MPC-584
December 14, 2018

Project Title
Expanding the Capabilities of Business Commute Optimization System to Model Additional Transportation Alternatives and On-Demand Needs

University
University of Colorado Denver

Principal Investigators
Moatassem Abdallah
Assistant Professor
University of Colorado Denver
Phone: (303) 315-7566
Email: moatassem.abdallah@ucdenver.edu
ORCID: 0000-0002-3077-6518

Caroline M. Clevenger
Associate Professor
University of Colorado Denver
Phone: (303) 315-7567
Email: caroline.clevenger@ucdenver.edu
ORCID: 0000-0003-2265-8447

Research Needs
Transportation systems are currently facing several interrelated challenges, including traffic congestion, air pollution, greenhouse gas (GHG) emissions, and increasing energy and infrastructure costs. For example, total transportation-related CO_2 emissions accounted for 34.4% of emissions in the United States in 2015, second only to the electricity sector (Environmental Protection Agency 2017a). Additionally, the transportation sector has been a primary source of air pollutant emissions accounting for over 50% of particulate matter (PM), 30% of nitrogen oxides (NOx), and 20% of volatile organic compounds (VOCs) in the United States (Environmental Protection Agency 2017b). Unlike other economic sectors, transportation runs nearly exclusively on petroleum which consumes more than 70% of the total petroleum production in the United States (Williams et al. 2017). Accordingly, the transportation sector is identified as an immediate high-priority target in reducing greenhouse gas (GHG) and air pollution emissions and thus Departments of Transportation (DOTs) continuously try to reduce transportation-related GHG emissions.

In addition to the environmental impacts, challenges of traffic congestion and rising energy and infrastructure costs present a pressing need to increase the efficiency of the transportation systems. Recently in the USA, it was commonly believed that construction and operation of new highways was a reasonable approach for addressing these challenges. Today, however, it is believed that an effective solution requires more efficient planning for, and utilization of, all transportation modes instead of focusing on mainly the personal automobile. For example, drive-alone commuting has been the primary mode of transportation in the US for many decades. Problematically, the trend has been increasing. In 1980 and 2010, modal share of drive-alone commute was 64.3% and 76.6%, respectively. Hence, much work is being conducted to identify successful policies and systems to increase modal shares of active transportation, ridesharing, and transit systems (Greene and Plotkin 2011).

This proposal focuses on expanding the capabilities of a system developed by the Principal Investigators (PIs) called, Business Commute Optimization system (BCOS). BCOS is designed to identify optimal selection of commute alternatives for employees in a business to minimize their transportation emissions and air pollution as well as commute time and cost. BCOS is designed to identify commute plan for each employee in a business that complies with an individual's commute preference and convenience while incentivizing commute behavior change using monetary incentives and savings. The new capabilities will enable BCOS to model additional transportation alternatives, including the use of (1) low emissions vehicles such as electric and hybrid vehicles; and (2) public transportation options such as Uber or Lyft in order to minimize transportation emissions as well as commuting time and cost, see example solution for Employee # 2 in Figure 1. Furthermore, the new capabilities will enable BCOS to analyze and optimize on-demand needs along with an optimal commute plan of business commuters, see Figure 1. The research team will expand the design and implementation of the optimization models in BCOS to achieve the above two objectives. Finally, the expansion of the system will include the development of mobile applications for IOS and android systems to facilitate data collection and interaction with business employees.

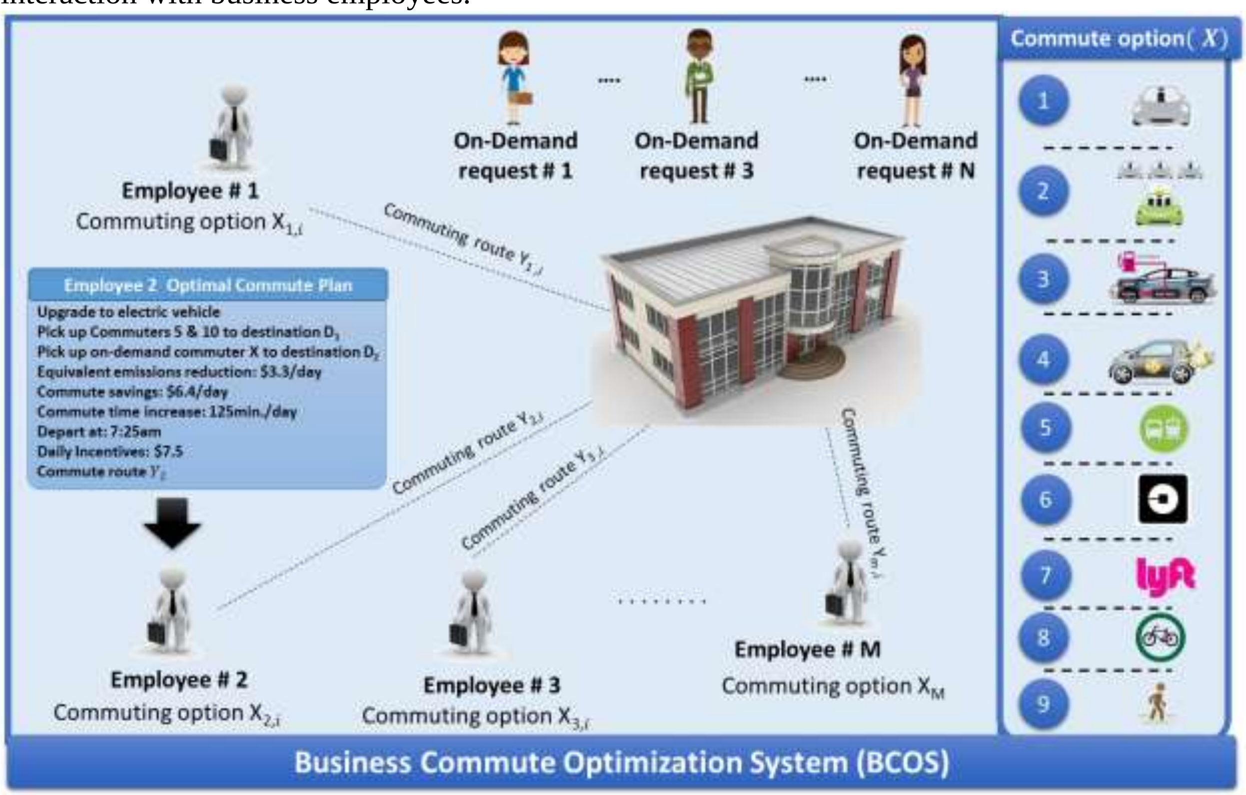

Figure 1. Outline of the proposed Business Commute Optimization system (BCOS)

Literature Review

The commute mode choices and their impacts have been extensively studied in the literature. To promote the use of alternative transportation modes for businesses, several studies have investigated the influencing factors on commute mode choice behavior, and their environmental impacts and costs. These studies are grouped and discussed in four categories as follows:

Commute Mode Choice Influential Factors

Several influential factors contribute to commute mode choice (Garvill 1999). These factors are reported in the literature as (1) commuter specific factors such as age, gender, physical health condition, and education level; (2) commute mode specific factors such as time, cost, safety, and perceived convenience; (3) commute specific factors urban characteristics of origin and destination; (4) commute mode benefit factors such as incentives for alternative commute modes; and (5) environmental factors such as weather conditions.

Specifically, Heinen et al. conducted an online survey to gather commute mode choice behavior of 4,000 respondents. They used the data to identify primary factors influencing bike commute choice. Their analysis showed that the workplace conditions and facilities e.g., presence of bicycle storage, locker room and clothes changing and shower facilities can highly motivate commuters to use biking (Heinen et al. 2013). Hamre and Buehler evaluated the relationship between commuter benefits and mode choice for the commute to work using preference data on 4,630 regular commuters in the Washington, DC region. Their analysis suggested that benefits for public transportation, walking, and cycling seem to work best when car parking is not free (Hamre and Buehler 2014).

Impacts of Commute Mode Choices

Commuters' mode choice and the resultant impacts of strategies on reducing GHG emissions have been studied extensively. To this end, de Nazelle et al. estimated 400 ton per day CO_2 emissions reduction using MOBILE6 emission factor model when other commute modes instead of driving are used for trips less than 3 miles (de Nazelle et al. 2010). Other researchers studied the benefits in public health when using more active transportation modes such as biking or walking. In this respect, Maizlish et. al found out that 18 minutes extension in daily commute time using biking or walking reduces diabetes and colon and lung cancer by 14% and 5%, respectively while minimizing GHG emissions by at least 9% (Maizlish et al. 2013).

Commute Mode Choice Incentive Programs

Full/partial subsidization of parking space at workplace along with the absence of alternative transportation incentive programs is one of the primary reasons for high modal share of drive-alone. There seems to be a growing tendency to design and implement incentivized policies and programs to encourage commuters to change their commute behavior. These policies and programs include: (1) parking cash-out; (2) employee parking pricing; (3) ridesharing and carpool matching; (4) emergency ride home; (5) teleworking; (6) employer-paid transit/vanpool benefits; (7) shuttles from transit stations; (8) and secure bicycle parking, showers and/or lockers. For example, in the parking cash-out program, the commuters can either continue using the employer-paid/subsidized parking space or get the equivalent cash out of the parking space as an additional taxable income. It is reported that the parking cash-out program can reduce the drive-alone commute mode by 17%, followed by 39% and 50% increase in bike/walk and public transportation usage, respectively (Shoup 1997). However, the parking cash-out program does not account for the commuters' benefit losses in terms of time, cost, convenience and carbon footprint when calculating the equivalent cash out parking space.

Business Commute Mode Choice Evaluation Tools

The existing tools to assess the costs and savings with respect to commuters as well as employers under different GHG emission control policies are limited. These tools are CUTR_AVR model (University of South Florida 1998), Business Benefits Calculator (Center for Urban Transportation Research 2002), and Commuter Choice Decision Support System (Federal Highway Administration 2003). For example, the Commuter Choice Decision Support System, supported by DOT and EPA, is an interactive tool capable of assessing conditions of a working place. The tool is intended to help employers decide on establishing a better work environment that reduces drive alone modal share. However, the aforementioned tools offer only limited guidelines regardless of the employees' preferences in terms of commute time or cost and therefore the optimality of the outcomes is not clear. Moreover, incentives are often calculated regardless of the individual's contribution to GHG emissions while commute preferences in terms of travel time, cost, and convenience are often not taken into account. To address these shortcomings, the PIs have previously developed a framework for collecting and incorporating commute preferences to optimize commute plans in terms of GHG and air pollution emissions as well as commute time and cost (Tawfik et al. 2015, Clevenger et al. 2016, Abdallah et al. 2017, Monghasemi et al. 2018a, 2018b) These recent publications were supported by a previously funded project by MPC and this proposal builds upon and extends such work as outlined below.

Research Objectives

The main goal of this research work is to expand the capabilities of an innovative system developed by the PIs called Business Commute Optimization System (BCOS). The new capabilities of BCOS will enable the analysis of additional transportation alternatives to identify optimal commute plans for business employees, facilitate its use by businesses using smartphones, and investigate its use for autonomous vehicles. The objectives of this research are summarized as follows:

1- Expand the capabilities of BCOS to model additional decision variables, including (a) hybrid or electric vehicles use to minimize transportation related emissions, and (b) public transit options such as Uber or Lyft.
2- Expand the capabilities of BCOS to model and integrate on-demand transit needs.
3- Develop new mobile Apps to facilitate data collection of business commuters.
4- Demonstrate the new capabilities of BCOS using a pilot case study of a business and on-demand needs.

Research Methods

The primary goal of the proposed research is to develop, test and refine innovative models to support multi-objective and dynamic optimization of business commute systems. BCOS consists of Geographical Information System and Multi-Objective Optimization Model as shown in Figure 2. The GIS and Optimization model require a number of input data, including business address, home address for each employee, travel schedule for each employee, existing commute behavior and its characteristics, parking cost, preferred transportation modes, and tolerance to commute duration. The GIS is designed to calculate six trip attributes with every commute mode and for every employee, including energy use, GHG emissions, air pollution emissions, travel time, distance, and cost. This GIS integrates existing transportation system data with information about every employee's home and work locations, available modes, desired commute times, flexibility in departure and travel times, and trip-chaining necessities to calculate the above six attributes. The optimization model is designed to identify the optimal commute method for each commuter in order to simultaneously minimize total GHG and air pollution emissions, commute time, and commute cost while maintaining convenience and incentivizing commuters using monetary incentives and savings. BCOS provides an optimized commute plan that complies with departure and arrival times, availability of commute alternatives, availability of budgets for incentivizing commuters, flexibility in commute time, and convenience by studying and analyzing all possible commute options, as shown in Figure 2. This research project will focus on expanding the capabilities of BCOS by modeling additional transportation alternatives, including the use of hybrid or electric vehicles as well as public transportation options such as Uber or Lyft. Additionally, BCOS will be expanded to integrate on-demand need to identify optimal commute plan for businesses. Mobile apps will be developed to (1) facilitate data collection of the GIS and optimization model, and (2) deliver the identified solutions by the optimization model to business employees, as shown in Figure 2. The PIs received funding for two previous projects to develop BCOS and the research work in this proposal will build on the findings and development of previous projects. The PIs has extensive expertise to expand the capabilities of BCOS and they have successfully developed numerous single and multi-objective optimization models that utilized linear and integer programming as well as evolutionary algorithms to support decision making (Abdallah et al. 2015a, 2015b, 2015c, 2016, 2017, Abdallah and El-Rayes 2016). The main tasks to accomplish the goals of this research are outlined in Figure 2. The project tasks are discussed in the work plan section.

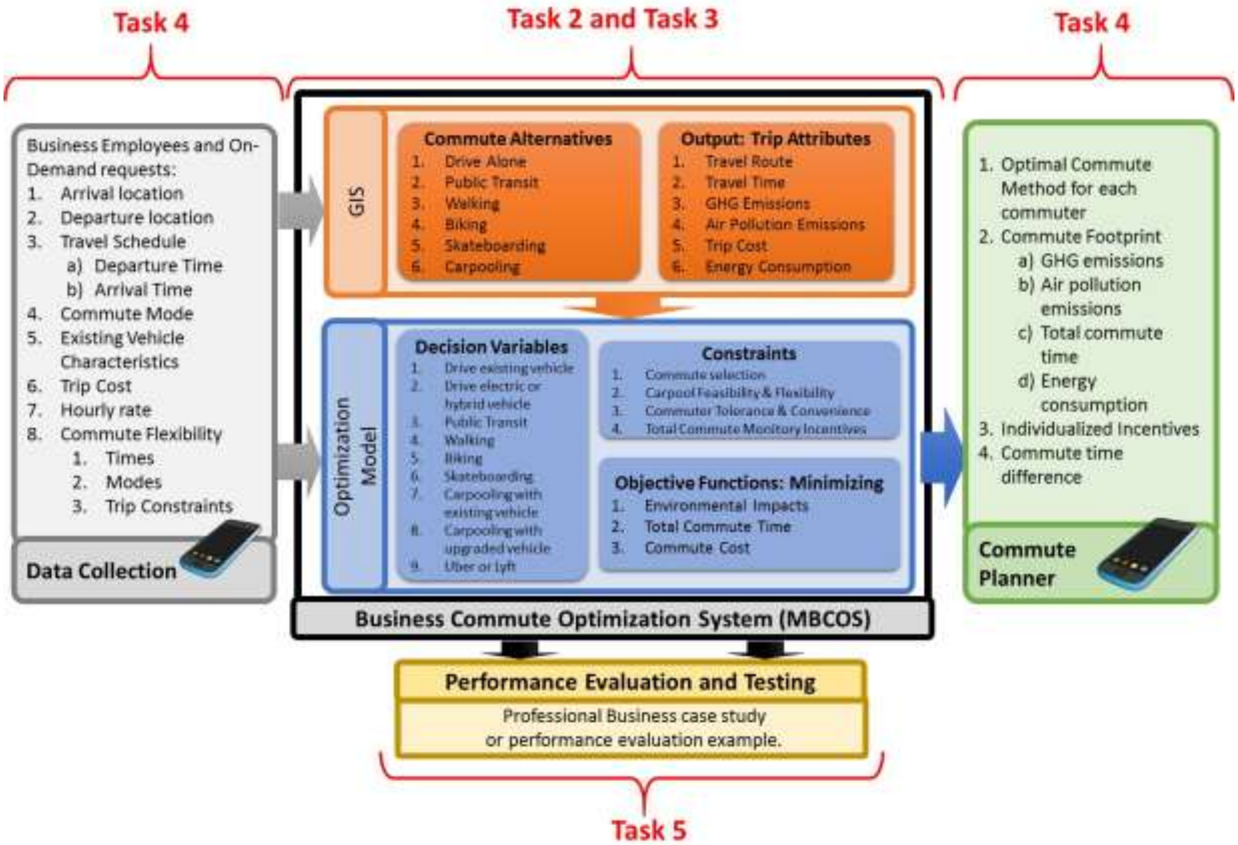

Figure 2. Components of BCOS and Main Research Tasks

Expected Outcomes

One of the unique concepts explored in this project is the integrated multi-objective optimization methodology that promotes transit ridership and sustainability of business commute systems. This integrated approach and its potential for wide spread application holds a strong promise to initiate a fundamental shift in transit modal shares of commute trips. The widespread application of the proposed system is expected to result in various benefits to communities and the transportation network by 1) increasing transit ridership; 2) reducing transportation related GHG emissions; 3) improving air quality; 4) increasing transportation efficiency; and 5) reducing congestion indirectly. For example, the proposed system will provide optimal solutions that will focus on minimizing transportation related emissions by increasing (a) public transit sharing, (b) carpooling, (b) the use of electric and hybrid vehicles, and (d) the use of green-friendly transportation modes such as walking and biking.

The findings of this research project will lead to journal and/or conference publications. Furthermore, the research team is planning to prepare and submit a research proposal to Cyber Physical Systems (CPS) program at the National Science Foundation. The findings of the research development along with the results of the case study will provide preliminary results for developing a large scale system that can optimize commuting for businesses.

Relevance to Strategic Goals

The findings of this research work are expected to contribute to "Environmental Sustainability" and "Livable Communities" strategic goals. The expected outcomes relevant to the above strategic goals are summarized as follows:

1. Reduction in transportation related GHG emissions: Currently Greenhouse Gas emissions from the transportation sector accounted, nationally, for 26% where more than half of the transportation emissions are produced by passenger cars and light duty trucks. The proposed system will provide optimal solutions that will focus on minimizing transportation related emissions by increasing (a) public transit sharing, (b) carpooling, (b) the use of low emission vehicles such as hybrid and electric vehicles, and (d) the use of green-friendly transportation modes such as walking and biking.
2. Incentives and savings for commuters: BCOS is designed to provide incentives and quantify savaging for commuters in order to identify implementable solutions. Any increase in the commute time or change in commute mode will be quantified as inconvenience and commuters will receive incentives and be educated on savings associated with implementing optimal solutions.
3. Better air quality: BCOS will quantify the emissions of the existing commute systems based on existing vehicles along with commute routes and time to capture the major contributors of emissions and air quality problems. Accordingly, the proposed optimal solutions will reduce emissions and improve air quality by providing higher incentives to commuters with higher impacts and potential for improvements.
4. Efficient transit systems, reduction in transportation demand, and less congestion: The proposed solution will provide optimal commute mode choice solutions and, accordingly, optimal use of existing commute systems in terms of transit modal share, carpooling and use of low emissions and green transportation modes. Widespread implementation of BCOS would increase transit demand; leading to reductions in traffic congestion and a more optimized transportation system.
5. Healthier Lifestyle: Alternative transportation modes such as walking, biking or carpooling are incentivized leading to direct health and social benefits.

Educational Benefits

To perform this research work, a team consisting of two professors and a graduate student at University of Colorado Denver was formed. Over the past five years, the faculty members have successfully advised and mentored hundreds of undergraduate and graduate students. The majority of these students are currently active and advancing in various industries today including transportation, planning, construction, engineering and consulting. This project will provide the research team with sustained support to train one Ph.D. student for one year. In addition, the faculty members will seek involvement from undergraduate and other graduate students in the Construction Engineering and Management program.

The proposed research and outcomes will serve as the foundation for new educational modules and materials to be integrated into graduate courses. Modules will be carefully designed and implemented to enable students to study and measure environmental impacts associated with transportation networks; and better understand the conflicting optimization objectives related to transportation network and budget-constrained incentive plans.

Tech Transfer

The research team will broadly disseminate and transfer the knowledge generated from the proposed research using: (1) publications in scientific journals and/or presentations in national conferences to disseminate the research findings to the broad research and industrial community; and (2) meetings with professionals in the transportation and construction industries, including state and federal transportation agencies such as Colorado Department of Transportation (CDOT) and California Department of Transportation (Caltrans). Additionally, the research team will explore opportunities to facilitate the transfer of new technologies to the industry by reaching out to businesses or communities that can directly benefit from optimizing their commute plans using BCOS. Finally, educational material will be generated to train graduate and undergraduate students and prepare them for the construction and transportation workforces.

Work Plan

In order to accomplish the objectives of this research work, the following research tasks will be conducted:

Task 1: Conduct Literature Review. The research team will conduct literature review on the use of electric and hybrid vehicles to minimize transportation emissions. Furthermore, the research team will explore the integration of autonomous vehicles in the transportation systems as a future application for BCOS.

Task 2: Expand the capabilities of BCOS to model additional transportation alternatives. This task will focus on expanding the capabilities of BCOS to analyze additional transportation alternatives, including (1) low emission vehicles such as electric and hybrid vehicles, and (2) public transportation options such as Uber or Lyft. BCOS will model the use of electric or hybrid vehicles to minimize transportation related emissions. For example, BCOS will allow commuters to upgrade their existing vehicle to electric or hybrid vehicles and potentially pick up other commuters in their way to work to minimize transportation emissions as well as commuting cost. BCOS will calculate potential savings and reduction in transportation emissions as a result of using electric or hybrid vehicles by commuters. Furthermore, BCOS will model the use of Uber and Lyft to commute to and from work in order to minimize transportation cost and emissions. The PIs will use the available cost models by Uber and Lyft to calculate trip costs. Transportation emissions will be calculated based on average emission rate of vehicles in the economic class (e.g. UberX), average distance where Uber/Lyft vehicle is available, and trip distance. The development steps of expanding the capabilities of BCOS will include (1) modeling additional decision variables, (2) expanding formulation of the objective functions and modeling additional constraints, and (3) implementing the new system computations using reasonable optimization algorithm. In order to enable the simultaneous optimization of the system objective functions, this task will explore and implement robust multi-objective algorithms such as (a) linear programming that guarantee an optimal solution with short computational time; or (b) evolutionary algorithms that adopt the concept of Pareto optimality in order to converge to a set of non-dominated optimal solutions. The PI has extensive expertise in modeling and solving multi-objective optimization models that utilize mathematical and heuristic optimization techniques.

Task 3: Expand the capabilities of BCOS to model On-Demand Needs. This task will focus on expanding the capabilities of BCOS to model and integrate on-demand transportation needs. Once optimal plans are identified for business employees, BCOS will analyze the integration of on-demand needs. On-demand solutions will be provided in a form of carpooling modes. For example, if the on-demand request is identified within or close to the route of the original travel plan and timeline of business employee(s), a carpooling solution will be identified. The capabilities of the optimization model will be expanded to identify optimal solutions for on-demand needs to simultaneously minimize transportation related emissions as well as commuting time and cost. The research team will follow similar steps to expand the capabilities of BCOS as discussed in Task 2.

Task 4: Develop mobile app for Android and ISO systems. This task will focus on developing mobile apps for android and IOS systems. The new mobile apps will facilitate data collection and interaction with business employees. The mobile apps will be designed to collect data from business employees on home and work addresses; departure and arrival times; necessary intermediate stops; existing and preferred transportation modes; year, make, and model of existing vehicle (if any); interest in commute behavior change; and parking cost. Furthermore, the mobile apps will be designed to provide recommendations on changing the existing commute behavior based on the outcome of BCOS. Commuters will receive information on recommended transportation mode, expected reduction in GHG and air pollution emissions, expected savings, reduction or increase in commute time, and monetary incentives if any. The research team will hire professional developer to design and develop the mobile apps in this task. The mobile app development will be outsourced to a professional developer overseas to minimize design and development costs.

Task 5: Demonstrate System Performance and Capabilities using a Case Study. The research team is planning to evaluate the model performance using a case study of a businesses located in Denver or similar application example. Data of business commuters will be collected using website services or smartphone app. The collected data will be analyzed using the GIS and fed into the optimization model. The optimization model will be used to identify optimal selection of commute alternatives for business commuters. The identified optimal commute plan will be sent to commuters using website services or mobile app.

Task 6: Prepare Final Report of the Project Findings. The research team will prepare and submit a final project report that summarizes the findings of the research work.

The proposed research tasks will be carried out according to the following schedule.

Project Tasks	Start (M)	Dur. (M)	Year 1												Year 2											
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Expanding the Capabilities of Business Commute Optimization System (BCOS)																										
Task 1. Conduct Literature Review	1	2																								
Task 2. Expand the Capabilities of BCOS to Model Additional Transportation Alternativ	3	4																								
Task 3. Expand the Capabilities of BCOS to Model On-Demand Needs.	7	5																								
Task 4. Develop Mobile App for Android and ISO Systems	11	6																								
Task 5. Demonstrate System Performance and Capabilities using Case Study	17	5																								
Task 6. Prepare Final Report of the Project Findings.	22	2																								

Project Cost

Total Project Costs:	$120,536.40
MPC Funds Requested:	$59,804.40
Matching Funds:	$60,732.00
Source of Matching Funds:	Faculty and student salaries

References

Abdallah, M., and El-Rayes, K. 2016. Multiobjective optimization model for maximizing sustainability of existing buildings. Journal of Management in Engineering, **32**(4). doi:10.1061/(ASCE)ME.1943-5479.0000425.

Abdallah, M., El-Rayes, K., and Clevenger, C. 2015a. Minimizing Energy Consumption and Carbon Emissions of Aging Buildings. *In* Procedia Engineering. doi:10.1016/j.proeng.2015.08.527.

Abdallah, M., El-Rayes, K., and Clevenger, C. 2015b. Optimizing building upgrades to minimize energy and water consumption. *In* ISEC 2015 - 8th International Structural Engineering and Construction Conference: Implementing Innovative Ideas in Structural Engineering and Project Management.

Abdallah, M., El-Rayes, K., and Liu, L. 2015c. Optimizing the selection of sustainability measures to minimize life-cycle cost of existing buildings. Canadian Journal of Civil Engineering, **43**(2). doi:10.1139/cjce-2015-0179.

Abdallah, M., El-Rayes, K., and Liu, L. 2016. Minimizing upgrade cost to achieve LEED certification for existing buildings. Journal of Construction Engineering and Management, **142**(2). doi:10.1061/(ASCE)CO.1943-7862.0001053.

Abdallah, M., Tawfik, A., and Clevenger, C. 2017. Time-cost-environmental trade-off analysis for business commuting systems. *In* Leadership in Sustainable Infrastructure. Canadian Society of Civil Engineers (CSCE), Vancouver, canada.

Center for Urban Transportation Research. 2002. Best Workplaces for Commuters-Business Benefit Calculator.

Clevenger, C., Abdallah, M., Tawfik, A., Adame, B., Akalp, D., and Ozbek, M. 2016. Exploring Student Commute Behavior and Identifying Opportunities to Minimize Commute GHG and Air Pollution Emissions: A Case Study. *In* Construction Research Congress 2016: Old and New Construction Technologies Converge in Historic San Juan - Proceedings of the 2016 Construction Research Congress, CRC 2016. doi:10.1061/9780784479827.238.

Environmental Protection Agency. 2017a. Fast Facts: U.S. Transportation Sector GHG Emissions.

Environmental Protection Agency. 2017b. Inventory of U.S. Greenhouse Gas Emissions and Sinks.

Federal Highway Administration. 2003. Commuter Choice Decision Support System.

Garvill, J. 1999. Choice of transportation mode: Factors influencing drivers' willingness to reduce personal car use and support car regulations. Resolving social dilemmas: Dynamic, structural, and intergroup aspects,: 263–279. Taylor and Francis, Philadelphia.

Greene, D.L., and Plotkin, S.E. 2011. Reducing greenhouse gas emission from US transportation. Arlington: Pew Center on Global Climate Change.

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. doi:10.5038/2375-0901.17.2.4.

Heinen, E., Maat, K., and van Wee, B. 2013. The effect of work-related factors on the bicycle commute mode choice in the Netherlands. Transportation, **40**(1): 23–43. Springer.

Maizlish, N., Woodcock, J., Co, S., Ostro, B., Fanai, A., and Fairley, D. 2013. Health cobenefits and transportation-related reductions in greenhouse gas emissions in the San Francisco Bay area. American Journal of Public Health, **103**(4): 703–709. American Public Health Association.

Monghasemi, S., Abdallah, M., Tawfik, A., and Clevenger, C. 2018a. Analysis of GHG Emissions Reduction Policies on Commuters and Organizations. *In* Construction Research Congress 2018. ASCE, New Orleans. pp. 594–603.

Monghasemi, S., Abdallah, M., Tawfik, A., and Clevenger, C. 2018b. Time-Environmental Impacts Tradeoff Analysis for Businesses Commuters. *In* Construction Research Congress 2018. ASCE, New Orleans. pp. 628–638.

de Nazelle, A., Morton, B.J., Jerrett, M., and Crawford-Brown, D. 2010. Short trips: an opportunity for reducing mobile-source emissions? Transportation Research Part D: Transport and Environment, **15**(8): 451–457. Elsevier.

Shoup, D.C. 1997. Evaluating the effects of cashing out employer-paid parking: Eight case studies. Transport Policy, **4**(4): 201–216. doi:10.1016/S0967-070X(97)00019-X.

Tawfik, A.M., Abdallah, M., Clevenger, C.M., and Adame, B.A. 2015. Business+ Commute Optimization System: Model Development and Pilot Real Life Casestudy. *In* 95th Annual Meeting of the Transportation Research Board of the National Academies. Washington, D.C.

University of South Florida. 1998. Center for Urban Transportation Research.

Williams, S.E., Davis, S.C., and Boundy, R.G. 2017. Transportation Energy Data Book: Edition

36. Oak Ridge National Lab.(ORNL), Oak Ridge, TN (United States).