# 2017 MCM

## Problem A: Managing The Zambezi River

The Kariba Dam on the Zambezi River is one of the larger dams in Africa. Its construction was controversial, and a 2015 report by the Institute of Risk Management of South Africa included a warning that the dam is in dire need of maintenance. A number of options are available to the Zambezi River Authority (ZRA) that might address the situation. Three options in particular are of interest to ZRA:

(Option 1) Repairing the existing Kariba Dam,
(Option 2) Rebuilding the existing Kariba Dam, or
(Option 3) Removing the Kariba Dam and replacing it with a series of ten to twenty smaller dams along the Zambezi River.

There are two main requirements for this problem:

**Requirement 1** ZRA management requires a brief assessment of the three options listed, with sufficient detail to provide an overview of potential costs and benefits associated with each option. This requirement should not exceed two pages in length, and must be provided in addition to your main report.

**Requirement 2** Provide a detailed analysis of Option (3) - removing the Kariba Dam and replacing it with a series of ten to twenty smaller dams along the Zambezi river. This new system of dams should have the same overall water management capabilities as the existing Kariba Dam while providing the same or greater levels of protection and water management options for Lake Kariba that are in place with the existing dam. Your analysis must support a recommendation as to the number and placement of the new dams along the Zambezi River.

In your report for Requirement 2, you should include a strategy for modulating the water flow through your new multiple dam system that provides a reasonable balance between safety and costs. In addition to addressing known or predicted normal water cycles, your strategy should provide guidance to the ZRA managers that explains and justifies the actions that should be taken to properly handle emergency water flow situations (i.e. flooding and/or prolonged low water conditions). Your strategy should provide specific guidance for extreme water flows ranging from maximum expected discharges to minimum expected discharges. Finally, your recommended strategy should include information addressing any restrictions regarding the locations and lengths of time that different areas of the Zambezi River should be exposed to the most detrimental effects of the extreme conditions.

*Your MCM submission should consist of three elements: a standard 1 page MCM Summary Sheet, a 1-2 page brief assessment report (Requirement 1), and your main MCM solution (Requirement 2) not to exceed 20 pages for a maximum submission of 23 pages. Note: Any appendices or reference pages you include will not count towards the 23 page limit.*

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## Problem B: Merge After Toll

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)?

*Your MCM submission should consist of a 1 page Summary Sheet, a 1-2 page letter to the New Jersey Turnpike Authority, and your solution (not to exceed 20 pages) for a maximum of 23 pages. Note: The appendix and references do not count toward the 23 page limit.*

**Problem C: “Cooperate and navigate”**

Traffic capacity is limited in many regions of the United States due to the number of lanes of roads. For example, in the Greater Seattle area drivers experience long delays during peak traffic hours because the volume of traffic exceeds the designed capacity of the road networks. This is particularly pronounced on Interstates 5, 90, and 405, as well as State Route 520, the roads of particular interest for this problem.

Self-driving, cooperating cars have been proposed as a solution to increase capacity of highways without increasing number of lanes or roads. The behavior of these cars interacting with the existing traffic flow and each other is not well understood at this point.

The Governor of the state of Washington has asked for analysis of the effects of allowing self-driving, cooperating cars on the roads listed above in Thurston, Pierce, King, and Snohomish counties. (See the provided map and Excel spreadsheet). In particular, how do the effects change as the percentage of self-driving cars increases from 10% to 50% to 90%? Do equilibria exist? Is there a tipping point where performance changes markedly? Under what conditions, if any, should lanes be dedicated to these cars? Does your analysis of your model suggest any other policy changes?

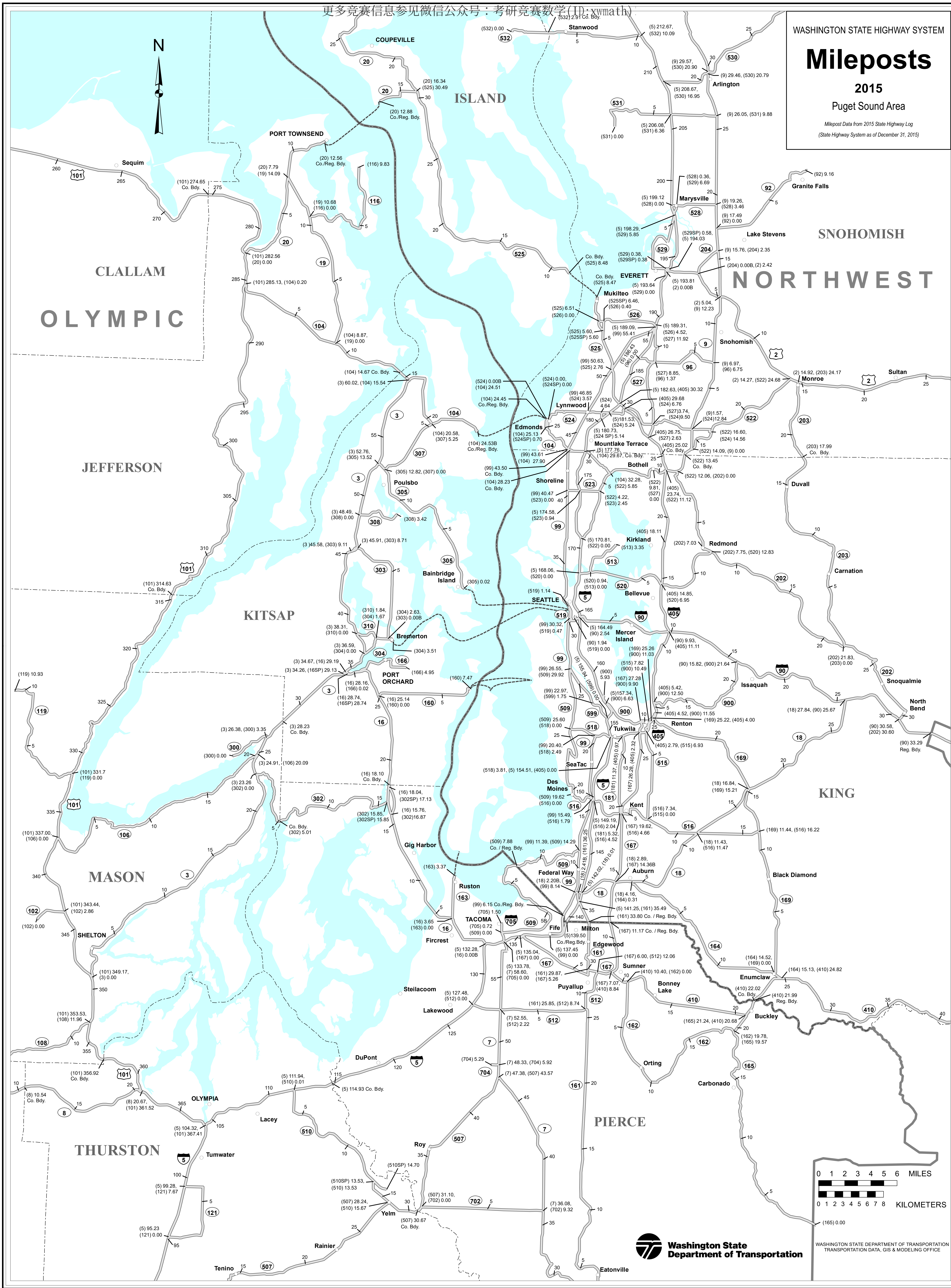
Your answer should include a model of the effects on traffic flow of the number of lanes, peak and/or average traffic volume, and percentage of vehicles using self-driving, cooperating systems. Your model should address cooperation between self-driving cars as well as the interaction between self-driving and non-self-driving vehicles. Your model should then be applied to the data for the roads of interest, provided in the attached Excel spreadsheet.

*Your MCM submission should consist of a 1 page Summary Sheet, a 1-2 page letter to the Governor’s office, and your solution (not to exceed 20 pages) for a maximum of 23 pages. Note: The appendix and references do not count toward the 23 page limit.*

Some useful background information:

- On average, 8% of the daily traffic volume occurs during peak travel hours.
- The nominal speed limit for all these roads is 60 miles per hour.
- Mileposts are numbered from south to north, and west to east.
- Lane widths are the standard 12 feet.
- Highway 90 is classified as a state route until it intersects Interstate 5.
- In case of any conflict between the data provided in this problem and any other source, use the data provided in this problem.

**Definitions:**
**milepost:** A marker on the road that measures distance in miles from either the start of the route or a state boundary.
**average daily traffic:** The average number of cars per day driving on the road.
**interstate:** A limited access highway, part of a national system.
**state route:** A state highway that may or may not be limited access.
**route ID:** The number of the highway.
**increasing direction:** Northbound for N-S roads, Eastbound for E-W roads.
**decreasing direction:** Southbound for N-S roads, Westbound for E-W roads.

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**2017 ICM**

**Problem D: Optimizing the Passenger Throughput at an Airport Security Checkpoint**

Following the terrorist attacks in the US on September 11, 2001, airport security has been significantly enhanced throughout the world. Airports have security checkpoints, where passengers and their baggage are screened for explosives and other dangerous items. The goals of these security measures are to prevent passengers from hijacking or destroying aircraft and to keep all passengers safe during their travel. However, airlines have a vested interest in maintaining a positive flying experience for passengers by minimizing the time they spend waiting in line at a security checkpoint and waiting for their flight. Therefore, there is a tension between desires to maximize security while minimizing inconvenience to passengers.

During 2016, the U.S. Transportation Security Agency (TSA) came under sharp criticism for extremely long lines, in particular at Chicago's O'Hare international airport. Following this public attention, the TSA invested in several modifications to their checkpoint equipment and procedures and increased staffing in the more highly congested airports. While these modifications were somewhat successful in reducing waiting times, it is unclear how much cost the TSA incurred to implement the new measures and increase staffing. In addition to the issues at O'Hare, there have also been incidents of unexplained and unpredicted long lines at other airports, including airports that normally have short wait times. This high variance in checkpoint lines can be extremely costly to passengers as they decide between arriving unnecessarily early or potentially missing their scheduled flight. Numerous news articles, including [1,2,3,4,5], describe some of the issues associated with airport security checkpoints.

Your Internal Control Management (ICM) team has been contracted by the TSA to review airport security checkpoints and staffing to identify potential bottlenecks that disrupt passenger throughput. They are especially interested in creative solutions that both increase checkpoint throughput and reduce variance in wait time, all while maintaining the same standards of safety and security.

The current process for a US airport security checkpoint is displayed in **Figure 1**.

- **Zone A:**
  - Passengers randomly arrive at the checkpoint and wait in a queue until a security officer can inspect their identification and boarding documents.
- **Zone B:**
  - The passengers then move to a subsequent queue for an open screening line; depending on the anticipated activity level at the airport, more or less lines may be open.
  - Once the passengers reach the front of this queue, they prepare all of their belongings for X-ray screening. Passengers must remove shoes, belts, jackets, metal objects, electronics, and containers with liquids, placing them in a bin to be X-rayed separately; laptops and some medical equipment also need to be removed from their bags and placed in a separate bin.

- All of their belongings, including the bins containing the aforementioned items, are moved by conveyor belt through an X-ray machine, where some items are flagged for additional search or screening by a security officer (Zone D).
- Meanwhile the passengers process through either a millimeter wave scanner or metal detector.
- Passengers that fail this step receive a pat-down inspection by a security officer (Zone D).

- **Zone C:**
  - The passengers then proceed to the conveyor belt on the other side of the X-ray scanner to collect their belongings and depart the checkpoint area.

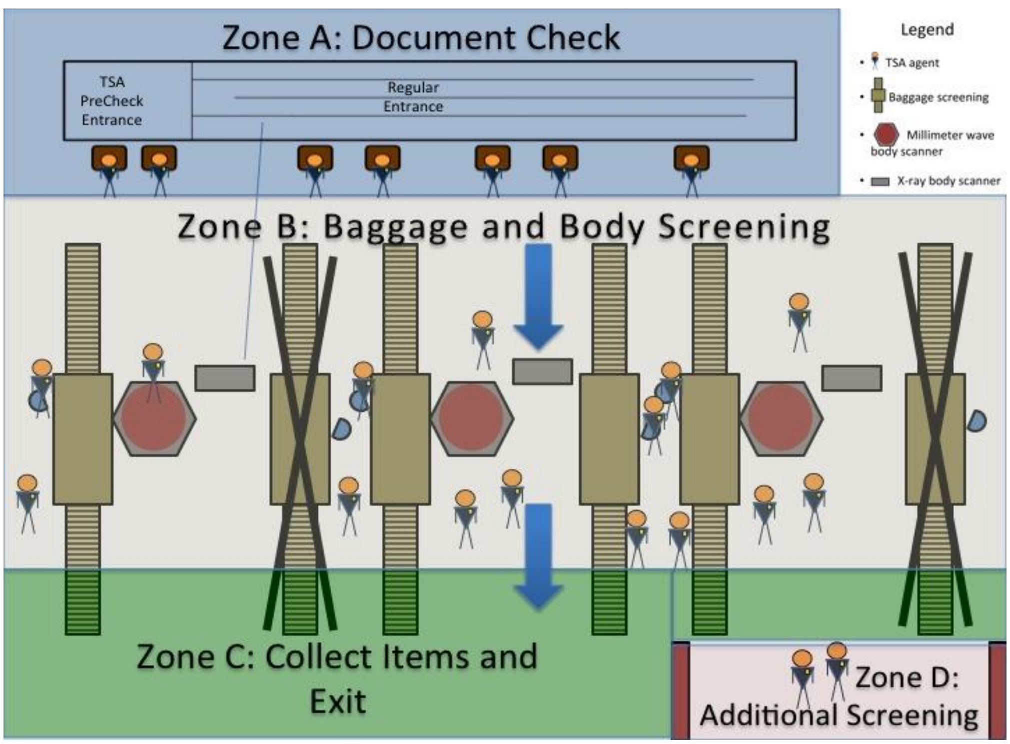


**Figure 1:** Illustration of the TSA Security Screening Process.

Approximately 45% of passengers enroll in a program called Pre-Check for trusted travelers. These passengers pay $85 to receive a background check and enjoy a separate screening process for five years. There is often one Pre-Check lane open for every three regular lanes, despite the fact that more passengers use the Pre-Check process. Pre-Check passengers and their bags go through the same screening process with a few modifications designed to expedite screening. Pre-Check passengers must still remove metal and electronic items for scanning as well as any liquids, but are not required to remove shoes, belts, or light jackets; they also do not need to remove their computers from their bags.

Data has been collected about how passengers proceed through each step of the security screening process. Click here to view the Excel data.

Your specific tasks are:

a. Develop one or more model(s) that allow(s) you to explore the flow of passengers through a security check point and identify bottlenecks. Clearly identify where problem areas exist in the current process.
b. Develop two or more potential modifications to the current process to improve passenger throughput and reduce variance in wait time. Model these changes to demonstrate how your modifications impact the process.
c. It is well known that different parts of the world have their own cultural norms that shape the local rules of social interaction. Consider how these cultural norms might impact your model. For example, Americans are known for deeply respecting and prioritizing the personal space of others, and there is a social stigma against "cutting" in front of others. Meanwhile, the Swiss are known for their emphasis on collective efficiency, and the Chinese are known for prioritizing individual efficiency. Consider how cultural differences may impact the way in which passenger's process through checkpoints as a sensitivity analysis. The cultural differences you apply to your sensitivity analysis can be based on real cultural differences, or you can simulate different traveler styles that are not associated with any particular culture (e.g., a slower traveler). How can the security system accommodate these differences in a manner that expedites passenger throughput and reduces variance?
d. Propose policy and procedural recommendations for the security managers based on your model. These policies may be globally applicable, or may be tailored for specific cultures and/or traveler types.

In addition to developing and implementing your model(s) to address this problem, your team should validate your model(s), assess strengths and weaknesses, and propose ideas for improvement (future work).

*Your ICM submission should consist of a 1 page Summary Sheet and your solution cannot exceed 20 pages for a maximum of 21 pages. Note: The appendix and references do not count toward the 20 page limit.*

**References:**

[1] http://www.wsj.com/articles/why-tsa-security-lines-arent-as-bad-as-youd-feared-1469032116

[2] http://www.chicagotribune.com/news/ct-tsa-airport-security-lines-met-20160823-story.html

[3] http://www.cnn.com/2016/06/09/travel/tsa-security-line-wait-times-how-long/

[4] http://wgntv.com/2016/07/13/extremely-long-lines-reported-at-chicago-midway-airports-tsa-checkpoint/

[5] http://www.cnbc.com/2016/04/14/long-lines-and-missed-flights-fuel-criticism-of-tsa-screening.html

# 2017 ICM

## Problem E: Sustainable Cities Needed!

## Background:

Many communities are implementing smart growth initiatives in an effort to consider long range, sustainable planning goals. “Smart growth is about helping every town and city become a more economically prosperous, socially equitable, and environmentally sustainable place to live.”[2] Smart growth focuses on building cities that embrace the E’s of sustainability—Economically prosperous, socially Equitable, and Environmentally Sustainable. This task is more important than ever because the world is rapidly urbanizing. It is projected that by 2050, 66 percent of the world’s population will be urban—this will result in a projected 2.5 billion people being added to the urban population.[3] Consequently, urban planning has become increasingly important and necessary to ensure that people have access to equitable and sustainable homes, resources and jobs.

Smart growth is an urban planning theory that originated in 1990’s as a means to curb continued urban sprawl and reduce the loss of farmland surrounding urban centers. The ten principles for smart growth are[4]

1. Mix land uses
2. Take advantage of compact building design
3. Create a range of housing opportunities and choices
4. Create walkable neighborhoods
5. Foster distinctive, attractive communities with a strong sense of place
6. Preserve open space, farmland, natural beauty, and critical environmental areas
7. Strengthen and direct development towards existing communities
8. Provide a variety of transportation choices
9. Make development decisions predictable, fair, and cost effective
10. Encourage community and stakeholder collaboration in development decisions

These broad principles must be tailored to a community’s unique needs to be effective. Thus, any measure of success must incorporate the demographics, growth needs, and geographical conditions of a city as well as the goal to adhere to the three E’s.

**Tasks:**

The International City Management Group (ICM) needs your help implementing smart growth theories into city design around the world. Select two mid-sized cities (any city with a population of between 100,000 and 500,000 persons), on two different continents.

1. Define a metric to measure the success of smart growth of a city. It should consider the three E's of sustainability and/or the 10 principles of smart growth.
2. Research the current growth plan of the selected cities. Measure and discuss how the current growth plan of each city meets the smart growth principles. How successful are the current plans according to your metric?
3. Using smart growth principles develop a growth plan for both cities over the next few decades. Support why you chose the components and initiatives of your plans based on the geography, expected growth rates, and economic opportunities of your cities. Use your metric to evaluate the success of your smart growth plans.
4. Also using your metric, rank the individual initiatives within your redesigned smart growth plan as the most potential to the least potential. Compare and contrast the initiatives and their ranking between the two cities.
5. Suppose the population of each city will increase by an additional 50% by 2050, explain in what way(s) your plan supports this level of growth?

*Your ICM submission should consist of a 1 page Summary Sheet and your solution cannot exceed 20 pages for a maximum of 21 pages. Note: The appendix and references do not count toward the 20 page limit.*

**References:**

[1] Smart Growth: Improving lives by improving communities. https://smartgrowthamerica.org/
[2] EPA, "This is Smart Growth." 2016 https://www.epa.gov/smartgrowth/smart-growth-publication
[3] World Urbanization Prospects. United Nations. 2014. https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Highlights.pdf
[4] EPA, "Smart Growth: A Guide to Developing and Implementing Greenhouse Gas Reductions Programs." 2011. http://www.sustainablecitiesinstitute.org/Documents/SCI/Report_Guide/Guide_EPA_SmartGrowthGHGReduction_2011.pdf
[5] Duany, Andres, Jeff Speck and Mike Lydon. *The Smart Growth Manual*. McGraw-Hill. 2010.

# 2017 ICM

## Problem F: Migration to Mars: Utopian Workforce of the 2100 Urban Society

The international agency, Laboratory of Interstellar Financial & Exploration Policy (LIFE), has recently (in this year of 2095) completed a series of short-term planned living experiments on our neighbor planet, Mars. New technologies, including personalized artificial augmentations units, will soon enable humans to inhabit manufactured cities on Mars by 2100. The first wave of migration, called Population Zero, will include 10,000 people.

The LIFE agency launched project UTOPIA: 2100, with the goal of creating an optimal workforce for the 22nd century to give all people the greatest quality of life with a vision of sustainability for the next 100 years. Over the last 20 years, several planned communities have been designed and built across Earth that tested several planned living conditions. These communities are driven by egalitarian principles in economics, government, workforce, and justice systems.

LIFE is seeking a set of mathematical and computational models that will inform the International Coalition on Mars (ICM) government on how to design an economic-workforce-education system that they can implement with Population Zero. In order to decide what procedure to follow, LIFE has hired the most qualified policy makers and data scientists with the goal to develop a set of policies to realize the migration to Mars. Your three-person policy modeling team is part of the group of advisors and policy makers. ICM has asked your group for a policy model and report that will result in a set of policy recommendations that will create a sustainable life-plan and will make the living experience on Mars in the year 2100 even better than the Earthly one in the current year of 2095.

New tools in network science, systems science, complex systems, organizational & industrial psychology, and other interdisciplinary fields provide new insights for understanding social and governmental systems, with important capabilities to deal with issues of scalability (relevant for both small and large populations and effects), modality (multiple layers), and dynamics (changes over time).

Population Zero aims to have optimal conditions in many workforce and social living factors (note that another team is being tasked with health policy, so ICM has asked that you exclude health care from your analysis). The mission of Population Zero is to create a sustainable society by maximizing both economic output (GDP) and happiness in the work place for its citizens. Of course, these two goals can be in opposition, so the policy recommendation has to consider balancing factors, such as:

- Income: Ensure adequate compensation so that all people can afford fundamental necessities (shelter, food, clothes).
- Education: Provide high quality education that prepares citizens for the needs and challenges of the 22nd Century.
- Equality: Improve the retention of women in the workforce, particularly in fields where they have been underrepresented or discriminated against on Earth.

Your ICM-directed tasks are:

1. Define parameters and specific outcomes related to the three priority factors (income, education, and social equality) in Population Zero. Some issues to consider are: a) minimum wage and salary distribution (income); b) skills required for an efficient workforce; types of governance and infrastructure needed to obtain these skills (education); and c) maternity and paternity leave, affordable childcare to ensure people can remain in the workforce (social equality).
    a. Identify and define the specific outcomes that would indicate positive results across the three factors for the next decade (years 2100-2110). Consider what the goal is for each of these factors; for example, is the objective to improve the quality of living for all citizens or improve quantity of output of the system.
    b. What are the major features of the population (eg. demographics, population size, and working conditions) that would contribute to these outcomes?
    c. Create metrics that you will use to evaluate whether the system is meeting its objective by identifying and defining the critical parameters for each of the three factors.

2. You have been asked to generate a sample population of 10,000 people to emigrate to Mars. Extract data from a census dataset (link to one is provided below) or synthesize one.
    a. From your data set, identify and analyze the demographic characteristics of this simulation of Population Zero. Analyze and describe demographic distributions, such as gender, ethnicity, age, and education levels.
    b. Consider the distribution of citizens in terms of factors that will also help to meet goals of UTOPIA: 2100 – to build a peaceful, cooperative, egalitarian society. Are your data sufficient to determine these factors? For example, should the distribution of innovators versus producers be considered? Of skilled versus unskilled labor? Of families versus single people?

Link to PUMS data (if you desire to use this census data):

- PUMS data can be found via following links:
  - http://www.census.gov/programs-surveys/acs/technical-documentation/pums.html
  - http://www2.census.gov/programs-surveys/acs/data/pums/2015/1-Year/
- These links show how to extract the data in R:
  - https://stat.ethz.ch/R-manual/R-devel/library/base/html/sample.html
  - https://cran.r-project.org/web/packages/sampling/sampling.pdf
- This link show how to extract the data in MATLAB:
  - https://www.mathworks.com/help/stats/datasample.html?requestedDomain=www.mathworks.com

3. Build a model that includes the three identified factors (income, education, & social equality). Using the parameters that you created in **task 1**, define the key elements of a successful society for the next 10 years. When integrating these three factors, what are the critical interdependencies among the parameters? Are there additional constraints required to preserve the outcomes over the 10 year period? How often should the model be evaluated to ensure the goals of UTOPIA 2100 continue to be met? What might be economic, social, cultural, and other global factors that might affect the viability of the model over that period? Based on these factors and constraints, answer the following:
   a. Determine the optimal minimum wage and salary distribution to best manage the tension between wellbeing (higher quality of life) and support for those less equipped to provide labor services.
   b. Identify terms in your model that can be most improved through contribution of new ideas. Describe the incentives to motivate contribution of those new ideas.
   c. What is the best childcare and paternity/maternity leave strategies?

4. Now that you have created models for the three factors, proceed to merge these models into a global model. In **task 3**, you designed a model to provide optimal outcomes for society, at large. Now, consider how the model will function for different groups?
   a. Identify the major subgroups of your workforce, and identify their main priorities. For example, unskilled labor force might be concerned with work hours, disability care, child care, and minimum wage, while the priorities of the professional workforce may be time off, training, and parental leave. Your model will dictate which subgroups you consider. You might have to develop new parameters to adequately evaluate each groups' priorities.

   b. With the understanding that each group will have a different set of needs, perspectives, and criteria for success, analyze how closely their needs are met in terms of income, education, and equality. For example, does your model function differently across educational levels? Different ages? Different cultural values? Does your model function better for women or men? How are families affected?
   c. With the consideration of the subgroups that you have identified, your previous model may no longer produce optimal outcomes. Adjust the model by adding new constraints or parameters to optimize the needs of the different subgroups. The goal is to maximize the priority outcomes of the subgroups without significantly reducing the global outcomes.

5. LIFE has planned additional migration phased over the next 100-years.
   a. How sensitive is your model to the population selection for various migration phases? Does the demographic distribution of this population significantly change the outcomes? How does your sampling procedure affect your model? If migration and growth in future years will be similar to Population Zero (10,000 people in a new manufactured city at a time), how would you change your model for the next few migrations? How sustainable are your recruitment and selection processes?
   b. Is this long-term plan substantially different than the 10-year plan? Are there elements in your 10-year vision and recommendations that are not sustainable for the 100 year vision? Identify any new parameters or constraints that will ensure your model continues to be effective for the entire 22$^{nd}$ century.

6. In shocking news, scientists discover a threat of a collision of Earth with a planet sized comet. We need to evacuate planet Earth and move as many people as possible to Mars to live in enlarged manufactured cities.
   a. Is your model still functional? Would it make a difference if migrations occurred in phases?
   b. Study the robustness of your model and comment on its general sensitivity to a much larger scale migration.
   c. State the strengths and weaknesses of your model relative to a major migration.

7. Write a policy recommendation addressed to the director of LIFE that includes the factors of income, education, equality policies based on your model and according to the directions of ICM. Will your recommendations change depending on the composition and size of the Population Zero? Explain the

reasoning that led you to your recommendations and analyze the results you are expecting to achieve.

*Your ICM submission should consist of a 1 page Summary Sheet, a 1-2 page policy recommendation, and your solution (not to exceed 20 pages) for a maximum of 23 pages. Note: The appendix and references do not count toward the 23 page limit.*

**References:**

https://www.kansascityfed.org/publications/community/transformworkforce

https://www.kansascityfed.org/~/media/files/publicat/community/workforce/transformingworkforcedevelopment/book/transformingworkforcedevelopmentpolicies.pdf

http://www.economist.com/blogs/freeexchange/2012/01/chinas-labour-force