# PROJECT SET 2 (Feb 12 - March 7, 2018)

In this project period, we will assemble 5 teams, each consisting of 3 students, ideally with one grad student and two undergrads. Composition of teams will be determined after everyone turns in the initial intent form distributed in class.

Presentations and final report will be due the week of March 6-9.

Please note: Two extra credit opportunities will be offered to students during this project:

- attend the Joint MATH/MAE colloquium on Fri, March 2, 12:30-1:30 in UC 302
- attend the SIAM student conference at CU Denver, Sat, March 3, 8-4pm.

In both events, Dr. Benedetto Piccoli will be the keynote speaker, who is a world expert in traffic flow modeling.

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## Project RED: Designing a Traffic Circle

(based on 2009 MCM Problem A)

Many cities and communities have traffic circles?from large ones with many lanes in the circle (such as at the Arc de Trimphe in Paris and the Victory Monument in Bangkok) to small ones with one or two lanes in the circle. Some of these traffic circles position a stop sign or a yield sign on every incoming road that gives priority to traffic already in the circle; some position a yield sign in the circle at each incoming road to give priority to incoming traffic; and some position a traffic light on each incoming road (with no right turn allowed on a red light). Other designs may also be possible.

The goal of this problem is to use a model to determine how best to control traffic flow in, around, and out of a circle. State clearly the objective(s) you use in your model for making the optimal choice as well as the factors that affect this choice. Include a Technical Summary of not more than two double-spaced pages that explains to a Traffic Engineer how to use your model to help choose the appropriate flow-control method for any specific traffic circle. That is, summarize the conditions under which each type of traffic-control method should be used. When traffic lights are recommended, explain a method for determining how many seconds each light should remain green (which may vary according to the time of day and other factors). Illustrate how your model works with specific examples.

## Project GREEN: The Keep-Right-Except-To-Pass Rule

(based on 2014 MCM Problem A)

In countries where driving automobiles on the right is the rule (that is, USA, China and most other countries except for Great Britain, Australia, and some former British colonies), multi-lane freeways often employ a rule that requires drivers to drive in the right-most lane unless they are passing another vehicle, in which case they move one lane to the left, pass, and return to their former travel lane.

Build and analyze a mathematical model to analyze the performance of this rule in light and heavy traffic. You may wish to examine tradeoffs between traffic flow and safety, the role of under- or over-posted speed limits (that is, speed limits that are too low or too high), and/or other factors that may not be explicitly called out in this problem statement. Is this rule effective in promoting better traffic flow? If not, suggest and analyze alternatives (to include possibly no rule of this kind at all) that might promote greater traffic flow, safety, and/or other factors that you deem important.

In countries where driving automobiles on the left is the norm, argue whether or not your solution can be carried over with a simple change of orientation, or would additional requirements be needed.

Lastly, the rule as stated above relies upon human judgment for compliance. If vehicle transportation on the same roadway was fully under the control of an intelligent system - either part of the road network or imbedded in the design of all vehicles using the roadway - to what extent would this change the results of your earlier analysis?

## Project YELLOW: Tollbooths

(based on 2005 MCM Problem B)

Heavily-traveled toll roads such as the Garden State Parkway, Interstate 95, and so forth, are multi-lane divided highways that are interrupted at intervals by toll plazas. Because collecting tolls is usually unpopular, it is desirable to minimize motorist annoyance by limiting the amount of traffic disruption caused by the toll plazas. Commonly, a much larger number of tollbooths is provided than the number of travel lanes entering the toll plaza. Upon entering the toll plaza, the flow of vehicles fans out to the larger number of tollbooths, and when leaving the toll plaza, the flow of vehicles is required to squeeze back down to a number of travel lanes equal to the number of travel lanes before the toll plaza. Consequently, when traffic is heavy, congestion increases upon departure from the toll plaza. When traffic is very heavy, congestion also builds at the entry to the toll plaza because of the time required for each vehicle to pay the toll.

Make a model to help you determine the optimal number of tollbooths to deploy in a barrier-toll plaza. Explicitly consider the scenario where there is exactly one tollbooth per incoming travel lane. Under what conditions is this more or less effective than the current practice? Note that the definition of ”optimal” is up to you to determine.

[**Follow-up optional problem (based on 2017 MCM problem B)**
Multi-lane divided limited-access toll highways use ”ramp tolls” and ”barrier tolls” to collect tolls from motorists. A ramp toll is a collection mechanism at an entrance or exit ramp to the highway and these do not concern us here. A barrier toll is a row of tollbooths placed across the highway, perpendicular to the direction of traffic flow. There are usually (always) more tollbooths than there are incoming lanes of traffic (see former 2005 MCM Problem B). So when exiting the tollbooths in a barrier toll, vehicles must ”fan in” from the larger number of tollbooth egress lanes to the smaller number of regular travel lanes. A toll plaza is the area of the highway needed to facilitate the barrier toll, consisting of the fan-out area before the barrier toll, the toll barrier itself, and the fan-in area after the toll barrier. For example, a three-lane highway (one direction) may use 8 tollbooths in a barrier toll. After paying toll, the vehicles continue on their journey on a highway having the same number of lanes as had entered the toll plaza (three, in this example).

Consider a toll highway having L lanes of travel in each direction and a barrier toll containing B tollbooths (B>L) in each direction. Determine the shape, size, and merging pattern of the area following the toll barrier in which vehicles fan in from B tollbooth egress lanes down to L lanes of traffic. Important considerations to incorporate in your model include accident prevention, throughput (number of vehicles per hour passing the point where the end of the plaza joins the L outgoing traffic lanes), and cost (land and road construction are expensive). In particular, this problem does not ask for merely a performance analysis of any particular toll plaza design that may already be implemented. The point is to determine if there are better solutions (shape, size, and merging pattern) than any in common use.

Determine the performance of your solution in light and heavy traffic. How does your solution change as more autonomous (self-driving) vehicles are added to the traffic mix? How is your solution affected by the proportions of conventional (human-staffed) tollbooths, exact-change (automated) tollbooths, and electronic toll collection booths (such as electronic toll collection via a transponder in the vehicle)?

# Project ORANGE: Expansion of I25 with a Toll Lane?

(based on KKTV article, Dec 4, 2017

Would you spend the extra cash to use a toll lane when I-25 is backed up? The Colorado Department of Transportation is hoping the answer is yes. CDOT officials just announced plans to add a toll express lane to both directions of the interstate between Monument and Castle Rock in an area known as "the gap" where there are currently only two lanes in each direction. It's a spot that's notorious for backups.

Both supporters and opponents of the toll lanes agree that the increased lanes are necessary.

Mark Waller is an El Paso County commissioner; he helped pass recent tax initiatives that will fund the eventual permanent lane expansion planned for that stretch of I-25.

"Colorado Springs, Denver, two of the 40 largest markets in America, and this section of road hasn't been updated since it was originally built in 1962," Waller noted.

Michael Lewis is the deputy executive director and chief operations officer for CDOT.

"Eighteen hundred crashes in a year's period, 620 of them personal injury crashes – that's really what this is about." While both sides agree the lack of lanes is a problem, they disagree on how to fund the solution.

"The value of an express lane: they are available for anybody when they need it. When they don't need it, then they don't need to use it because they still have capacity," Lewis said.

"After the voters just supported to ballot initiatives to raise $25 million locally to support this state and federal project, my constituents aren't excited, certainly are not excited about any sort of tooling provision to make this work," Waller countered.

CDOT says the toll lanes are the only way to get the project done fast enough. The permanent, extra lanes will still be added to the outside lanes of I-25, but that will take time while CDOT notifies landowners on either side of the interstate of the expansion.

The toll lanes are a temporary fix, they will be created in what is now the median and left shoulder of the roadway. They will keep the toll lane even when outside lanes are added, making the interstate four lanes in each direction in the area.

CDOT has not said how much the tolls would be.

# Project BLUE: Campus Transportation

The proposed activity is to develop a mathematical model for the transportation network of a University campus, consists of pedestrian traffic, bicycle and shuttle traffic. We will use the specific layout of the UCCS campus, specifically the expanded campus, as described in the 2020 UCCS Master Plan. The initial model will be developed based on the Core Campus and will then be expanded to include the North Campus and East Campus. The network will consist of academic buildings, parking lots and residential areas (nodes) and roads, walking paths (edges) and will incorporate the unique feature of the projected 2.25mile spline running through the entire campus. The focus of this study will be to analyze and predict (through numerical simulations) the collective behavior of the student population as they move through this network at various times of the day by using appropriate dynamic models of the density of the crowds. The study will also help predict transit times of students between various nodes, e.g. taking into account the limited resources available, such as limited number of shuttles, especially during peak times.

Several mathematical approaches relevant to this modeling project have been developed already in the context of transportation networks and modeling supply chains, mainly using fluid flow models. More sophisticated methods (based on granular flow or kinetic theory) exist in the literature for modeling vehicular and pedestrian traffic. While we do not expect the proposed model to embrace such high-powered techniques, at least initially, we do anticipate a realistic macroscopic description that will present sufficient opportunities to understand the complexity of the transportation needs on the UCCS campus.