.8	11.8	12.6	7.6	0.4	0.0	17.0	4.5	4.5

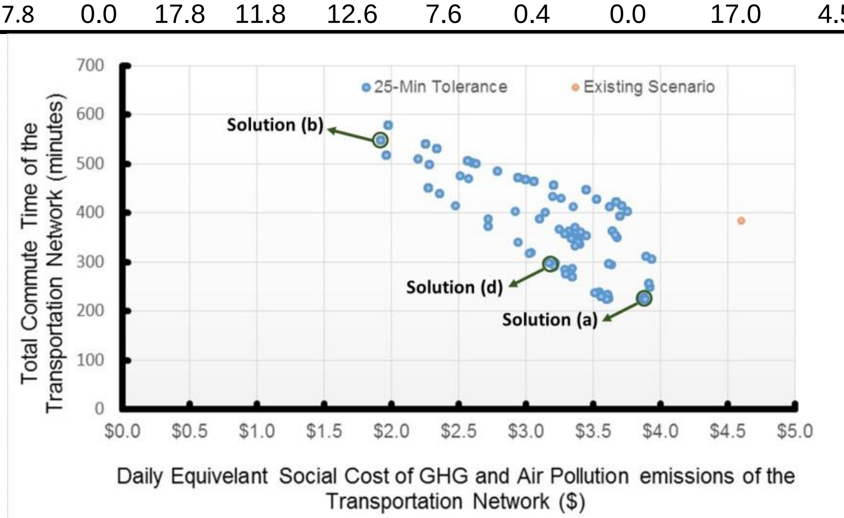

Figure 2. Time-cost-environment trade-off solutions for student community at Fresno

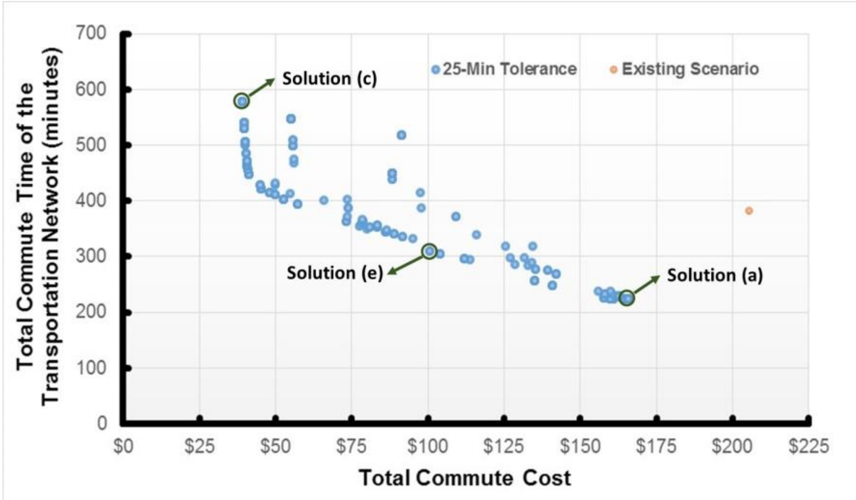

Figure 3. Time-cost-environment trade-off solutions for student community at Fresno

7 Summary and Conclusions

Over half of the reported emissions by the environmental protection agency from the transportation sector are generated from passenger cars and light-duty trucks. Significant portion of these emissions are caused by single occupant (drive-alone) automobile trips. Furthermore, business transportation plans are always non optimized; relying mainly on personnel convenience, time, and cost rather than environmental impacts and savings. This paper presents the development of an optimization system that is capable of identifying the optimal selection of individualized business commute alternatives in order to minimize GHG and air pollution emissions, commute time and cost. The optimization system is integrated with GIS to quantify various commute attributes such as trip time, distance, cost, and GHG and air pollution emissions for each possible commute alternative of each commuter. The output of the GIS is fed into an optimization model to minimize environmental impacts, and commute time and cost. The optimization model is developed in two phases (1) formulation phase, and (2) implementation phase. The first phase focused on identifying the model decision variables to model all the commute alternatives for each commuter in a business. In addition, this phase focused on formulating the objective function to minimize (i) total negative environmental impacts of a business, (ii) total commute time, and (iii) total commute cost. The model integrated a number of constraints to maintain commuter tolerance, commute logic, and carpool for two commuters. The second phase focused on executing the model computations to identify the optimal trade-offs among the three optimization objectives. Furthermore, this phase focused on identifying the model input data and recommendations for minimizing commute environmental impacts, time, and cost.

A case study was analyzed to evaluate the performance of the developed optimization model and demonstrate its new capabilities. Commute data from 21 students at California State University at Fresno was collected using online survey then analyzed. The optimization model was able to identify time-cost-environmental trade-offs for the student community and provide recommendations that maintain the commuter tolerance and achieve the optimization objectives. The recommendations of the model showed promising expectations for implementation based on savings in the commute time and cost and potential for reducing negative environmental impacts. Future expansion of the model will analyze additional objectives such as burned calories as health benefits. Furthermore, future expansion of the system could include the dynamics of the transportation networks to provide further practical solutions based on the traffic congestions and route choices.

References

American Association of State Highway and Transportation Officials. (2013). *Commuting in America 2013 : the national report on commuting patterns and trends.* American Association of State

Highway and Transportation Officials, Washington, DC.
Bhat, C. R., and Sardesai, R. (2006). “The impact of stop-making and travel time reliability on commute mode choice.” *Transportation Research Part B: Methodological*, 40(9), 709–730.
Black, W. R. (2010). *Sustainable transportation : problems and solutions*. Guilford Press, New York.
Center for Urban Transportation Research (CUTR). (1999). “CUTR_AVR model.”
Chatman, D. (2003). “How Density and Mixed Uses at the Workplace Affect Personal Commercial Travel and Commute Mode Choice.” *Transportation Research Record: Journal of the Transportation Research Board*, Transportation Research Board of the National Academies, 1831, 193–201.
Clevenger, C. M., Abdallah, M., Tawfik, A. M., Adame, B. A., Akalps, D., and Ozbek, M. (2016). “Exploring Student Commute Behavior and Identifying Opportunities to Minimize Commute GHG and Air Pollution Emissions: A Case Study.” *Construction Research Congress*, San Juan, Puerto Rico.
Damsted, J. (2006). “Business benefit.”
Environmental Protection Agency. (2013). “Sources of Greenhouse Gas Emissions.” <http://www.epa.gov/climatechange/ghgemissions/sources/transportation.html> (Aug. 1, 2015).
Hamre, A., and Buehler, R. (2014). “Commuter Mode Choice and Free Car Parking, Public Transportation Benefits, Showers/Lockers, and Bike Parking at Work: Evidence from the Washington, DC Region.” *Journal of Public Transportation*, 17(2), 67–91.
Heinen, E., Maat, K., and van Wee, B. (2011). “Day-to-Day Choice to Commute or Not by Bicycle.” *Transportation Research Record: Journal of the Transportation Research Board*, Transportation Research Board of the National Academies, 2230, 9–18.
Meyer, J. R., Gomez-Ibanez, J. A., Tye, W. B., and Winston, C. (1999). “Essays in transportation economics and policy a handbook in honor of John R. Meyer.” Brookings Institution Press, Washington, D.C.
National Compensation Survey. (2015). “Civilian Access to Subsidized commuting.” U.S. Bureau of Labor Statistics.
Rossetti A, M., and Eversole S, B. (1993). *Journey to work trends in the United States and its major metropolitan areas, 1960-1990*.
Shoup, D. (2005). *The high cost of free parking*. Planners Press American Planning Association, Chicago.
Tawfik, A., Abdallah, M., Clevenger, C., and Adame, B. A. (2016). “Business+ Commute Optimization System: Model Development and Pilot Real-Life Case Study.” *Transportation Research Board (TRB) 95th Annual Meeting*, Washington, D.C.
U.S. EPA Office of Policy, P. and E. (2015). *Inventory of U.S. greenhouse gas emissions and sinks : 1990-1994*. U.S. Environmental Protection Agency, Washington, DC.
US Federal Highway Adminstration, and US Environmental Protection Agency. (n.d.). “Commuter Choice Decision Support System.” <http://www.ops.fhwa.dot.gov/primerdss/index.htm> (Feb. 16, 2016).
Yang, L., Hipp, J. A., Adlakha, D., Marx, C. M., Tabak, R. G., and Brownson, R. C. (2015). “Choice of commuting mode among employees: Do home neighborhood environment, worksite neighborhood environment, and worksite policy and supports matter?” *Journal of transport & health*, 2(2), 212–218.