# Framework for a Lottery-Based Incentive Scheme and its Influence on Commuting Behaviors—an MIT Case Study

by

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B.S. Applied Mathematics
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## ABSTRACT

Congestion pricing has been widely regarded as the most effective technique used to manage travel demand. Since congestion pricing is about charging road users to internalize the external cost induced by their travels, there have been concerns about the social equity issues it raises and the political opposition it often faces. This thesis focuses on another travel demand management strategy that is contrary to congestion pricing, a reward-based scheme which provides positive incentives to commuters when they change their travel behavior. More specifically, commuters could be rewarded credits when they travel to work via walking, bicycling, taking public transit or carpooling instead of driving alone. The credits accrued can either be used to exchange for a deterministic cash prize, or a chance to enter a grand lottery draw. This thesis reviews the research literature to explain the influence of lottery schemes on behaviors and modifies a theoretical model to suggest how equilibrium mode choices can be influenced by lotteries. A general framework to design such a lottery scheme is proposed and, based on the framework, several alternatives to implement a lottery-based incentive scheme to manage commuter parking demand at MIT are developed and evaluated.

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# Chapter 1

# Introduction

## 1.1 Background

Excess auto use is in general considered to be responsible for a wide range of problems, such as road congestion, greenhouse gas emissions, and increasing parking costs. In Cambridge MA, especially the Kendall Square Area, the problems associated with auto use during workdays are rather prominent. As a host for two major research universities, the city of Cambridge has limited parking spaces available while there is a high demand from graduate students, staff and tourists. Kendall Square, which is in close proximity to MIT, has a high density of companies. With the future replacement of two parking garages at MIT being considered, finding parking spaces may become increasingly difficult for employees at MIT and Kendall Square. In addition to the scarcity of parking spaces, peak-hour congestion is also considered a critical issue in the area (S Pollack, 2012). In efforts to reduce auto use in the Kendall Square area, there have been many policies implemented to provide commuters with benefits to try and regularly use alternative commuting modes. From the government's side, enhancements have been made to biking facilities at Cambridge[1]. Employers have been subsidizing the public transportation costs to employees who travel by transit (such as discounted fares, free transit passes for those who hold parking permits). Inspired by the promising outcomes of INSINC (a large-scale field experiment where lotteries are used to shift commuting behaviors) (Pluntke & Prabhakar, 2013), MIT and several other employers in Kendall Square will jointly implement a pilot program which utilizes lottery-based incentives to further curb car travels during peak hours in the Kendall Square areas in 2015. This thesis, as part of the analysis leading up to the experiment, investigates the impacts of lotteries in inducing transportation behavior change and attempts to propose a framework for designing a lottery scheme that will reduce the single-occupant auto commuting trips. Finally, the thesis will propose detailed designs of lottery schemes based on travel habit

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[1] For a comprehensive information on the biking in Cambridge, please visit: https://www.cambridgema.gov/CDD/Transportation/gettingaroundcambridge/bybike.aspx

information collected from MIT employees, who are representative of the overall employee population in the Kendall Square Area.

## 1.2 Motivations

There have been a variety of problems associated with auto use. Reduction in CO2 emissions has been generally recognized as an essential way to curb global warming and the catastrophic risks associated with it (Graham-Rowe, Skippon, Gardner & Abraham 2011). Based on the report of *CO2 Emissions from Fuel Combustion Highlights* from International Energy Agency (Van der Hoeven, 2011), it is estimated that as of 2011 the transportation sector accounts for approximately 23% of worldwide CO2 emissions, making it the second largest contributor to emissions. For transportation, the road sector produces more than 72% of the total transportation related emissions and has been the major growth driver since 1990. In developed countries, high auto-ownership rates and extensive car travels contribute to majority of emissions in the transportation sector. In US, approximately 28% of greenhouse gas emissions come from transportation, and among them about 61% are contributed by passenger cars and light-duty trucks (EPA, 2013). In addition to global warming, emissions from auto can also cause serious air pollution, one well-known example being the infamous Los Angeles smog in 1943. Congestion is another negative externality imposed by car travels. Statistics indicate that in 2011 an average US auto commuter's travel time increases by 38 hours a year due to road congestion. In Washington DC area where congestion is most severe, the delay reaches as high as 67 hours per month (Schrank, Eisele, & Lomax, 2012). As such, in order to minimize the environmental costs of auto emissions and congestion delays arising from excess car travels, it is critical to manage the demand for mobility in a variety of settings.

## 1.3 A Comparison Among Travel Demand Management Techniques

In general, techniques used to manage auto travel demand fall into two categories: pricing and subsidizing. In essence, externalities associated with excess car use are caused by incentive misalignments between individuals and the transportation system. In choosing travel mode and time, a commuter will rarely consider the emissions and potential increased congestion level caused by his trip. However, for the transportation system, there exists a social optimal level of traffic volumes that keeps the emission and congestion levels within a targeted range. To reduce gaps between individual and societal incentives, we could either make travelling via auto more expensive through charging additional fees, or increase the attractiveness of alternative modes by providing subsidies or incentives.

A wide range of empirical evidence (Graham-Rowe et al., 2011; Saleh, 2007) indicates that pricing, especially congestion pricing, is most effective in reducing car travel and therefore road congestion. The main idea behind congestion pricing is to charge drivers some price, which equals the external costs they impose from using the road at a specific time, and thus make them aware of the presence of the external costs when making their travel decisions. In economics terms, decongestion on the road network is a resource shared by all road users and therefore can be regarded as a public good. There is an optimal level of traffic, beyond which any additional road use will result in congestion and increasing level of emissions that affect all road users. Without any measure to deter that additional road user from entering the traffic when it is at the optimal capacity, externalities thus occur. Theoretically, if first best congestion pricing can be implemented, it shifts drivers' demand for the road network towards the direction where the demand for roads equal capacity, and therefore an equilibrium is reached. For more details on congestion pricing refer to (Bliemer, Steg, & Van Wee, 2008).

Congestion pricing, as effective a tool as it is, imposes negative incentives on road users and has many critics who decry the equity issues it raises. In New York City, where hours wasted in congestion rank top among US cities, the proposal for charging congestion fees for traffic in the Manhattan CBD triggered much controversy and eventually failed to gather the political support needed to implement the proposal (Schaller, 2010). Another tool to manage auto demand is through subsidies to encourage the deserved "good" behavior. This thesis examines the application of lottery-based incentives in managing auto demand for commuting trips. Under such a lottery-based incentive scheme, commuters are rewarded with credits if they commute to work in modes other than driving alone. The credits accrued can be used to exchange for prizes with varying probabilities. Compared to congestion pricing, the non-coercive nature of lottery-based incentive scheme is more likely to increase commuters' subjective well-being, regardless of the commuters' mode choices. If a commuter chooses to drive alone to work, the commuting cost will probably increase under congestion charging and remain the same under the incentive scheme. When the commuter chooses one alternative mode, say transit, his or her travel time is likely to increase. Under congestion charging, it is likely the commuter shifts the travel mode because he or she cannot afford to continue driving, or found extra charges unappealing. On the other hand, the incentive scheme can compensate the commuter for increased commuting time. More importantly, in the case where the mode shifts occur voluntarily under an incentive scheme, the commuter's subjective well-being (a measure of satisfaction level) is found to increase, even though the overall travel time might also increase due to the mode shift (Ettema, Garling, Olsson, & Friman, 2010). Consequently, any mode change induced by a positive incentive, or reward, would be personally beneficial to the commuter. In Netherlands, a peak-hour avoidance project (Spitsmijden) was implemented in 2010 (Donovan, 2010). Commuters were given cash incentives for avoiding driving during peak hours. The percentage of peak hour car trips was reduced by almost 50%, however only 5%-10% came from mode shift. Questions thus remain, that whether a lottery would be strong enough an incentive to induce a relatively large mode shift. Furthermore, it is of interests to determine the mechanism behind lotteries' influences on commuting behaviors.

## 1.4 Thesis Organization

To answer the question of how a lottery-based incentive can influence mode choice for commuting trips, an extensive review of literatures is conducted. Chapter 2 presents a review of relevant literature from the field of transportation and beyond. In Chapter 3, a framework for designing the lottery scheme is proposed. Based on travel behavior data collected on the MIT community, Chapter 4 focuses on the case study of MIT and proposes several lottery incentive designs. Chapter 5 summaries the key components for implementing the lottery-based incentive scheme at MIT and concludes with summaries and future research directions.

# Chapter 2

# Literature Review

In this chapter, a review of the research literature is conducted to help assess the influence of lottery incentives on commuters' mode decisions. Since no direct evidence is available to answer this question, two questions are proposed: first, what is the mechanism behind lotteries changing behaviors; and second, how do commuters choose their travel mode to work everyday. This chapter is organized as follows. In Section 2.1, case studies of lotteries that are used to induce behavior changes, including transportation behavior, are presented. Section 2.2 presents theories from classic microeconomics and behavior economics that explain the appeal of lotteries. Section 2.3 presents both experiments and theories on how people make mode choices for their weekday commuting trips. Section 2.4 concludes this chapter with key findings and insights from studies reviewed. Throughout this thesis, a lottery incentive is similar to a fixed-prize raffle. People will be rewarded with some credits if they behave in a certain way, and they can use the credits to participate in raffle drawings. In most cases, the greater number of credits accrued, the probability of winning a prize is increased.

## 2.1 Case Studies on Behavior Changes Induced by Lotteries

As presented in this section, lotteries have been widely applied in various domains to foster behavior changes. While theoretical models suggest people would respond to lotteries through changing their behavior depending on the value of the lottery prize (Morgan, 2000;Loiseau, Schwartz, Musacchio, Amin & Sastry, 2011; Lange, List & Price, 2007), empirical evidences do not always confirm these theoretical predictions. This section reviews lottery-based incentive schemes implemented in fields of public economics, survey methodology, health care, transportation and marketing. The impacts of lottery incentives in changing people's behaviors vary greatly. In evaluating the effectiveness of each lottery scheme, one needs to understand the goal of the scheme and whether that goal is consistent with the personal welfare maximization of a participant.

Another factor that needs consideration is the attractiveness of the lottery relative to the perceived cost of (or difficulty in achieving) the desired behavior change.

### 2.1.1 Public Economics

Public economics is perhaps one of the earliest fields where lotteries were used to induce behavior changes and their impacts were systematically studied. In 1612, the first lottery in America was held and half of its proceeds were used to finance the local government's operating expenses (Landry, Lange, List, Price & Rupp, 2006). Since then, lotteries have been used in various fund raising activities, generating capital for universities—most notably Harvard, Princeton and Columbia to local infrastructure (such as bridges and municipal buildings) and even the Revolutionary War. [2]

In an important work, Morgan (2000) presents a model that proves the provision of a public good will be higher under a fixed-prize lottery than voluntary contribution. Under a set of simple assumptions, bettors will be better off when they choose to contribute to the public good through purchasing lottery tickets. Consequently, lotteries reduce the gap between private optimum and social optimum. To evaluate this theoretical prediction, Morgan and Sefton (2000) conducted two lab experiments. In those experiments, participants were anomalously paired into groups of two. Each participant was given the same number of tokens as endowment, and they could decide how many to donate to a group account which resembles the role of public goods in real life. For each token they keep, they get 100 points. For each token they donate, they get 75 points each. In the lottery treatment, the winner of the group will be awarded additional points if there are enough tokens in the group account. Each person's chance of winning equals the

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[2] Interestingly, the first recorded lotteries in human history were from the Chinese Han Dynasty between 205 and 187 BC, and historians believe these lotteries were held to finance national defense projects such as the Great Wall of China. Benjamin Franklin used lotteries to finance weapons for the Continental Army. In 1768, George Washington held lotteries to assist in funding for a road into the wild west of Virginia. (Rodgers and Stuart,1995; Wikipedia's Lottery entry).

percentage of his donation relative to the total number of token at the group account. Points are used to redeem cash at a fixed rate. In the second lab experiment, the group size doubled to 4, and more treatment conditions were introduced that resemble the real life options faced by any person deciding whether and, if yes, how much to contribute to public goods. Results from the two experiments support the theoretical predictions: (1) participants donate more to the group account if there are lottery incentives present. On average, donations raised via a lottery were 52% of all endowments while donations raised by simple voluntary contributions were 40%; (2) donations to the group account increased as the lottery prize increased. When lottery prizes doubled, donations increased to 69% of total endowments; and (3) decreasing the return from donating to the group account reduced total contributions, when lottery prizes stayed the same. When the return from donating to the group account is zero, the total contribution to group account dropped to 12% of total endowments while the lottery prize offered was still 10%. For a detailed experiment design and analysis of results, see Morgan and Sefton (2000).

In addition to lab experiments conducted to investigate the effectiveness of lotteries in raising contributions to public goods, field experiments are also carried out. Landry et al (2006) conducted a door-to-door fundraising experiment with approximately 5,000 households. Households are randomly divided into four treatment groups: voluntary contribution, voluntary contribution with a $1000 seed money donation, a single-prize lottery with a prize of $1000, and multiple-prize lotteries with $250 each. Table 2-1 summarizes the experiment design.

|  | Session 1<br>Oct 2–3 | Session 2<br>Oct 23–24 | Session 3<br>Nov 6–7 | Session 4<br>Nov 13 |
|---|---|---|---|---|
| *VCM*<br>7 Solicitors | 3 Solicitors<br>607 Approach<br>208 Home | 4 Solicitors<br>579 Approach<br>238 Home |  |  |
| *VCM—Seed*<br>$1000 Donation<br>12 Solicitors | 3 Solicitors[a]<br>173 Approach<br>51 Home | 6 Solicitors<br>662 Approach<br>236 Home | 3 Solicitors<br>447 Approach<br>166 Home |  |
| *Single-prize*<br>$1000 prize<br>10 Solicitors | 2 Solicitors<br>186 Approach<br>56 Home | 5 Solicitors<br>515 Approach<br>194 Home | 3 Solicitors<br>262 Approach<br>113 Home |  |
| *Multiple-prize*<br>4 Prizes—$250<br>15 Solicitors | 3 Solicitors<br>248 Approach<br>99 Home | 4 Solicitors<br>440 Approach<br>148 Home | 4 Solicitors<br>393 Approach<br>115 Home | 4 Solicitors<br>321 Approach<br>131 Home |

Table 2-1: The Design of the Experiment Conducted by Landry et al (2006)

In the table above, each cell includes numbers of solicitors, requests made to households and those who were at home are reported. As an example on how to interpret the table, the first cell (row 1 and column 1) records that under the voluntary contribution condition (VCM), 3 solicitors were employed to approach 607 households from October 2-3. Among those 607 households, 208 were at home and answered the door.

As reported by Landry, et al. (2006), the amounts raised under four treatments are: $452, $426, $677, and $752. The results from this field experiment also support the theoretical predictions. Under lottery treatments of single-prize and multiple-prize, participation rates almost doubled and the total contributions increased by 50% compared to the voluntary contribution treatments.

One interesting finding is that the effect of lotteries in increasing contribution amounts and participation rates is similar to the effect of physical attractiveness of solicitors. As the attractiveness in female solicitors increases, the average donation amounts also increase, which is largely due to an increased participation rate in households where a male answered the door.

In addition to experiments conducted by Landry et al. (2006) and Morgan and Sefton (2000), there are many other experiments, such as Schram and Onderstal, 2009; Corazzini, Faravelli and Stanca, 2006, both in a laboratory setting and in the field that examine the effect of lotteries in inducing participation and increasing contributions to the public good. Compared to voluntary contributions, in general the results show that people donate more with a lottery prize incentive.

### 2.1.2 Survey Methodology

The lottery incentive has become a popular option to stimulate response rates. An array of studies and experiments has been conducted and reports inconsistent results on the effectiveness of lottery incentives. As reviewed by Singer (2002), positive results are reported by works such as Balakrishnan et al. (1992). However, Warriner et al., (1996) report no effects in experiments under lottery incentives, as do four studies reviewed by Hubbard and Little (1988).

For a specific population segment—students, a controlled experiment was conducted to investigate the impacts of lotteries in incentivizing them to participate in surveys (Porter & Whitcomb, 2003). The participants for the experiment were high school students recruited from around US, who  had few reasons, except perhaps potential lottery prizes, to participate in the online survey. The participants were randomly divided into five groups --- one control group with no lottery prize, and four experiment groups with lottery prizes from $50 to $200. The survey was administrated through sending participants an initial email with survey link. The four experiment groups were informed on the lottery prize they may receive if they finished the survey. Three days after the initial email, a reminder email was sent to non-respondents. A final reminder was sent five days after the first reminder to non-respondents. The response rates are shown in the Table 2-2 below.

| Group | After 1st E-Mail (%) | After 3rd E-Mail (%) |
|---|---|---|
| Control (no incentive) | 4.6 | 13.9 |
| Incentive—$50 | 5.4 | 15.0 |
| Incentive—$100 | 5.3 | 16.2 |
| Incentive—$150 | 6.0 | 15.6 |
| Incentive—$200 | 5.8 | 15.4 |
| All incentive groups | 5.6 | 15.6 |
| Total sample | 5.4 | 15.2 |

Table 2-2: The Survey Response Rate by Porter and Whitcomb (2003)

Table 2-2 summarizes response rates among in different treatment groups. The response rate was calculated as the number of participants who answered the survey divided by the total number of participants invited.

After three emails, the difference in response rates was largest between the control group and the experiment group under the treatment of a $100 lottery prize, which was calculated to be 2.6%. Within each group, the increase in response rates between first email and the third email ranges from 9.3% (the control group) to 10.9% (the group with $100 lottery incentive). Although the 2.6% response rate increase achieved by $100 lottery incentive is significant, it seems minimal when compared to the impacts of subsequent email reminders.

For surveys conducted at MIT, no direct link could be found on the amount of lottery prize and the response rate. In 2014, there are six institution-wide surveys, and results are summarized in the table below.

| **MIT Surveys Conducted in 2014** | | | |
|---|---|---|---|
| Topic | Length | Incentive | Response Rate |
| Graduating Student Survey | <10 minutes | Lotteries for prizes valued at $500 or less | 77% Bachelors, 68% Masters |
| First Year Student Survey | No Information | None | 86% |
| Senior Student Survey | No Information | A thank-you gift and a lottery for Kindle | 70% |
| Alumni | No Information | None | 20% |
| MIT Commuting Survey | <10 minutes | A lottery for prizes valued at $500 | 55% |
| MIT community attitudes on sexual assaults | 10-15 minutes | $10 gifts or donations to all respondents | 35% |

Table 2-3: The Response Rates of Surveys Conducted at MIT in 2014[3]

According to J. Patel from the MIT Institutional Research Office of Provost, there are various factors that affect response rates, with topic being the most influential one. Comparing the response rate at MIT and other institutions, the relationship between the institution and students is another important factor that impacts response rate. For example, across institutions, surveys that provide financial incentives (such as lottery and thank-you gifts) may have a little higher response rate, but surveys conducted in small liberal arts colleges have much higher response rates than at large universities, regardless of the incentives provided.

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[3] The numbers presented in the table was calculated based on the data from http://web.mit.edu/ir/surveys/.

### 2.1.3 Public Health

Many health problems are optimally dealt with by improving doctor-prescribed treatment adherence by patients (Gomes et al., 2012; ,Volpp et al., 2008 (a); and Volpp et all., 2008 (b)). For example, for non-communicable diseases (such as cardiovascular diseases, diabetes, cancer, and chronic respiratory diseases), the ideal treatment method is prevention rather than medical cure. In the prevention stage, physical activities and healthy diets are recommended. Yet, many patients lack the motivations to follow such recommendations. In the cure stage, sub-optimal adherence to prescribed drug protocols increases the risks of exposure to side effects, thus rendering the medical treatment less effective. Given the appeal of lotteries, using them as incentives seem like a relatively straightforward way to motivate patients for their cooperation and adherence.

In 2008, Volpp et al. conducted a randomized trial where a lottery-based financial incentive is given to participants for achieving a pre-determined weight loss goal. Fifty-seven participants were randomly divided into three groups. For all participants, information on diets and exercise strategies for weight loss was given upon enrollment. Participants were required to attend monthly weigh-ins, regardless of which group they were in. To ensure the follow-up participation, $20 was awarded if a participant showed up for a weigh-in. For the control group, there was no incentive to achieve the weight loss goal except for intrinsic motivations. For the lottery group, participants were given daily weight loss goals that they need to achieve in order to qualify for the daily lottery. The total weight loss goal was 16lb over 16 weeks. The daily lottery randomly offered a prize of $10, or $100, with winning probabilities of 20% and 1% respectively. There was at most one winner for each draw. For the drawing mechanism, each participant chose a randomly generated 2-digit number as ID. Each day, a 2-digit number was generated. If the number generated matched exactly some ID and that participant reached the weight loss goal, he or she won $100. If the number generated matched some ID digit-wise (either first digit or second digit matches with the first or second digit of ID) and the participant met the weight loss goal, he or she won $10. The third group received another financial intervention. For the third group, they were given a monthly weight loss goal.

They were offered the opportunity to deposit \$0.01-\$3 daily to their account, and researchers matched their deposit 1:1 and a fixed \$3 if they put any deposit at all. However, the accumulated deposit would only be given to them when they reached the monthly weight loss goal. If not, they received nothing and would lose their own money that they had voluntarily deposited.

When the experiments ended, the percentages of people who reached weight loss goals in control group, lottery group and deposit group were as follows: 10.5%, 52.6% and 47.4%. The differences between each group are statistically significant within a 95% CI. After the experiments, a 7-month follow up was conducted, and no evidence can be found that the weight loss was sustained for participants who reached goals under lottery and deposit incentives.

In 2008, Volpp et al. conducted another experiment where lotteries are used to incentivize Warfarin (an anticlotting drug) adherence. Because of the medical characteristic of Warfarin, failure to take the Warfarin dose at the right time with the prescribed amount will result in a greater risk of stroke and bleeding complications to patients. Therefore, it is also in the patients' interests to optimally adhere to a prescribed Warfarin intake standard.

In this experiment, participants were eligible to win daily lottery prizes if they took all Warfarin doses correctly. The first batch of participants were given lottery prizes with an expected value of \$5, while the second batch were given \$3. Sensors were installed on pill compartments to monitor the intake of participants. Participants who took the medicine correctly were automatically entered for the daily lottery. At the end of the experiment, participants from both batches showed much improvement in Warfarin adherence. The incorrect pill taken rate dropped significantly. Due to the small sample size (10 people for each batch), no conclusion could be drawn on whether the lottery with the larger expected payoff of \$5 was more effective than the case with \$3.

In the two experiments described above, without the presence of any incentive, reaching weight loss targets and adhering to medicine intake standards will benefit all participants. In other words, goals of the lottery incentive are consistent with personal welfare maximization. Lottery incentives can often serve as some "commitment device" (Bryan, Karlan & Nelson, 2010), and encourage participants to put more effort to reach these goals. However, among people who achieved weight loss goals under the lottery incentive, within7 months following the withdrawal of the incentive, they uniformly gained weight to varying degrees. It seems the positive behavior change induced by lotteries is more likely to be temporary than habitual.

### 2.1.4 Education

A comprehensive study has been carried out by Roland Fryer in 2010 to study the impacts of financial incentives on student achievement. In his study, approximately 38,000 students from 261 schools were given financial rewards for improving "educational inputs", such as attending classes and reading books, and "educational outputs", such as grades. One interesting finding was that rewards for educational inputs were more effective than outputs in changing behavior. One possible reason could be that students know how to control input but no clear idea on how to control output. Financial incentives work better in motivating people to do things they directly know how to do.

In one field experiment conduced by Levitt et al. (2011), financial incentives were given to students in a low-performing school for improved performance on standardized tests. Students are given rewards if they meet the monthly achievement goals. Rewards include a cash reward of $50 and a lottery prize of $500 with 10% chance of winning. By the end of the 8-month program, the effects of the incentives are "modest", as reviewed by Gneezy, Meier and Rey-Biel (2011). Moreover, the effects were more significant for students whose previous grades were near the achievement goals, and their performances continued to be better than their counterparts in the control group after the financial incentives were withdrawn (Levitt et al., 2011; Gneezy, Meier & Rey-Biel, 2011). The sustained better performance suggest that behavior change induced by lotteries can have long term impacts if the short term change can lead to habituation or "human capital gains" with lasting returns (Gneezy, Meier & Rey-Biel, 2011)..

### 2.1.5 Transportation

A team from Stanford University, led by B. Prabhakar, has carried out two large-scale implementations of lottery schemes (INSTANT and INSINC) in encouraging people to shift their travel from peak to off-peak hours in India and Singapore (Merugu, Prabhakar & Rama, 2009; Pluntke & Prabhakar, 2013).

The preliminary results showed that the percentage of travellers in the lottery schemes who avoided peak hour commute was more than 10%, which is very promising since in transportation, a 10% reduction in traffic during congested periods could improve the overall traffic condition greatly.

Under the project of INSTANT (Infosys-Stanford Traffic project) [34], approximately 14,000 Infosys employees at Bangalore (India) participated for a period of 6 months from Oct 2008 to April 2009., The base office of the 14,000 employees is in Bangalore while they live primarily in Electric City. There is one major road connecting these two cities with distance of 15km. Of the participants, about 9,000 travel in buses chartered by Infosys, 3,000 by private autos (cars and motorcycles), and 2,000 by other means such as public transport. Based on historical data, commuters who travel to work on the chartered buses after 7:30 am experience 1.5 to 2 times longer travel time (an additional 70-90 minutes) due to congestion. Nevertheless, most of them still traveled during those peak hours. One reason could be that because of the team-oriented company culture, members on the same team tend to arrive at similar times.

To encourage participants to travel to work at less congested time, a lottery-based incentive scheme was adopted. Under the scheme, credits are awarded to participants daily depending on their arrival time at the office. Upon arrival, employees are required to swipe their ID cards as check-in. The credits accrued by each participant qualify them to enter a weekly lottery drawing. The more credits they have, the higher chance each participant has to win a reward. After the drawing, credits were deducted so as to encourage a continuing shift in travel times. The detailed design of credit allocation is shown in the below Figure 2-1.

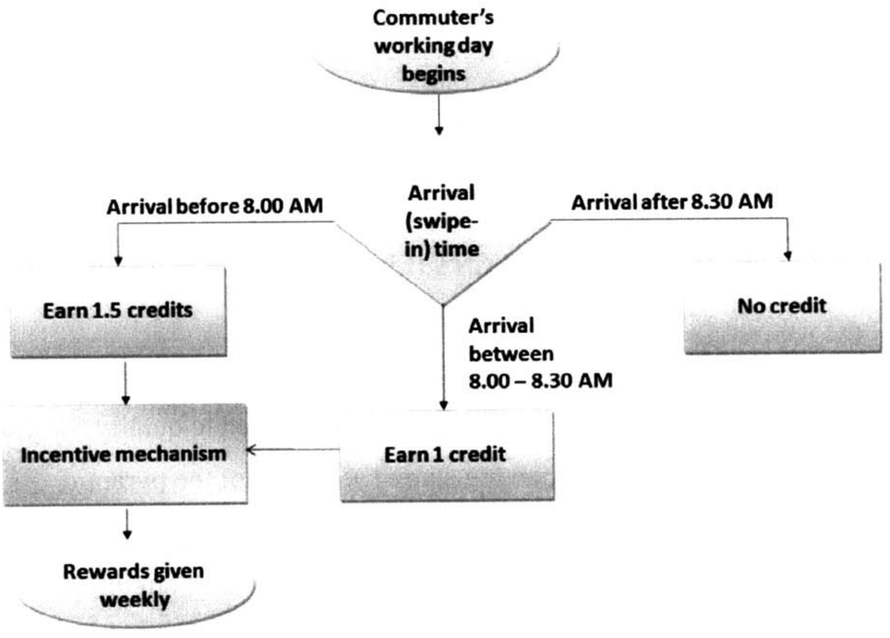


Figure 2-1: Flow Chart on the Lottery Scheme in INSTANT (Merugu, Prabhakar & Rama, 2009)

For the weekly lottery game, there were four levels of prizes: Rs. 500 ($10 based on an exchange rate of Rs.50 to $1), Rs. 2,000 ($40), Rs. 6000 ($120) and Rs. 12,000($240). The number of credits needed to enter each increasing level of lottery is: 3, 7, 12 and 20. Numbers of winners in each increasing level of lottery are 48, 12, 4 and 2 respectively. The reward structure is summarized in the graph below.

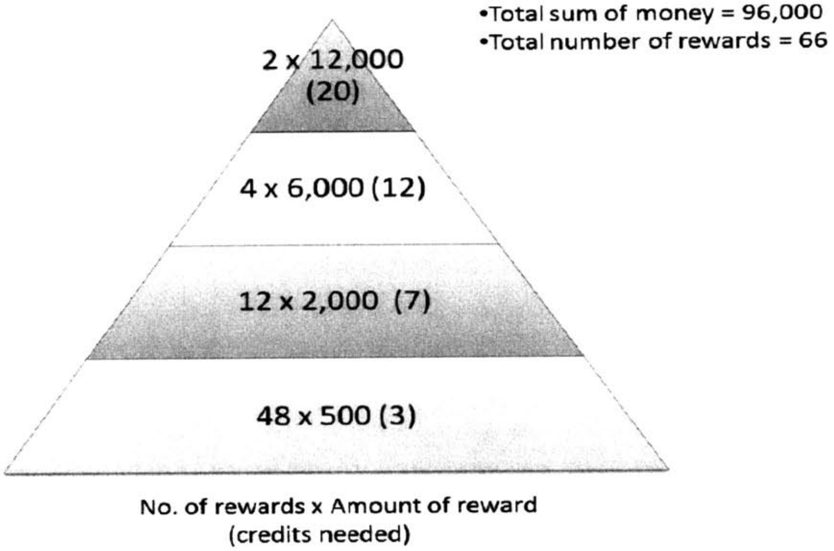


Figure 2-2: Lottery Structure in INSTANT (Merugu, Prabhakar & Rama, 2009)

Each level of the pyramid shown in Figure 2-1describes the number of rewards given out each week, the value of each prize (in Rs.) and the credits needed to qualify for the lottery. In the experiment, the lottery drawing started at the top of the pyramid. Participants who did not win at one level were automatically entered into the immediate adjacent lower level of lottery drawing. In the case where number of eligible participants was less than the number of winners, the reward money at this level was allocated to lower levels.

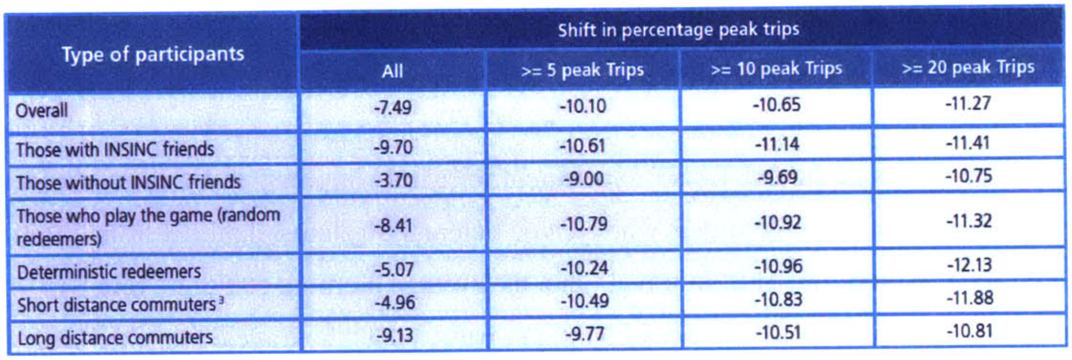
After each drawing, credits were deducted from both winners and losers; and the resulting balances were carried over to next week's drawing. For winners, the credits deducted equals "the number of credits needed to qualify for the level they had reached before the draw", which was not necessarily the level at which they have won. For losers, credits deducted equal the difference between credits needed to qualify for the level they had reached and the credits needed for the level immediately below it. For example, for a loser at the top level, the credits needed to qualify at this level were 20 while credits for the lower level are12. Therefore, the credits deducted for this participant is 8 (i.e 20-12=8) for the following week's lottery

The reported results of the INSTANT experiment were truly impressive. By the end of the 6-month experiment, commuters who arrived before 8:30 almost doubled from 2,000 to 4,000. As a result of this shift in travel time, the average morning commute time (averaged over both off-peak and peak hours) per participant who traveled on chartered buses decreased from 71 minutes to 54 minutes.

A peak-avoidance project INSINC, built on INSTANT, was carried out in Singapore from January 2012 to December 2013 (Pluntke & Prabhakar, 2013). The goal of INSINC was to encourage commuters to travel via subway during off-peak hours. For eligible participants, they earned some credits for all of their weekday subway trips. If the trip was initiated in the off-peak shoulder hours (6:30-7:29 am and 8:30-9:30 am), they earned triple points. Specifically, a weekday trip of X kms would earnX credits; and if the trip started during off-peak shoulder hours, it would earn 3X credits. In addition to the lottery option available in INSTANT, participants in INSINC could redeem their credits at a fixed rate: 1000 credits/ SG$1 (approximately $0.75).

For INSINC, there were two new program features as compared to INSTANT. The first was the social element. Participants can invite their social network friends to join, and they won extra credits for friends' sign-ups. The second was an "optimized" personalized travel advice. For each participant, a weekly travel advice was given and if they followed, there would be bonus credits.

By the end of the INSINC project, commuters who previously travelled during peak hours often shifted more than 10% of their trips to off-peak shoulder hours. The results are summarized in Table 2-4 below.



| Type of participants | Shift in percentage peak trips | | | |
|---|---|---|---|---|
| | All | >= 5 peak Trips | >= 10 peak Trips | >= 20 peak Trips |
| Overall | -7.49 | -10.10 | -10.65 | -11.27 |
| Those with INSINC friends | -9.70 | -10.61 | -11.14 | -11.41 |
| Those without INSINC friends | -3.70 | -9.00 | -9.69 | -10.75 |
| Those who play the game (random redeemers) | -8.41 | -10.79 | -10.92 | -11.32 |
| Deterministic redeemers | -5.07 | -10.24 | -10.96 | -12.13 |
| Short distance commuters[3] | -4.96 | -10.49 | -10.83 | -11.88 |
| Long distance commuters | -9.13 | -9.77 | -10.51 | -10.81 |

Table 2-4: Shifts in Percentage Peak Trips for Different Types of Participants in INSINC (Pluntke & Prabhakar, 2013)

In Table 2-4, the shifts in peak trips were greater in the group with INSINC friends than in the group without INSINC friends. On an overall level, people who travelled more during peak hours (>=10 peak trips) shifted more of their trips to off-peak than those who travelled less (>=5 peak Trips).

### 2.1.6 Marketing

The lottery incentive, as a general promotion technique, has been declining in usage (Chandon, Wansink & Laurent, 2000). Nevertheless, the number of lotteries conducted in marketing to promote sales is perhaps among the largest compared to lotteries used in other fields. Chandon , Wansink & Laurent (2000) came up with a framework to analyze the effectiveness of sales promotion techniques,including lotteries (referred to as sweepstakes in the paper)]. According to this paper, consumers are attracted to sales promotions for reasons beyond simple monetary savings. The benefits of sales promotions are categorized as utilitarian and hedonic benefits. For utilitarian benefits, they are mainly instrumental. Typical utilitarian benefits include cost savings and conveniences from sales promotions. Hedonic benefits are related to the pleasant emotions consumers experience from shopping and participating in promotions. In assessing the benefits consumers get from different promotion schemes, they conducted interviews to find out how consumers perceive benefits given by hypothesized promotions. The findings from this experiment are summarized in the graph below.

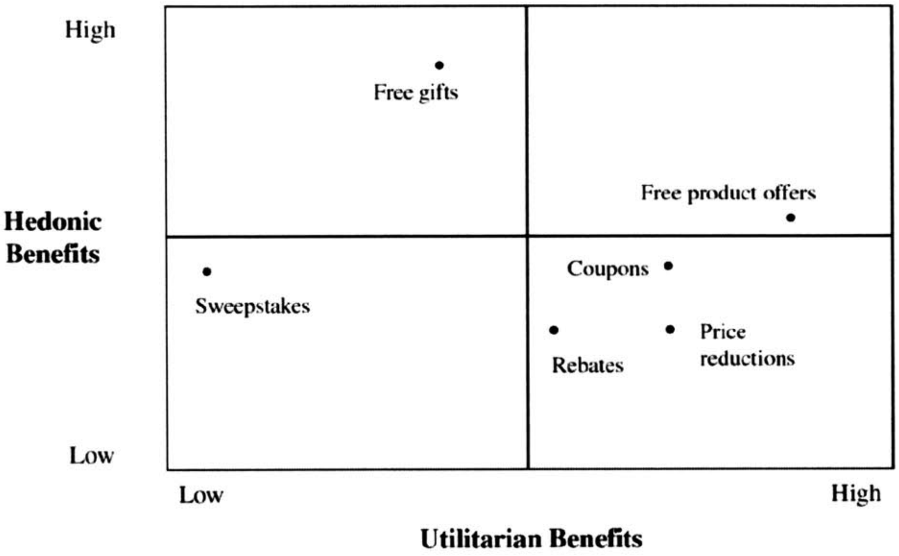


Figure 2-3: Classification on Commonly Used Promotion Techniques. (Chandon, Wansink & Laurent, 2000)

In Figure 2-3, the horizontal axis represents the utilitarian benefits (such as cost savings) while the vertical axis represents the hedonic benefits ( such as the fun emotions experienced from participation alone). One thing to note here is free gifts have lower utilitarian benefits than rebates. The reason can be that usually free gifts are not necessarily those desired by consumers. The main attractiveness of free gifts comes from the surprise element of a gift.

From the findings presented, as promotion strategies, lotteries (sweepstakes) are strictly dominated by free gifts and free product offers. Still, lotteries provide higher hedonic benefits than direct price reduction schemes, such as rebates. In other words, the appeal of lotteries to consumers is mainly emotional, rather than monetary savings.

## 2.2 Theoretical Models on the Lottery Incentives' Impacts on Behaviors

Under distinct sets of assumptions on how people make decisions, different theories have been proposed to explain the rationales behind lottery-based incentives. In this section, representative theoretical explanations are presented to facilitate the readers' understanding of the mechanism of how people make decisions under lotteries. The critical differences in theories are whether people are always "rational". In this thesis, we follow the definition for rationality (*Chicago man*) given by McFadden (1999). Section 2.2.1 reviews models (Morgan, 2000; Loiseau et al., 2011) when people are rational and make decisions based on the expected utility framework. Section 2.2.2 describes concepts that are relevant to why people participate in lotteries from prospect theories [39] where rationality does not always hold. In section 2.2.3, choice theory that models people's preferences over different lotteries will be introduced (Kahneman and Tversky, 1979).

### 2.2.1 Classic Economics

There is a rich body of literature that investigates how to use lotteries to increase the supply for public goods. Although transportation is not directly a public good, the benefits it brings can be cast as one. For example, on a daily trip to work, a commuter will benefit from an uncongested road in terms of travel time, fuel costs, possibly reduced greenhouse gas emissions and more. Therefore, for commuters, decongestion can be viewed as a public good. And commuters can make contributions to it by changing their driving time, or switching to alternative modes. In this section, two models that explain how a lottery incentive will change people's welfare (or utility in economics term) and the outcome of the public good provisions will be introduced.

In Morgan's work, people make more contributions to a socially desirable public good if offered a lottery reward as compared to a totally voluntary contribution. The proceeds from the lottery ticket sales are used to fund that public good and the lottery prize. The higher the contribution a person makes, the higher their chance of winning in most cases.

Intuitively, this is similar to the case of lotto: as the bettor buys more lottery tickets , his or her probability of winning increases. Under the assumptions of heterogeneous preferences and incomes and quasi-linear utility functions, the level of public good contributed is higher with a fixed-prize lottery than voluntary contributions.
As the prize amount increases to infinity, the provision level of public good also increases, and approaches to the first-best level (Morgan, 2000). An intuitive explanation for why lotteries raise a higher amount of contribution to public good is that a lottery ticket reduces the misalignment between personal incentives and social ones, and hence makes contributing to the public good more in accord with maximizing personal utilities. Morgan and Sefton (2000) conducted one lab experiment to investigate this theory, as reviewed in section 2.1.1. The data collected conforms to the prediction that the proceeds, net of lottery prize, are greater in fixed-prize lotteries than voluntary contributions. Moreover, lotteries with larger prizes raise more proceeds, and lottery ticket purchases decreases when the public good, which will be funded by the proceeds, is less valued by the participants.

In addition to effects of using a fixed-prize lottery to increase public good provisions, researchers also investigated the case with multi-level lottery prizes. In one study conducted by Lange, List and Price (2007), models are built to predict the total public good provided through the multi-prize lottery. In a multi-prize lottery, there are multiple prizes with distinct amounts and each participant can only win once. Based on their model, both fixed-prize and multi-prize lotteries can attract more contributors and provide higher level of public goods than voluntary contributions. The authors also evaluated their theories with experiments. Experimental data largely supports their theories; such that the lotteries generally dominate voluntary contributions. There are also some unanticipated findings from their data. For example, they find that as the risk level in lotteries increase, the decline in contributions is greater with a fixed-prize lottery than with a multi-level lottery. Yet, the total level of public good provided is larger with a fixed-prize lottery than with a multi-level one.

Concepts from Morgan's model will be used in later chapters to develop the lottery scheme to induce mode changes from commuters, and therefore details of this model is presented below. Key assumptions are: (i) the agents have different utility functions in quasi-linear form (i.e., heterogeneous agents with quasi-linear preferences); (ii) the initial endowment for each agent is the same; (iii) agents are rational, as defined by McFadden; (iv) agents have unbiased perceptions on the odds of the lotteries. The notations and setup follow Morgan (2000).

Let $N$ denote the number of agents in an economy. For each agent, his utility function is quasi-linear and takes the form

$$U_i = w_i + h_i(G)$$

where $w_i$ is a numeraire good which denotes the wealth of agent $i$, and $G \in R^+$ is the level of public good provided. The initial endowment, or income, for each agent is the same.

We further assume the function $h_i(G)$ is strictly increasing and concave with respect to $G$ ($\frac{dh_i}{dG} > 0$ and $\frac{\partial^2 h_i}{\partial G^2} < 0$ for all $i$). The public good $G$ is generated by each agent's transferring some of the numeraire good into $G$, on a one-for-one basis. Under the assumption of rationality, each agent will decide how much to contribute to the public good $G$ such that his expected utility is maximized.

(i) Social Optimum

In deriving what is the social optimum, a planner will choose the level of public good $G$ such that the total welfare is maximized. Total welfare is defined as

$W = \sum_{i=1}^{N}(w_i + h_i(G)) - G$. The problem can be defined as below:

$$\begin{aligned} &\max_{G} \sum_{i=1}^{N}(w_i + h_i(G)) - G \\ &s.t. \quad G \le \sum_{i=1}^{N} w_i, \qquad (1) \\ &\qquad\;\; G \ge 0. \end{aligned}$$

To solve the above optimization problem, a necessary condition is $\frac{dW}{dG} = 0$. After simplification, it becomes $\sum_{i=1}^{N} h_i'(G^*) = 1$, where $G^*$ is the optimal level of public good that should be provided in the economy. Assuming an interior solution (no corner solution), the optimal level of public good provided by each agent should satisfy

$$\sum_{i=1}^{N} h_i'(G^*) = 1$$

(ii) Voluntary Contribution

Under voluntary contribution, each agent chooses how much to contribute to the public good to maximize his own utility. Let $x_i$ denote the amount of numeraire good agent *i* contributes to the public good *G*. $x(S)$ denotes the sum of contributions by *S* agents, where $S \subseteq N$. Given the contributions from other agents, i.e. $x(N \setminus i)$, agent *i* faces the optimization problem below:

$$\begin{aligned} &\max_{x_i} U_i \\ &s.t. \quad U_i = w_i - x_i + h_i(x(N)), \\ &\qquad\ \ x(N) = x(N \setminus i) + x_i, \qquad (2) \\ &\qquad\ \ x_i \leq w_i, \\ &\qquad\ \ x_i \geq 0. \end{aligned}$$

Agent *i* chooses $x_i \in [0, w_i]$ to maximize $U_i = w_i - x_i + h_i(x(N))$, where $x(N)$ is the total contributions to public good *G*. Solving the above optimization problem simultaneously for all *N* agents in the economy, a Nash Equilibrium could be found and therefore the total level of public good provided under voluntary contribution. As reviewed by Morgan (2000), voluntary contributions always underprovide the public good compared to first-best levels. In other words, if all agents contribute to the public good at Nash Equilibrium solution, $x(N) < G^*$, where $G^*$ denotes the social optimum.

(iii) Fixed-prize lottery

A fixed-prize lottery is also commonly known as the raffle. The derivation could be as follows: the planner chooses a fixed amount prize *R*, in units of numeraire good. *R* is the same to all agents and commonly known. By contributing $x_i$ to the lottery game, agent *i*'s chance of winning is $\pi(x_i,x_{-i})=\frac{x_i}{x(N)}, \text{ where } x(N)=x_i+x_{-i}$. $x_{-i}$ denotes the contributions from all other *N-1* agents.

Assume the lottery prize R comes from the total contributions, the public good available would be $G=x(N)-R$. The lottery will only happen if the total contributions are greater than R, otherwise the lottery will be called-off and contributions will be returned to each agent. For agent *i*, he will choose his amount of contribution $x_i$ to maximize the expected utility $E(U_i)$.

$$\max_{x_i} E(U_i)$$

$$\begin{aligned} st.\quad & E(U_i)=w_i-x_i+\frac{x_i}{x(N)}R+h_i(x(N)-R), \\ & x(N)=x(N\setminus i)+x_i, \qquad\qquad\qquad (3) \\ & x_i\le w_i, \\ & x_i\ge 0. \end{aligned}$$

To solve (3), it is necessary to solve $\frac{dE(U_i)}{dx_i}=0$. Simplification yields

$$\frac{x(N\setminus i)}{(x(N))^2}R-1+h_i'(x(N)-R)=0 \quad (4)$$

Similar to the setting in voluntary contribution, if we solve (3) simultaneously for all N agents, there will only be one unique Nash Equilibrium solution. In other words, with the presence of lottery in each agent's utility function, there is a unique level of contribution to be made to the public good for each agent, if the assumptions are met.

To compare how contributions to the public good G change when the fixed-prize lottery is introduced, we proceed as follows. First, assume the contribution under a fixed-prize lottery is the same as social optimum. In this equilibrium, if only the first $n'$ agents have contributed a positive amount to the lottery, then $\sum_{i=1}^{n'}(\frac{x(N\setminus i)}{(x(N))^2}R-1+h_i'(x(N)-R))=0$ (Sum (4) over $n'$ agents).

Let $G^*$ denote the social optimum level of public good, then the above expression can be reduced to $\sum_{i=1}^{n'}h_i'(G^*)-n'+(n'-1)\frac{R}{R+G^*}=0$.

However, on the other hand, it is true that $\sum_{i=1}^{N}h_i'(G^*)=1$ when the contribution to public good is social optimal, the inequality below holds:

$$\begin{aligned}
&\sum_{i=1}^{n'}h_i'(G^*)-n'+(n'-1)\frac{R}{R+G^*}\\
&\le\sum_{i=1}^{n}h_i'(G^*)-n'+(n'-1)\frac{R}{R+G^*}\\
&=1-n'+(n'-1)\frac{R}{R+G^*}\\
&=(n'-1)(\frac{R}{R+G^*}-1)\\
&<0
\end{aligned}$$

As such, the assumption that a public good provided under a fixed-prize lottery equals the social optimum is incorrect. In fact, as proved by Morgan (2000), the fixed-prize lottery provides strictly less public good than social optimum, i.e., $x(N)<G^*$, but as the prize level R increases, $x(N)$ becomes closer to $G^*$.

Summarizing the key points from the above model, to participate in the lottery, an agent (say agent $i$) will decide how much to contribute to the public good. This contribution will incur a "cost"-- $x_i$ to this agent from his initial endowment. Under voluntary contribution, this cost will bring an increase in the level of public good. If people do not value public good-- $h(x_i)$ as much as they do their personal wealth-- $x_i$, they will not donate. Under the lottery incentive, the cost of $x_i$ will not only bring an increase in public good provided, but also a chance of winning a lottery. In this model, this chance of winning is valued at $\frac{x_i}{x(N)}R$. With this additional benefit from donating to the public good, agent $i$ will decide differently on $x_i$. For the whole economy consisting of $N$ agents, each agent will make decision on how much to contribute simultaneously. Solving all agents' optimization problems simultaneously yields a unique solution to each agent's problem. In other words, under the lottery incentive, there is only one optimal $x_i^*$ that maximizes agent $i$'s utility function. The aggregate amount of public good raised through the lottery incentive can be thus determined.

To apply Morgan's model to solve transportation problems, changes are needed. Loiseau et al (2011) have proposed a theoretical model that analyzes the impact of lotteries in congestion management. In their model, the public good is decongestion and a commuter contributes to it by shifting part of the travel demands to off-peak hours. Travels during peak and off-peak hours are valued differently by this commuter, and are represented by different utility functions. In addition, in travelling during peak hours a commuter will also experience the cost of delays from congestion caused by all commuters on the roads. During off-peak hours, the model assumes there is no cost from congestion delays. As in Morgan's model, assumptions on rationality and unbiased probability perception still hold. Using notations from Loiseau et al's model, the utility function for agent $i$ is shown as below. Further assume there is $n$ agents in the transportation system and they have identical demand $d=\frac{D}{n}$. Each agent decides how much to travel during off-peak hours, and $x_i$ denotes the percentage of agent $i$ 's travel demand in off-peak hour; $1-x_i$ therefore denotes the percentage of his travel demand during the peak. Agent $-i$ represents all agents other than $i$. $p$ represents some fixed price for joining this lottery scheme, and can be set to 0.

$$U_i(x_i,x_{-i})=d\cdot[P_i(1-x_i)+O_i(x_i)-p-(1-x_i)\cdot L_p(D-d\cdot\sum_{j=1,j\neq i}^{n}x_j)]$$

where $P_i(\cdot)$ and $O_i(\cdot)$ are agent $i$ 's utility functions for traveling during peak and off-peak

**periods respectively. $L_p(\cdot)$ is the cost from delay during peak, and is the same for all agents**

We assume agents always prefer to travel during peak hours to off-peak hours, i.e. $\frac{dP_i(1-x_i)}{dx_i} > \frac{dO_i(1-x_i)}{dx_i}$ for all $i$. Therefore, without any other consideration, each agent will choose $x_i = 0$, which means they will strictly prefer to travel during the peak rather than off-peak. When agent $i$ shifts a fraction of his demand to off-peak, he incurs a cost of shifting that is denoted by:

$$c_i(x_i) = P_i(1) + O_i(0) - (P_i(1-x_i) + O_i(x_i)).$$

The total shift in demand to off-peak is represented as $G = \sum_{i=1}^{n} x_i \cdot d$. With the introduction of a lottery incentive to agents, agent $i$'s utility function becomes

$$U_i(x_i, x_{-i}) = d \cdot [P_i(1-x_i) + O_i(x_i) - p - (1-x_i) \cdot L_p(D-G) + R \cdot \frac{x_i}{G} - \Delta p],$$

**where $R$ and $\Delta p$ are chosen such that $\Delta p = \frac{R}{D}$ and $\sum_{i=1}^{n} d \cdot (R \cdot \frac{x_i}{G} - \Delta p) = 0$.** If all agents choose not travel during off-peak under the lottery incentive, then there will be no rewards, i.e. $R = 0 \text{ if } x_i = 0 \ \forall\ i \in \{1,2,\ldots,n\}$.

Solve the optimization problem below for all $n$ agents in the transportation system and we can get the optimal decision for each agent and therefore the outcome of how much travel demand would be shifted to off-peak in this transportation system.

$$\begin{aligned}
&\max_{x_i} \ U_i(x_i, x_{-i}) \\
&s.t. \quad U_i(x_i, x_{-i}) = d \cdot [P_i(1-x_i) + O_i(x_i) - p - (1-x_i) \cdot L_p(D-G) + R \cdot \frac{x_i}{G} - \Delta p], \\
&\qquad D = d \cdot n, \\
&\qquad G = d \cdot (x_i + x_{-i}), \qquad\qquad (4) \\
&\qquad x_i \leq 1, \\
&\qquad x_i \geq 0.
\end{aligned}$$

Loiseau et al. (2011) shows that when the number of agents in the transportation system increases to infinity, there exists one unique solution to the problem above. At this optimal solution, $G = d \cdot (x_i + x_{-i})$, or in the case where there are infinite number of agents we integrate the individual off-peak demand over the set of total agents, representing the total off-peak travel demand which is nonzero for any reward $R > 0$.

The research problem of this thesis is how to use lottery to induce mode shifts from commuters. The above model, as proposed by Loiseau et al (2011), can be modified to show the impacts of lotteries in shifting travel modes as well. Specifically, in the above model, each agent has two travel choices: peak and off-peak travel. In the case of travel mode, we can assume the agent has 2 modes: driving alone and otherwise. Regardless of which exactly alternative mode (walking, biking, transit and carpooling) an agent chooses, this agent will have a representative utility function for not driving alone. We also assume, these two utility functions satisfy that commuters strictly prefer driving alone than alternative modes. Demand for travel is divided into two parts: travel via driving alone and travel via alternative modes. With this modification, the above model can be used to prove under the lottery incentive, the percentage of demand for alternative modes will be non-zero for a non-zero lottery prize.

### 2.2.2 Behavior Economics

Instead of the economics model described in 2.2.1which relies on the fundamental assumption of rationality, there are behavior anomalies that are proposed by behavior economists to explain the appeal of lotteries. In this section, concepts from prospect theory (Kahneman and Tversky, 1979) that are often used in designing incentive schemes will be introduced. Since prospect theory is mainly descriptive, examples are used to illustrate the concepts.

According to prospect theory, when facing different risky alternatives, people make decisions not only based on expected payoff, as assumed by classic economics models. In fact, people's behaviors usually exhibit common anomalies that arise from cognitive biases. Therefore, in making risky decisions, people will adopt "system 1" thinking and follow some psychological principles (Kahneman, 2011). Four concepts that can be relevant to explain the attractiveness of lotteries that come from prospect theory are: reference dependence, loss aversion, non-linear probability weighting, and diminishing sensitivity to gains and losses.

Reference dependence refers to the fact that when making risky decisions, there is a reference point based on which one person evaluates risky alternatives as either gains or losses[4]. Instead of the material outcome of each alternative, it is what the alternative compares to the reference point that will affect the person's decision. (Kahneman, 2011)

Loss aversion summarizes the frequently observed facts that loss will trigger greater emotion change than gain of the same value. In other words, people dislike losses more than how much they like gains of equivalent values. Consequently, an incentive in the form of a loss is more powerful than an incentive in the form of a gain. For example, For a Chicago-man, who conforms to the standard economics model, losing $1 and gaining $1, will bring him the same utility change, in absolute value. However, experiments have aptly demonstrated that people experience greater change in utility from losing $1 than gaining $1.

Non-linear weighting of probabilities refers to the bias people often experience in evaluating probabilities. Empirical evidences suggest that people tend to overweigh small probabilities, and underweight large probabilities. Intuitively, this conforms well to what is generally observed: people have a tendency to believe they are the exception to general rules; they are luckier than others in winning big lotteries, or avoiding undesirable outcomes.

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[4] Interested readers can refer to the Wikipedia page for more details and examples. http://en.wikipedia.org/wiki/Behavioral_economics

People also have diminishing sensitivities towards gains and losses. For example, for a person with zero dollars, giving him \$100 will bring him greater utility (e.g., happiness) than the case where he already has \$200 as an endowment and is given the same \$100.

In conclusion, for a rational man that conforms to the classic economics model (the Chicago man), participating in lotteries whose proceeds are used to fund public goods, they will achieve higher utilities. For people who follow the psychological principles as described in prospect theory, their behaviors are likely to be nudged by lottery-based incentives because of non-linear weighting of probabilities. In other words, those people participate in lotteries because they believe, perhaps without any calculation of probabilities, that they will be luckier and have greater odds in winning.

### 2.2.3 Allais Paradox and the Theory of Disappointment Aversion

Under the framework of expected utility, a person would always choose the lottery with higher expected payoff to maximize his utility. The models we introduced in section 2.2.1 are all based on this assumption. However, when facing different lotteries, people's preferences are not always based on expected payoff, as demonstrated by the Allais Paradox[5]. In this section, the theory of disappointment aversion (F. Gul, 1991) will be introduced to explain people's preferences over lotteries.

In the work of F. Gul (1991), two choice problems are proposed as follows. In the first choice problem, consider two lotteries. Lottery 1 gives \$200 with certainty and the Lottery 2 gives \$300 with a winning probability of 0.8. Intuitively, people would choose the first lottery with a certain payoff of \$200, despite the fact that the second lottery has a higher expected payoff, which equals \$240. In the second choice problem, there are again two lotteries. Lottery 3 yields \$200 with a probability of 0.5 while Lottery 4 yields \$300 with a probability of 0.4. Most people prefer Lottery 4 even though they have a higher chance of winning in Lottery 3. One explanation given by Savage (1972) is: " Many

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[5] http://en.wikipedia.org/wiki/Allais_paradox

people prefer Gamble 1 (Lottery 1) to Gamble 2 (Lottery 2) because, speaking qualitatively, they do not find the chance of winning a very large fortune in place of receiving a large fortune outright adequate compensation for even a small risk of being left in the status quo. Many of the same people prefer Gamble 4 (Lottery 4) to Gamble 3 (Lottery 3); because, speaking qualitatively, the chance of winning is nearly the same in both gambles, so the one with the much larger prize seems preferable."

In 1990, Gul proposed a model that can explain people's seemingly inconsistent preferences over lotteries in the above example. Descriptively speaking, in this model, a lottery p is divided into two parts. One part has a prize that is preferred to the "certainty equivalent" of p (defined as "elation prize") and another part has a prize that is less preferred to the "certainty equivalent" of p (defined as " disappointment prize"). In choosing lotteries, people seek not only to maximize the elation prize but also minimize the disappointment prize. For details of the model, F. Gul (1991) provides an excellent reference.

## 2.3 Shifting Mode Choices— Theories and Experiments

In this section, papers that discuss how to impact people's mode choices, specifically how to encourage shifts from auto, are reviewed.

Unlike consumer goods, people rarely choose to travel because they enjoy travelling itself. Rather, people's demand for travel is derived from their demand to be in other places. In terms of mode choices, whenever the need for travel arises, people have to choose a mode to fulfill the trip. Therefore, mode choice largely depends on the trip and associated modes available. For example, in the Boston area, for a person who lives near Alewife Station in North Cambridge and work at MIT, reasonable modes available would be biking, transit and driving (since walking would take too long—over one hour-- and therefore usually not feasible for a trip to work). For his leisure trip to Walden Pond in Concord, as there is limited transit near access, most likely the only reasonable mode would be driving. Walking and biking can also be reasonable if exercising is also part of the purpose for this trip. In this thesis, the focus is on how to design lottery-based incentives to influence mode choices for commuting (to work) trips.

In addition to availability of travel modes, how people make decision regarding modes for commuting is another important factor to consider. For some modes used for a specific trip, the concept of generalized cost can be used to capture the cost of choosing this mode (K. Small, 2013). Intuitively, people will choose modes with low generalized costs. However, from observations, mode choice is not always consistent with the predictions made solely using generalized costs. In particular, as proposed by Aarts and Dijksterhuis (2000), mode choice is more habitual than the result of a decision process that involves rational thinking (Aarts and Dijksterhuis, 2000; I. Ajzen, 1991). Especially for almost daily commuting trips, not many people would go through a complete decision process for choosing which mode to travel every day. Experiments have been carried out to examine possible ways to influence mode choice. In this section, two experiments will be reviewed to examine to impacts of incentives on mode choices.

In Japan, Fuji & Kitamura (2003) conducted a one-month experiment where free bus tickets were given to 23 habitual drivers in the experiment group. At the end of the experiment, bus usage was significantly higher in the experiment group than the control group (consisting of 20 habitual drivers). Metrics such as attitudes, frequency and habits were measured for both auto and bus among participants. Results showed that after given the incentive of one-month free bus ticket, drivers' attitudes toward buses were more positive and they also used buses more frequently. One month after the experiment ended, the switch from auto to buses was sustained for a number of drivers from the experimental group. For details on the experiment design, implementation and results, the full paper of Fuji and Kitamura (2003) is a good reference. The authors have developed a hypothesis to explain the mechanism behind why a free bus ticket can attract drivers shift to busses. They propose that the free bus tickets give drivers an opportunity to unfreeze their driving habits. If they find taking buses to be more enjoyable than they previously imagined, they are likely to form the habit of taking buses instead of driving.

In the Netherlands in 2010, daily cash prizes were rewarded to people who avoided peak hour travels by using alternative modes such as transit, driving at off-peak hours, or working at home. If commuters drove in the shoulder period of peak hour, they were awarded 3 euros. If they completely avoid the peak, they were awarded 7 euros. In total, there was an approximately 50% reduction in peak hour auto trips, a majority of which came from shift in travel times. Yet, the mode shift ("Route changes" as illustrated in Table 2-5 below) was also significant, which was more than 9% of the total trips. A full description of the experiment can be found in the work of Ettema, Knockaert & Verhoef (2010).

| Location | Incentive | Modifications to travel behaviour | | | |
|---|---|---|---|---|---|
| | | Departure time | Route changes | Mode shifts | No trips |
| **1. Zoetermeer** | €3 | 35% | - | 10% | 1% |
| **2. Gouda** | €7 | 4% | - | 14% | 3% |
| **3. Hollandse Brug** | €4-6 | 16% | 9% | 7% | 6% |
| **4. Moerdijk Brug** | €4 | 15% | 28% | 5% | 6% |

Table 2-5: Percentage Changes in Peak Commuting Trips in Spitsmijden (Ettema, Knockaert & Verhoef, 2010)

The above two experiments suggest that mode shifts are possible, even among habitual drivers. Additionally, providing positive incentives can be effective in achieving mode shifts. Since lotteries, when properly designed, are a powerful positive incentive in fostering behavior changes such as reaching weight loss goals, adhering to medicine protocols and inducing commute time shifts; it is entirely possible that lotteries could be used to nudge commuters drive less to work, and use a range of alternative travel modes.

## 2.4 Summary— Key Findings

Theoretical models have shown that under proper assumptions, providing lottery incentive would not only increase the level of public good provisions, but also improve welfare of people who participate in the lottery. As the lottery prize increases, the amount of public good raised would approach the first-best level. In other words, for a rational person, participating in lotteries where proceeds are used to fund public good of his concern is welfare improving regardless of the outcome of the lottery. In real life, the rationality assumption rarely holds. A much more robust explanation for why providing a lottery incentive comes from prospect theory. Generally speaking, when facing a small chance of probability, such as the odds of winning a lottery, people tend to believe they are luckier than predicted by probabilities and generally overestimate that small probability.

Even though the appeal of lotteries seems universal, not every behavior could be influenced by it. There are several factors to consider in designing a lottery incentive.

First, whether the behavior which the lottery is used to nudge towards is beneficial to the agent. In the cases of public health, weight loss and adherence to medicine protocols will benefit agents personally. Lotteries provide them with a more direct motivation since the possibility of cash prize can be realized in the short run while the benefits of weight loss and correctly prescribed medicine intake are only available in the long run. Under the lottery incentive, people probably are more determined to work towards the long-term goals. In survey methodology, when participants have minimal motivations to complete online surveys, the extent to which lotteries can increase response rate is very limited. In fact, as shown in the case study, sending email reminders increases response rates more than lotteries do.

Second, in addition to the possible monetary gains, emotion is another reason why people participate in lotteries. The application of lotteries in promoting sales has suggested that the main appeal of lotteries as a sales technique comes from the hedonic benefit it brings to consumers.

Third, lotteries are more effective in changing input than output related behavior. In case of education, providing lottery incentives to students will improve their efforts (inputs), such as increased attendance rate, but not necessarily their grades (outputs). One implication that could be drawn is that lotteries are effective in changing behaviors that people can directly control. As illustrated in the example given by Gneezy, Meier & Rey-Biel (2011), students know how to attend class, read a book, but not necessarily know how to perform better during tests.

# Chapter 3

# A Framework for Lottery-based Incentive Schemes

The case studies in section 2.1 show that lotteries have been widely used to foster positive behaviors. Shifting travel modes from driving alone is one behavior that could be induced under properly designed reward schemes. Based on the literature reviewed in Chapter 2, a framework for designing a lottery-based incentive scheme with insights from microeconomics and behavior economics is proposed in this chapter. Examples used to illustrate the framework are based on lotteries used previously to influence commuters' mode choices. Specifically, the goal of an incentive scheme to be developed under this framework is to reduce single-occupant auto trips and encourage commuters' usage of alternative modes—walking, biking, transit and carpooling. A flowchart depicting how incentive schemes work is presented in Figure 3-1 and the major aspects of the framework are discussed below.

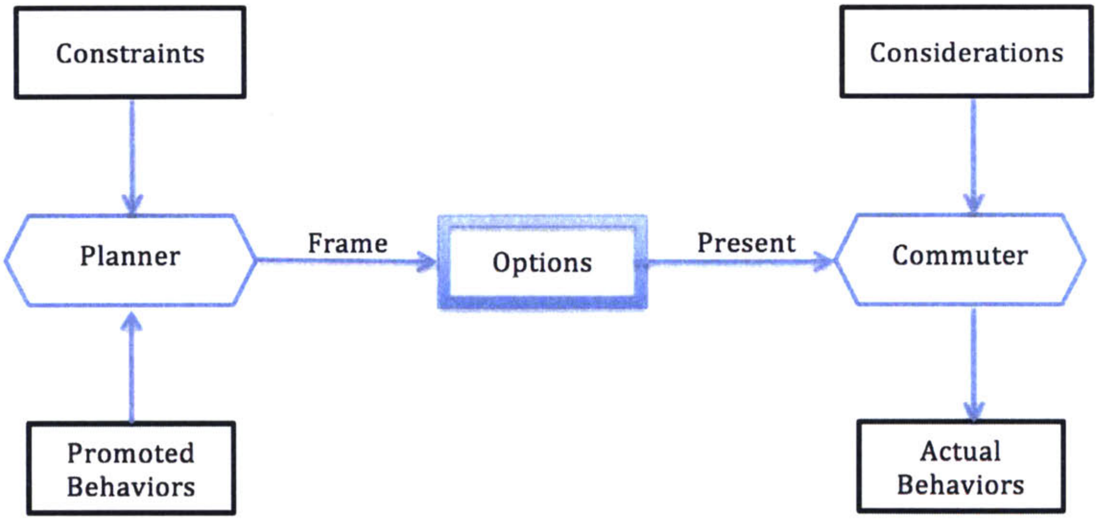

Figure 3-1: The Framework for Development of a Commuter Lottery Reward Scheme

First, planners and policy makers face a set of determined goals, priorities and constraints. After balancing objectives and constraints, for any incentive scheme they need to decide what are the behaviors they hope to promote from the participants, or commuters in the context of influencing mode choices. Then, combining the behaviors to be fostered and the resources available, planners will decide how to frame the options for rewarding commuters and subsequently present those options to commuters. The process of framing and presenting options requires planners' understanding of how commuters make decisions regarding their travel choices.

Second, commuters have a range of interrelated motives in making travel decisions. As reviewed by Baird and Zhao, when making travel related choices, such as mode choice, commuters consider both utilitarian attributes of the mode, route and time of a commuting trip and other benefits of health and sustainability. More importantly, travel choices can also be influenced by social norms and habits. The utilitarian aspect of a travel choice can be analyzed using microeconomics theory, as illustrated by the economics model in section 2.2.1. When designing options, planners need to take into consideration the multilevel motives that will influence commuters' responses to these different options. In the case where lotteries are used to promote positive behaviors, options include ways to assign the winning probabilities to commuters. Moreover, since commuters' motives also include the non-utilitarian benefits, options should also be framed to include components that address these motives. For example, when designing a lottery scheme to promote walking, one possible option can be framed on three levels: walking to work will bring the chance to win a lottery (monetary benefits), is good for health (personal benefits), and reduces carbon emissions (social benefits). The process of presenting options to commuters is similar to the execution of the incentive scheme. Considering those options presented by planners and their own concerns, commuters will respond by either choosing from the options offered, or continue with their current choice. The effectiveness of such a scheme can thus be measured by the observed behaviors of commuters.

Given the above process of how an incentive scheme works, a large number of schemes can be designed, with variations in behaviors promoted, mechanisms and resources available. In the context of using lotteries to incentivize commuting trips with alternative modes, a framework, which consists of common parameters to consider, is proposed as below.

## 3.1 Stakeholders of the Incentive Scheme

Stakeholders include all parties whose benefits may be influenced by the incentive scheme. There are two major parties involved: those who provide support for the scheme to be implemented and those who can potentially benefit from the scheme. For the first group who provides support, planners need to consider what their goals and concerns are. This is important in designing implementation methods that are feasible and efficient given the support available from this group. Assume that a company located in CBD is faced with the problem of how to manage the increased parking demand from its employees. The company can decide to build or lease additional parking spaces to meet the higher demand, or provide employees with incentives to use alternative modes. Depending on the time and monetary costs of building or leasing new parking spaces, the maximum support (usually in terms of the funding required) can be estimated. Moreover, the parking demand curbed under the incentive scheme should be comparable to the number of parking spaces that can be built or leased with a similar level of financial support.

Since the essence of a lottery-based incentive is to reward those who exhibit positive behaviors, eligibility for the incentive scheme is important to ensure a fair distribution of welfare among the second group of stakeholders. In the same example where the hypothetical company is deciding between whether to build or lease more parking spaces or incentivize mode shifts to reduce parking demand, if an incentive scheme is implemented, the eligibility for this incentive scheme would impact the welfare of all employees. As the nature of the incentive scheme is to provide subsidy to employees who commute to work every day, it seems intuitive that all employees should be able to participate in the scheme. However, from the perspective of increasing the probability of achieving a certain amount of reduction in auto commuting trips, including only a part of the employee population may be more effective than making everyone eligible for the new incentive. Employees who have alternative modes easily available are more likely to be encouraged to change than those who do not. If the winning probability is too low due to a large number of eligible participants or the winning prize is not attractive, people may not be motivated to participate at all. One possible way to maximize the probability of inducing commuting trips via alternative modes is to allocate the credits only to those who have reasonable access to alternative modes. With a smaller number of eligible participants, employees to whom alternative modes are available will be more convinced by a higher probability of winning and therefore actually try one of the alternative modes as a commuting mode. However, under this eligibility criterion, those who live farther away where driving alone is the only sensible option are essentially excluded from the chance of winning, potentially resulting in an inequitable welfare distribution among all employees.

## 3.2 Constraints on Resources Available

Constraints in adopting a lottery-based incentive scheme come from three aspects: finance, technology, and feasibility of implementation. To illustrate what are considered constraints in an incentive scheme, the example is continued to be used here of the hypothetical company that confronts the problem where parking demand exceeds current supply of parking spaces.

Finance refers to the available financial support to implement this program. As shown in section 2.2.1, microeconomics models have proven that as the lottery prize increases, “bettors” would donate more to the public good to increase their chance of winning. Those models can also be used to analyze the application of lotteries to influence the mode choice, as the assumptions of the models generally hold in the context of the new application. For Morgan’s model, the three main assumptions are heterogeneous agents with quasi-linear preferences; public good funded by the lottery is socially desirable and initial endowment for each individual is the same. Another additional assumption in the work of Loiseau et al (2011) where lotteries are used to shift travel time is that people strictly prefer to travel during peak rather than off-peak. Those assumptions also hold reasonably well when lotteries are used to incentivize travel mode shifts from driving alone to alternatives. First, using alternative commute modes would reduce wasted hours and fuel in congestion and would be beneficial to the environment; and thus can be considered a socially desirable public good. Second, for people who currently choose to drive alone, their revealed choices can be used to demonstrate they prefer driving alone to alternative modes; otherwise they would have chosen differently. Therefore, the conclusions of these models can also show that commuters are more likely to adopt modes that would earn them greater chance of winning when the lottery prize increases. Additionally for the lottery reward structure, which is discussed in a case study in the next chapter, possible designs can be derived from the settings in Morgan (2000) and Loiseau et al's (2011) models.

Even though the theoretical models predict that the influence of the lottery-based incentive scheme on mode decisions would increase with the amount of the lottery prize, in reality there would inevitably be a constraint, or an upper bound, on the budget available. As explained earlier, when the company needs to address the problem of inadequate parking spaces, the maximum budget available to the incentive scheme would appear to be some amount below the resources needed to build or lease those additional parking spaces that can accommodate the excess demand.

The other two aspects—technology and implementation feasibility—are different but share similarities. Technology refers to what methods are theoretically available to solve problems that might occur in designing the incentive scheme, while implementation feasibility is an assessment of the methods to select those that are implementable. For example, how best to detect modes used among commuters is a key problem to solve in designing incentive schemes to influence mode choices.

One possible method is to ask commuters to install movement tracking smartphone applications. For each commuting trip, the application would record one geographical location for a time interval of several seconds or longer. Based on these records, information on the route chosen and speeds can be calculated. Combining this information with the road network and transit network, mode(s) used for this commuting trip can be thus inferred. To increase the accuracy of identifying the modes used, data mining techniques can be used to develop the classification algorithm. Once the algorithm is available, identification of the mode(s) used for each trip would only require the basic information on movement and therefore increase the efficiency in identifying modes. To be more specific, a mode choice in essence is categorical. Variables such as the travel speed, locations, the overlapping of locations with those in the transit network can be used to differentiate modes. For the training data, information on each mode used, its associated travel speeds and geographical locations, and geographical details of transit network are included. A decision tree can be built to select the variables to be included. Once the tree is built, there would be no need to query the transit network database every time a new commuting trip data becomes available, and therefore reduce the efforts and increase the efficiency in identifying modes used. This method is technologically feasible especially given the wide range applications of machine learning. However, whether it is implementable would depend on the specifics of the incentive scheme, such as the budget, time available to develop the decision tree and participants' willingness to installing such movement tracking applications.

Another method to detect modes used by commuters would be through the related records, such as parking and transit trip records. In general, for commuters who regularly take transit or drive to work, they would have transit cards or parking permits. By checking these records commuting modes of transit and driving can be determined. For non-motorized modes of walking, biking, and even running, smartphone applications such as *Moves* (Sapona, Lester, Froehlich, Fogarty & Landay, 2008) have reported high precisions in identifying activities using these modes. As for commuters who are dropped off, there is no straightforward way to differentiate carpooling with a colleague or being dropped off by others (such as taxi drivers and family members). Without using any data on details of car trips undertaken by all eligible commuters in the incentive scheme, one plausible method is to adopt the self-reporting mechanism to identify if a commuter is being dropped off by a colleague, i.e. using carpooling, or others.

### 3.3 Framing of Options

After identifying the goals of the incentive scheme, eligibility of participants, and constraints on available resources, planners can begin to design the options available to participants under the incentive scheme. In order to effectively design the options, it is necessary to consider the motives that eligible participants may have in making decisions. Since the reward of the incentive scheme is a lottery, an option should include three components: allocation of winning probabilities, structure of rewards, and inclusion of features that address participants' non-utilitarian motives.

Winning probabilities should be designed to reward those whose observed behaviors are those promoted. Specifically, if the planners hope to promote alternative commuting modes other than driving alone, then participants who walk, bike, take transit or carpool to work should be rewarded with a higher probability of winning the lottery prize. One method to quantify the probabilities is to assign credits for promoted behaviors. Examples where this method was adopted can be found from cases of INSTANT (Merugu, Prabhakar and Rama, 2009) and INSINC (Pluntke and Prabhakar, 2013). The credits are similar to lottery tickets. The more credits one person has, higher chance of winning the reward. One intuitive way to assign credits is that those who exhibit more promoted behaviors would receive more credits. Lottery rewards can have different structures depending on the number of prizes and winners for each prize. Depending on the goal of the incentive scheme, there are different allocation mechanisms and reward structures.

While the lottery rewards offer participants a real monetary incentive towards promoted behaviors, associating non-monetary benefits to those behaviors can also turn out to be a powerful "nudging" tool. In an example given by given by Baird and Zhao (2014), households were randomly divided into control and experimental groups and the idea to reduce electricity usage was promoted in both groups. For experimental groups, electricity consumption was framed in terms of sustainability and conservation, and their consumption in relation to their neighbors. At the end of this experiment, households in the experimental group reduced their electricity usage by 2% on average, compared to those in control group.

## 3.4 Presentation of Options

In presenting the options framed in 3.3 to participants, two key goals are to increase the initial sign up rates for the scheme and subsequent participation rates among eligible participants. In order to achieve this objective, the following parameters should be considered.

An integrated platform that presents customized options, records behaviors, and awards lottery prizes needs to be developed and implemented. The goal of such a platform is to minimize people's costs in participating and foster positive participating experiences. Any additional features that would retain participation should be included. For example, gamification features should be added whereas possible to improve the user experience and thus engage future participation. In the platform implemented in INSINC, the allocation of lottery prizes is through fun online games.

The data collection required to report and validate participants' behaviors method should be accurate and require minimal or no active effort from participants. In the context of collecting data on modes used, smart-phone based applications (such as *Moves* on IOS and Android) can be used to automatically track details of commuting trips and send the necessary information to the platform.

Feedback on the participants' performance can be implemented to encourage consistent efforts. The contents of the feedback can include a summary of impacts of their behaviors, how they compare to their fellow participants, and a customized “strategy” to increase their chance of winning the rewards.

# Chapter 4

# An MIT Case Study --- A Proposal to Implement Lottery-based Incentives to Reduce Single-Occupant Auto Commuting Trips

Based on the framework proposed in Chapter 3, a lottery-based incentive scheme to reduce parking demand from MIT employees is proposed in this chapter. For each aspect of the framework described in Chapter 3, several possible designs will be discussed. The goal of this chapter is two-fold: first, to illustrate how to apply the framework to address real world concerns; second, to propose an implementable incentive scheme to help MIT manage its parking demand.

## 4.1 Overview

Two of the major parking garages on MIT campus are in disrepair and are soon to be demolished. The MIT administration needs to decide whether to use the space for new parking garages, or academic or commercial development. As estimated by a report from MIT Transit Lab, the cost of building new underground parking garages is very high: if the new parking garages were to be built, the average parking cost per space would be in excess of $7000 per year in order to recover the infrastructure, operating and maintenance costs. As part of the project that investigates how to reduce parking demand from the MIT community, this chapter presents how to utilize a lottery-based incentive scheme to reduce single-occupant auto trips and promote alternative commuting modes of walking, biking, transit and carpooling.

Under the framework in Chapter 3, each aspect will be discussed in the sections below. The general idea behind a lottery-based incentive scheme to reduce single-occupant auto trips is that commuters who choose alternative modes of walking, biking, transit, and carpooling will be allocated credits, which can be exchanged for rewards.

## 4.2 Eligibility for the MIT Incentive Scheme

There are two groups of stakeholders in the incentive scheme. The first is the MIT administration that would decide whether to invest in an incentive scheme to address to problem of inadequate parking spaces. The second group consists of members of the MIT community who demand parking. Since within the MIT community, the majority of parking demand comes from employees rather than students, the second group would thus refer to MIT "benefit-eligible" employees (generally those who work half-time or more). Ideally whenever members from the second group, who are also referred to as participants in the incentive scheme, exhibit the behavior to be promoted—i.e. commuting to MIT via alternative modes -- should be rewarded with credits. However, given a possible budget constraint, one way to maximize the likelihood of achieving the greatest reduction in single-occupant trips is to use the budget on people who have greater access to alternative commuting modes. In this way, if the number of eligible participants decreased compared to the case where all employees are eligible, people would perceive an increase in the chance of winning. Consequently, if it were assumed that a higher chance of winning a lottery would result in a higher probability of people participating, people would be more likely to use alternative modes and earn credits when the number of eligible participants is reduced. However, under this design, those stakeholders for whom driving alone is the only reasonable mode are excluded from this distribution of lottery-based rewards and their benefits from MIT decrease compared to their peers who are included in the lottery-based reward scheme. One way to compensate these stakeholders is to offer them other benefits that are more relevant to their commuting modes, such as a continued subsidy to park on campus. Since for this chapter, only the lottery-based incentive scheme is discussed, all "benefit-eligible" MIT employees who work half-time and more, regardless of their likelihood of choosing alternative modes, are considered as eligible participants and therefore included in the welfare distribution of lottery-based rewards.

## 4.3 Constraints on Implementation

The constraints on implementing the lottery-based incentive scheme primarily lie in two areas—financial constraints and feasibility ones. For financial constraints, the key question is what level of budget should be allocated to ensure a certain level of confidence in achieving the target reduction in parking demand. As discussed in Chapter 3, the maximum amount that will be allocated to an incentive scheme from the MIT administration is unlikely to exceed the cost of building new parking spaces, nevertheless there needs to be a comparably high certainty that the incentive scheme can effectively address the issue of excess parking demand. As there have been no experiments conducted where a lottery-based incentive is implemented to influence commuting mode choices, no threshold prize amount could be found that would guarantee a mode shift. Nonetheless, insights from other related studies could still be borrowed to estimate the level of prize needed.

First, there have been experiments conducted that utilize monetary prizes (in forms of lotteries and cash) to shift commuting time. The overall prizes and their respective results reported from teams that carried out these experiments are summarized in Table 4-1.

| **Project Name** | **Year** | **Location** | **Rewards** | **Reward Frequency** | **Result** |
|---|---|---|---|---|---|
| Spitsmijden | 2012 | Netherland | €2-€7 per person for avoiding travelling during peak hours | Per trip | 20%-50% of participants shifted to off-peak |
| INSTANT | 2008-09 | Bangalore, India | $1920 to 66 winners through lottery drawings | Per week | Number of participants shifting to travel before the peak doubled (from 21% to 34%) |
| INSINC | 2012-2013 | Singapore | S$1-S$100 prizes for each participant through lottery-based games. (Total number of winners unreported) | Unreported | 7.49% reduction in peak trips |

Table 4-1 Summary on Lottery-based incentive Schemes Implemented to Influence Commuting Behaviors

As the total amount of prizes given out over the period of experiments for Spitsmijden and INSINC is not directly available, and cannot be inferred based on the data published, the amount used in INSTANT is calculated to estimate the magnitude of those prizes implemented in experiments that reported positive results. For INSTANT, there were approximately 14,000 eligible participants. The lottery prizes were given out each week, with a total prize of $1,920 and the number of winners 66. Over the period of six months, the total lottery prize value awarded was approximately $50,000. Based on the salary information obtained from Glassdoor.com, the median salary for senior management positions or similar is around $3,200 per month.

At MIT, as of 2015 the total number of employees is around 11,840, which is of a similar scale as the company in INSTANT. Assuming the incentive scheme at MIT adopts the same reward structure as INSTANT, the total prizes awarded would be approximately $50,000. Since the income levels at MIT are higher than that in the case of INSTANT, the level of prizes should also be greater to attract participation. The actual amount allocated towards lottery prizes would depend on the total budget available for the scheme. As there would be costs allocated to other areas of the incentive scheme, such as developing an integrated platform to minimize the input effort from participants, a balance should be achieved in maximizing the prize money and ensuring enough budget for other features of the scheme.

In addition to using monetary prizes to influence travel decisions, there are experiments that aim to influence travel behaviors through addressing the non-utilitarian motives behind commuting mode decisions. For example, in the experiment conducted by Zhao and Baird, 35 participants were recruited from those who participated in Bike To Work events. The app *Moves* was installed on the participants to track their movement activities. Based on the modes they used to commute to work, a weekly feedback was provided to participants in the experimental group on the time they spent walking, running and biking; greenhouse gas emissions they avoided, calories they burnt, how their performance compared to others in the study and the national average. At the end of every feedback report, an overall evaluation— Great, Good and Below Average was given. These overall evaluations were displayed side by side with emoticons that represented the three evaluations. The main result reported was there was a general decrease in participation over the period of the study. The rate of decrease was greater in the control group (62%) than the experiment group with feedback reports (48%). Since the sample size of this experiment is rather small, how statistically significant the difference between 62% and 48% is cannot be inferred from the results published. Nevertheless, associating the non-utilitarian benefits, such as emissions avoided, calories burnt and satisfaction derived from comparisons with others, with the commuting modes does influence mode decisions to some extent.

Another constraint on the scheme is on data collection: what are the data that can be collected, what are the level of details needed from the data, and how to collect it. The purpose of the data collection is to identify people's modes used for their daily commuting trips to and from MIT. Traditionally, such information on mode used is obtained from self-reporting, as in surveys and census interviews. These methods are not only costly to administrate but also prone to errors. With the high market share of smartphones, one way to collect such information is from smartphone applications (i.e. apps). From the technology point of view, there are GPS-based apps that can track people's movement and report data that includes origin-destination information, route choices and travel speeds. For one trip, based on the travel speed and route information, the mode(s) used can be inferred. Specifically, travel speed can help differentiate among walking, biking and motorized modes of transit and auto[6]. Since the speeds for transit and auto are similar, route information is needed to differentiate the two. If the route travelled is similar to a bus route, and there are frequent stops (which can be detected when speed is reduced to 0), then it is very likely the mode used is transit. For carpooling, if there are two auto trips with high correlation in paths and arrival time, then it is highly likely these two people have shared the ride. To improve the precision and computational efficiency of differentiating modes used, techniques from decision tree learning can be adopted. Because of the categorical nature of the mode variable, a decision tree can be built and tested on the training and validation data sets. Applying the decision tree to the test set, if the errors are within some pre-determined tolerable range, the tree can thus be used to differentiate the modes on future data collected.

In the case of MIT where detailed parking records and transit transaction records of employees are available, another way to identify modes used would be a combination of these records and partial information collected from movement tracking apps. From transit transaction records, participants who use transit can be determined. From the

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[6] Based on the experiment conducted by Schutz et al., the average speed of walking under free-living conditions is 1.38m/s. The range of speed for biking is from 4.5 m/s to 6.7 m/s under normal conditions, according to the Wikipedia page on "Bicycle performance".

parking records, participants who drive to work can be identified. To differentiate between drive alone and carpooling, two methods can be used. The first is self-reporting. Participants who shared the ride can report their mode on the online platform that administrates the scheme. The second method is through movement tracking apps. If two or more participants have similar driving paths and arrival times, but only one parking space is occupied, they can be considered as carpooling. The first method requires some efforts from participants, while the second method would only require participants to install apps and carry their phones. For participants who walk and bike to work, the modes can be directly identified from the aforementioned apps. For the mode of being dropped off at MIT, it can be tricky to differentiate from carpooling. One method to differentiate it would be as follows. With the help of *Moves*, it can be determined to be a motorized trip. After querying the transit transaction database for an individual's ID, the absence of any record can determine it to be an auto trip. During peak hours, number of arrivals in cars would be large. It is possible the person being dropped off and someone who drives to campus has similar paths, arrival time and maybe even the parking/drop off locations. Therefore, it can be difficult to determine whether these two people have shared the ride or not. Theoretically, using the method of building decision trees can improve the accuracy of predictions and therefore differentiate carpooling among participants and being dropped off by non-participants (such as taxi drivers). However, this problem can be solved easily by treating being dropped-off the same as carpooling. For participants who are dropped off, they do not occupy any parking space and therefore being dropped-off should also be among the modes to be promoted in this incentive scheme.

Though it is technologically feasible to collect travel data using smartphone apps, additional considerations should be taken into account in implementation. First, the level of details collected from these movement-tracking apps should not violate people's privacy. One way to address this issue is to assign an anonymous ID to each app, and design computer programs that analyze the data and produce travel summaries automatically. Second, the apps used should not drain phone batteries too quickly as to affect employees' regular uses of phones. Third, in the rare case where a participant does not have a smartphone, alternative methods of data collection are needed. One possible solution is to provide a pre-configured smartphone to this participant. Another method is to ask this participant to self-report on the commuting mode used, and administrators of the incentive scheme would manually check if the mode entered by the participant is reasonable.

Since 2012, research has been conducted at MIT using mobility data collected from smartphone apps (Gonzalez et al., 2012). Using apps to collect travel data is likely to be a reasonable feature of the incentive scheme to be implemented in MIT.

## 4.4 Framing of Options in the Incentive Scheme

This section discusses possible designs of different options available to participants in the incentive scheme. Each option should specify the detailed reward structure and how winning probabilities are allocated. Additionally, each option should be associated with features that can promote the non-monetary benefits of shifting to alternative modes. In section 4.4.1, four mechanisms to allocate winning probabilities through assigning credits are discussed. This section concludes with a recommended mechanism for the MIT case. For different levels of risk aversion exhibited by participants, three reward structures are presented in section 4.4.2. Section 4.4.3 describes non-monetary benefits that can be associated with each option to address participants' non-utilitarian motives, which influence their mode choices.

### 4.4.1 Credit Allocation Mechanisms

In the proposed lottery game, participants will be awarded credits when they do not drive alone to work. The credit allocation mechanisms are discussed in this section. When a participant has accrued enough credits, the credits can be used to exchange for rewards, including probabilistic ones such as lotteries. Different structures of the rewards are discussed in the next section.

Given the probabilistic nature of any lottery game, credits do not represent a deterministic reward, but rather a possibility of winning. For planners who will decide on details of a lottery scheme, they choose a credit allocation mechanism (how many credits to award to each person for what behavior) so as to achieve the maximum reduction in the parking demand. For participants, they take the credit allocation mechanism as given and, based on this possible "reward", choose a travel mode to maximize their own benefits. The hierarchical nature of the decision making process resembles a bi-level optimization problem with the upper level decision makers being the planners and the lower level being the participants. Though it can be difficult to determine the objective functions due to lack of knowledge of people's utility functions, credit allocation mechanisms should be designed with considerations for possible interactions between the planners and participants. In other words, planners need to make predications about possible reactions from participants, and therefore use credit allocation as a tool to maximize the reduction in parking demand. In this section, four credit allocation mechanisms are presented and discussed and one mechanism is proposed for the MIT case.

According to Morgan's model, people who donate more to the public good are given greater odds of winning. In the context of using a lottery incentive to influence mode choices and encourage participants to drive less, commuters who incur greater costs to avoid driving alone will earn more credits, so as to ensure that their expected payoff from the lottery game justifies their efforts in using a specific travel mode. One question that remains is the quantification of commuters' efforts in choosing a specific travel mode. The concept of generalized cost can be used in measuring the efforts, and one component of generalized cost is the distance between a commuting trip's origin and destination. For example, for a participant who lives nearby MIT, such as in Central Square, Cambridge, his or her effort in commuting to MIT would be less than some other participant who lives farther away, such as in Newton, regardless of which travel mode is used. In terms of travel modes, planners would have some preferences over which mode(s) are chosen by commuters under the incentive scheme they design. For example, when the goal is to reduce parking demand, walking, biking and using public transit are all desired mode choices as they occupy no parking spaces and therefore planners will give commuters who use these modes higher winning chances in the scheme they design. When the goal is to reduce carbon emissions per person per trip, walking and biking should be mostly preferred, followed by using transit, carpooling and driving alone. Planners could also devise the credit allocation mechanism such that the credits are awarded based on the emission level of travel mode. In this section, distance of a commuting trip and mode chosen are used to quantify the effort a participant makes and thus the basis for designing credit allocation mechanisms.

### *Credit Allocation Mechanism 1*

Assume the objective is to reduce parking demand. Each car occupies one parking spot. Therefore, the preferred travel modes are walking, biking and taking transit, followed by carpooling. Credits for using each mode can be awarded accordingly, with the most preferred modes having highest credits and driving alone zero credits. To simplify the problem of assigning credits for different distances of commuting trips participants make, distances can be categorized into zones. Below is the distribution of residential geographical locations of MIT participants and the parking and transit passes/permits they have. Yellow represents annual parking permit holders while red represents MBTA LinkPasses (that can be used for all subway and bus services). The size of each pie represents number of participants living in the municipality.

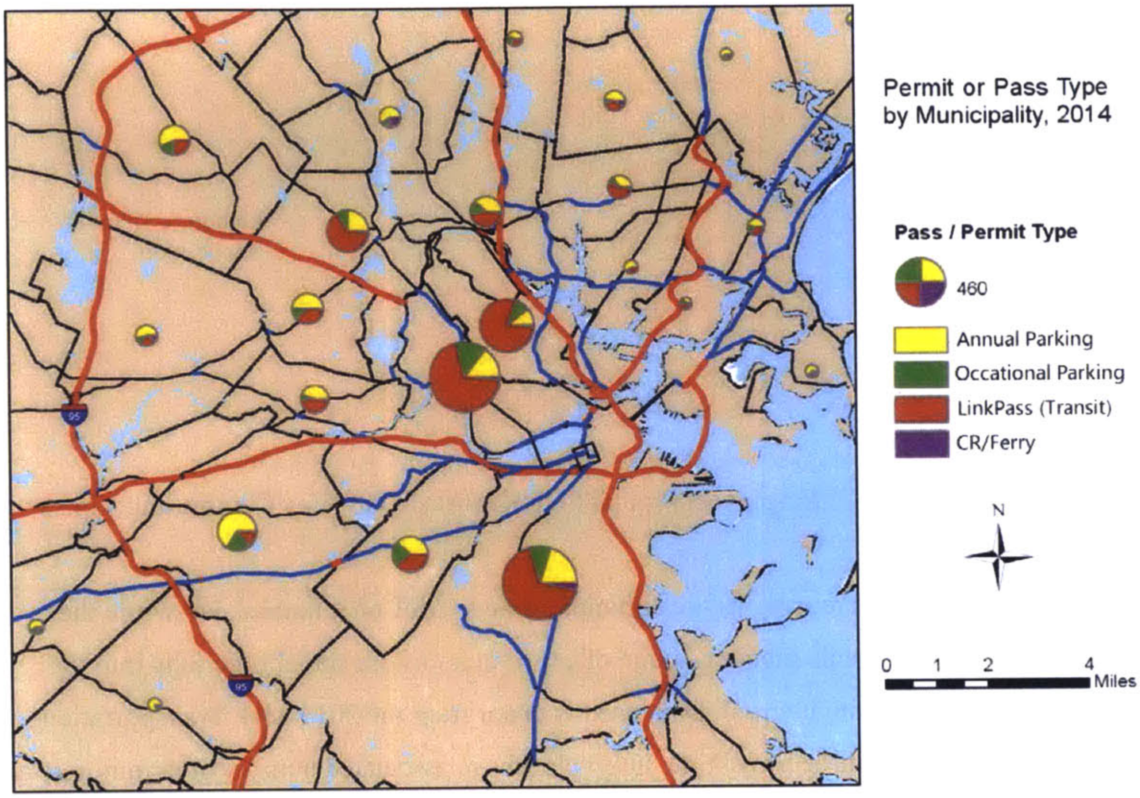

Figure 4-1[7] The Distribution of MIT Participants' Residential Locations and Associated Permit/Pass Types

Based on the travel time on a normal day reported from 2014 MIT Commuting Survey, the histogram for travel time of MIT employees on a normal day is as shown in Figure 4-2 below:

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[7] The figure was produced by Matthew Hartnett (2015).

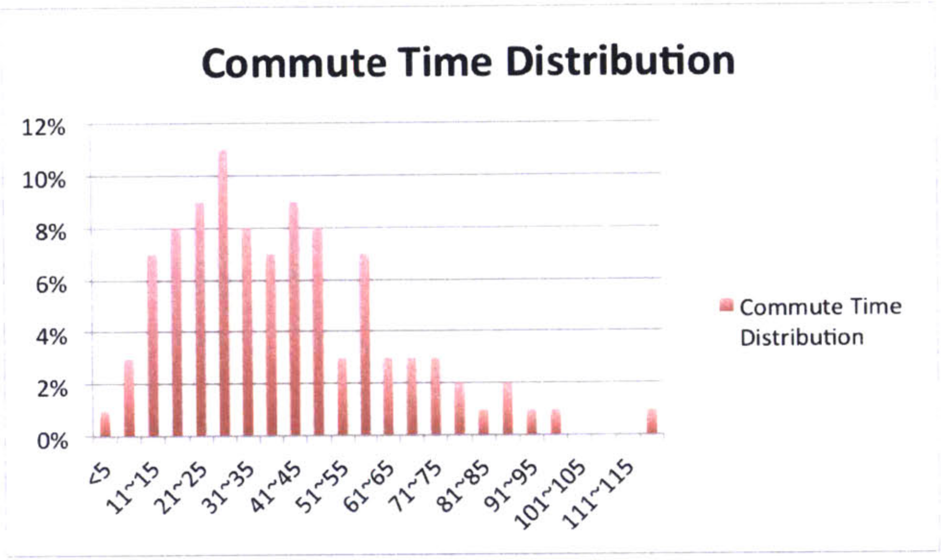

Figure 4-2 MIT Employee Typical Self-Reported One-Way Commuting Times

The horizontal axis represents the commute time to MIT on a normal day while the vertical axis represents the percentage of commuters whose travel time falls into the respective travel time interval. Data used is taken from the 2014 MIT Transportation Survey. There are three travel time intervals whose associated number of commuters are local maxima: 26~30 minutes, 41~45 minutes and 56~60 minutes. One possible way to categorize the distances of commuting trips is based on the travel time and is presented below.

For trips with same distance from origin to destination, define T as the minimum commute time using walking, biking, transit or a combination of the above. The geographical locations of participants' households can thus be categorized into different zones:

| | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
|---|---|---|---|---|
| T (minutes) | **[0, 30)** | [30, 45) | [45, 60) | **[60, ∞)** |

Table 4-2 Criteria for Zone Categorization

In Table 4-2, the zones are categorized based on commuting times. However, to facilitate the implementation of the incentive scheme, a more straightforward categorization method based on geographical location is needed. To determine the appropriate geographical zones that reflect the commuting time defined in Table 4-2, two methods are available.

The first method partitions the geographical areas into concentric circles with MIT being the center. As the subway lines are approximately radial shape, the innermost circle, i.e. Zone 1 would have the radius that can be calculated from 30 minutes on subway or 30 minutes biking. For Zone 2, its radius can be determined as the minimum of either 45 minutes on subway or biking. For Zone 3 and 4, biking for a time period over 45 minutes is unlikely, and therefore their radiuses would be determined from minimum time using subway lines. The second method utilizes the transportation software TransCad. In TransCad, the shortest path ("short" in terms of travel time) in modes of walking and taking transit from one TAZ to another TAZ can be determined. Based on the walking time, biking time can be inferred since walking and biking usually share paths. By enumerating the minimum travel time in all modes from TAZs where participants reside to the, TAZ where MIT is located, all 4 zones can be described as sets of TAZs where participants, housing locations belong. The first method defines zones on an aggregate level and can be more easily computed. The second method defines each zone as a set of TAZs and therefore is more precise in terms of ensuring each participant is correctly categorized into zones based on his or her minimum commuting time to MIT.

For commuters who live farther away, their effort in using the same alternative commute mode is greater and therefore should be awarded higher credits to compensate for the effort in using the desired modes. Assume 1 credit is awarded to Zone 1, 1.5 to Zone 2, 2 to Zone 3 and 2.5 to Zone 4.

As specified in the beginning of this section, the goal of this mechanism is to reduce parking demand. Since commute modes of walking, biking, transit require no parking spaces, they should be assigned equal credits. The parking space required per person for commuters who travel via carpooling is larger than 0 but less than 1; therefore, carpooling will be assigned some positive credit but less than those assigned to walking, biking and transit. Assume 2 credits are assigned to modes of walking, biking and transit, 1 to carpooling and 0 to driving alone. Combining the distances from participants' households to MIT and planners' desired modes used by commuters, the credits can be allocated as shown in Table 4-3:

| Credit Allocation Mechanism 1 | | | | |
|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
| Walking | 2 | 3 | 4 | 5 |
| Biking | 2 | 3 | 4 | 5 |
| Transit | 2 | 3 | 4 | 5 |
| Carpooling/ Dropped Off | 1 | 1.5 | 2 | 2.5 |
| Drive-alone | 0 | 0 | 0 | 0 |

Table 4-3 Credit Allocation Mechanism 1

*Credit Allocation Mechanism 2*

From Table 4-3, it can be seen that participants who live farthest from MIT are awarded highest credits if they use modes other than driving alone. From the implementation point of view, people in Zone 4 are least likely to use alternative modes because of the inconveniences of alternative modes. For example, the travel time is likely to be much lower if they travel from Zone 4 to MIT by auto than any other alterative modes. Also, it may be more difficult to find a MIT colleague to carpool, and therefore carpooling may also be inconvenient. As a result, awarding the Zone 4 participants higher credits will not necessarily be more effective in inducing them to shift from driving alone to other modes. Instead, perhaps higher credits could be awarded to participants who can change from driving alone to other modes more easily. In this way, there will be a greater chance of success in reducing single-occupant auto trips.

For people who live in Zones 1 and 2, the minimum travel time to MIT is less than 45 minutes, which suggests they probably have better accessibility to various alternative modes. Planners could also widen the reward gap between walking, biking, transit and carpooling, and therefore making modes that require no parking spaces—walking, biking and transit—more attractive in the incentive scheme. However, for the participants who reside in Zones 3 and 4, carpooling is the most realistic option if they do not drive alone. Therefore, credits rewarded to carpooling should match the other alternatives for Zone 3 and also exceed all of the others for Zone 4.

Therefore, starting with the base of Mechanism 1, another mechanism is proposed in Table 4-4.

| Credit Allocation Mechanism 2 | | | | |
|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
| Walking | 4 | 4 | 3 | 2 |
| Biking | 4 | 4 | 3 | 2 |
| Transit | 4 | 4 | 3 | 2 |
| Carpooling/ Dropped Off | 1.5 | 2 | 3 | 4 |
| Drive-alone | 0 | 0 | 0 | 0 |

Table 4-4 Credit Allocation Mechanism 2

*Credit Allocation Mechanism 3*

One probable result from reducing parking demand is a reduction in carbon emissions from commuting trips. Inversely, if the primary goal of the lottery-based incentive scheme is to reduce carbon emissions from auto trips, demand for parking is likely to decrease. Under this goal, modes of walking and biking produce no emissions and therefore should be awarded highest credits, followed by transit and carpooling. Assume 2 credits are assigned to walking and biking, 1.5 to transit and 1 to carpooling. A third potential way to allocate credit is summarized in Table 4-5.

| Credit Allocation Mechanism 3 | | | | |
|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
| Walking | 2 | 3 | 4 | 5 |
| Biking | 2 | 3 | 4 | 5 |
| Transit | 1.5 | 2.25 | 3 | 3.75 |
| Carpooling/ Dropped Off | 1 | 1.5 | 2 | 2.5 |
| Drive-alone | 0 | 0 | 0 | 0 |

Table 4-5 Credit Allocation Mechanism 3

*Credit Allocation Mechanism 4*

Following a similar argument for Mechanism 2, under the goal of reduction in emissions from commuting trips, perhaps it would be more effective to incentivize people who may be more likely to change from driving to more available alternative modes. For participants who live in Zone 4, their minimum commute time using non-auto modes is more than one hour; therefore, they may not be as likely to shift to alternative modes of walking, biking and transit as those who live in closer zones. One possible way to allocate credit in this case is described in Table 4-6.

| Credit Allocation Mechanism 4 | | | | |
|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
| Walking | 4 | 4 | 3 | 2 |
| Biking | 4 | 4 | 3 | 2 |
| Transit | 3 | 3 | 2.25 | 2 |
| Carpooling/ Dropped Off | 2 | 2 | 2.5 | 3 |
| Drive-alone | 0 | 0 | 0 | 0 |

Table 4-6 Credit Allocation Mechanism 4

*Recommended Credit Allocation Mechanism for MIT Trial*

As discussed in section 3.3, associating the non-utilitarian benefits with different options would increase the likelihood of people choosing them. Combining the goals of reducing parking demand and emissions, the following mechanism is proposed and recommended for the case in MIT.

| Credit Allocation Mechanism 5 | | | | |
|---|---|---|---|---|
| | Zone 1 | Zone 2 | Zone 3 | Zone 4 |
| Walking | 4 | 4 | 3 | 2 |
| Biking | 4 | 4 | 3 | 2 |
| Transit | 2 | 3 | 3 | 2 |
| Carpooling/ Dropped Off | 1 | 1.5 | 2.5 | 3 |
| Drive-alone | 0 | 0 | 0 | 0 |

Table 4-7 One Recommended Credit Allocation Mechanism for MIT Trial

Assume that for any participant, his or her objective in choosing a travel mode under the incentive scheme is to first maximize the credits obtained and then minimize travel time. Participants living in the four zones would thus choose walking/biking, walking/biking, transit and carpooling respectively based on the mechanism presented in Table 4-7. This outcome satisfies the objective that people who live in Zones 1 and 2 who have easy access to alternative modes are awarded higher credits to increase the likelihood of them actually adopting alternative modes. Meanwhile, people in Zones 3 and 4 are rewarded with a relatively high chance of winning when they make the effort to commute via transit and carpooling respectively.

### 4.4.2 Reward Structures

In essence, lotteries are games that provide probabilistic payoffs. As reviewed in the application of lotteries in marketing (section 2.1.6), people often prefer deterministic rewards to lotteries. Despite this, one primary reason why people participate in lotteries is precisely because of the "hedonic benefits" stemming from uncertainty in rewards. Therefore, in this section, different options for the reward structure are discussed. Some gamification features of the rewards are also presented.

For participants who are extremely risk averse and do not like lotteries, providing an option of redeeming the credits for a fixed cash prize would attract their participations in the first place. The amount of the deterministic prize should be set significantly smaller than the expected payoff of a lottery scheme, so that the deterministic prize will not dominate the lottery option. In the INSINC experiment, the fixed cash prize was offered in the following way: X credit=$0.001X in Singapore dollars (approximately $0.0008X in US dollars). By the end of the experiment, about 12.4% of participants preferred the deterministic prize option over the lottery-based ones. From the psychological point of view, the exchange option for deterministic cash would guarantee a minimum payoff to participants, and therefore attract their initial engagement.

For participants who are less risk averse, lotteries with different prize levels would be attractive. Two kinds of lotteries can be offered: One is a frequent, say daily, lottery game with a medium range of prizes and another is a less frequent, say weekly, lottery drawing with larger payoffs. The exact frequencies would depend on the budget available. Based on summaries in Table 4-1, it seems the frequency of daily and weekly would be reasonable. However, for a daily lottery to be attractive, the expected payoff cannot be too small or else participants would not be attracted to participate. The reasons for differentiating between lotteries are two-fold: first, providing the option of a grand lottery is likely to increase the initial participation rate more than when only a medium-valued lottery prize is available. When the lottery prize is large and the corresponding chance of winning is small, non-linear weighting of probabilities can be evident. In this case, providing a lottery with a large prize would attract additional participation. Furthermore, the Allais Paradox suggests that when chances of winning are approximately the same, the lottery with the larger prize is preferred. Second, prospect theory indicates that people are more impatient in the short run; therefore by providing a frequent, such as daily, lottery game that is fun and with positive expected pay off would engage people's participation constantly. If only the grand lottery option is available, people may not put consistent effort into earning credits so as to increase their chance of winning, as the payoff is not immediate.

As a summary of the analysis above, for the lottery-based incentive scheme at MIT, three reward structures can be considered. First, there needs to be a reward option where participants can use credits to exchange for a fixed prize (such as cash). This will attract enrollment in the first place. Since people in general are risk averse, it is important to provide a minimal return from participating in the lottery scheme. The second option is a lottery with a large prize, drawn with a weekly or even monthly frequency, which attracts participation through utilizing the perception anomaly that people tend to be overly optimistic about their chance of winning. The third option can be lottery games that provide small prizes, but higher winning probabilities than the lottery with a large prize. The reason for this option is that people tend to be impatient in the short run, and therefore this option can encourage participants to accrue credits consistently. Details of each exchange option are presented below.

### *Reward Option 1--Deterministic Cash Rewards*

The reward option of deterministic cash can ensure a minimum return for the credits accrued by participants. Participants can use credits to redeem for cash at a fixed rate. The exchange rate cannot be too high, or else it will become the dominant reward option. In the INSINC experiment, the exchange rate was 1000 credits for $1 in Singapore dollar, which was approximately $0.75. For one commuting trip in Singapore the average distance traveled was around 10km (Singapore Land Transport Statistics In Brief, 2012), if the trip happens during off-peak, 20 additional credits could be earned. Under the deterministic option, $0.20 was awarded for passengers who traveled during off-peak. For the scheme at MIT, one possible exchange rate would be 1 credit for $0.10. In this way, for participants who travel via modes other than driving alone, their minimum pay off would be at least $0.20 (assuming two commuting trips per day per participant).

### *Reward Option 2— A Lottery with the Large Prize*

The reason for offering this option is to provide a large lottery prize so that people be motivated to participate. For surveys conducted in the MIT community, lotteries are often used to increase response rates. Among those lotteries, the prizes are usually $500 or equivalent. Therefore, for the prize level of this lottery, $500 would probably be large enough. The number of winners per drawing and frequencies of this lottery depends on the budget of the incentive program, and will be at least one winner per drawing, and the frequency can be at least once per month. However, whenever the budget for this incentive scheme allows, the prize level, drawing frequency and number of winners should be made as great as reasonable to increase the attractiveness of this lottery option. For this section, it can be assumed there will be one lottery drawing of $500 with one winner every month.

All participants with positive credits are eligible for this lottery drawing, and the more credits they have, the higher chance of winning. After each draw, winner(s) will have all their credits deducted and non-winners will have their credits decreased to half. The reason for credit deduction on all participants is to ensure their consistent ongoing effort in earning credits, i.e. travel via alternative modes.

### *Reward Option 3—Lottery Games with Medium Range of Prizes*

Under this option, participants can choose to participate in lotteries of small to medium prizes. As reviewed in Chapter 2, one major appeal of lotteries comes from the gamification effect it has. Therefore, an online-game or app-based game (such as treasure hunting and wheel of fortune) can be utilized to implement these lotteries with small rewards. Participants who choose to use their credits to play the small games would be notified of whether they have won or not as soon as the games end. As long as a participant has enough credits to play the games, they can play multiple times a day. The total amount of prizes given out each day depends on the budget of the scheme. In the "Spitsmijden" (peak avoidance in Dutch) experiment in the Netherlands, 3~7 euros were awarded to commuters who traveled off-peak, and by the end of the experiment, peak-hour commuting trips were reduced by almost half. Using this result as a guideline, the small prizes can be from $1 to $10. Assume there are 1000 participants with positive credits who also choose to enter these lotteries with relatively small prizes, and total prizes awarded daily is $100, one possible allocation of prizes would be five lotteries with prizes equal $10, five with prizes equal $5, and five with prizes equal $2 and fifteen with prizes equal $1. Alternatively, the number of lotteries and prizes can be assigned randomly everyday, with the total reward equals to $100.

Once the three reward structures are determined, the total budget that needs to be allocated to prizes can be calculated. For ease of computation, assume there are 10,000 eligible participants (in total there are approximately 11,840 MIT employees) and 80% of them have reasonable access to alternative modes. Based on *Credit Allocation Mechanism 5* as shown in Table 4-7, it is further assumed 20% live in zone 1 and would choose to walk/bike, 20% live in zone 2 and would choose transit, 20% live in zone 3 with half of them choosing transit and another half choosing carpool, and 20% live in zone 4 with all choosing to carpool. The total number of credits given out each day would be approximately 51,000 (assuming two commuting trips every day).

If all these credits were used to exchange for cash, the amount needed would be $5,100. Further we assume only 1% of the total participants with positive credits would indeed choose this option. The 1% here compensates for the small likelihood of the hypothetical situation where nearly 80% of MIT employees choose alternative modes. In this case, everyday $51 a day is needed for the fixed prize.

For the second reward structure, assume there is a total of $100 given out as lottery prizes everyday. For the third reward structure, assume there is a $500 drawing every week. Under all the previously stated assumptions, the total budget needed for rewards every week would be $1,051. For a period of 6 months (approximately 25 weeks), the budget needed would be $26,275.

### 4.4.3 Non-utilitarian Benefits

Since non-utilitarian motives often influence people's decisions on mode choices (Zhao and Baird, 2014), associating each travel mode with some non-utilitarian benefits would increase the attractiveness of this option and therefore increase the likelihood of people adopting it. For each travel mode, information on how much greenhouse gas emissions can be saved compared to auto, how many calories can be burnt, and how participants perform in these metrics compared to others can be important considerations in the process of mode decision making. Therefore, when presenting the modes available to participants, not only should they know how many credits they will earn by choosing some mode, but also how many social benefits (such as emissions avoided) and personal health benefits (such as calories burnt) they can achieve. After a period of time, information on how they rank in metrics of accumulated emissions avoided, walking time, non-driving time and more among all participants, i.e. their colleagues, can be provided as a social comparison, usually serving as a strong motive for improvement.

## 4.5 Presentation of Options Through an Online Platform

An integrated online software platform can be built to facilitate the implementation of the lottery scheme, and specifically present the options developed in section 4.4 to participants to attract and engage them. If needed, this platform can have an app to allow for easy access from smartphones. The primary purpose of using this system is to inform participants regarding their available options to commute to/from work while minimizing the efforts needed to participate. Additional features, such as the drawing of prizes through instant games, can be included in the platform to strengthen user engagement. In section 4.5.1, data collection and validation techniques are discussed, and a cost-effective structure to implement for the case of MIT is presented. Section 4.5.2 describes features of the platform that can increase the saliency of each option. Section 4.5.3 presents game features that the platform needs to have to facilitate the process of allocation of rewards.

### 4.5.1 Data Collection and Validation

As discussed in section 4.3, there are two main methods to detect the commuting mode(s) used by participants. The first solely utilizes trip information collected by movement tracking apps, which include real-time geographical locations and speeds. Since the commuting mode used is essentially a categorical variable, data mining techniques can help differentiate modes from trip information data. However, since MIT has records of parking information and transit usage on all eligible participants, one easier way to determine mode(s) used by a participant would be a combination of these records and information collected by apps.

To implement the second method, the platform should have the following functions. First, each participant would have a unique ID, such as the MIT Employee ID, registered with the platform. Second, the platform would be designed to be able to query or interface with the databases of parking records and transit transaction records automatically. Since MIT employees enjoy subsidized transit fares, their employee ID can be used to look up their transit usage. From parking records, information on whether an employee has parked on campus can be determined. By integrating the platform with the parking and transit databases, the transit and driving commuting modes can be determined. For the walking and biking modes, movement-tracking apps can automatically identify and send reports to the platform. For carpooling, employees who shared the ride would need to report the details to the platform in order to receive credits (for both the driver and passengers). Participants who are dropped off or picked up at MIT would also need to report to the platform in order to receive credits. For those self-reported travel modes, the platform would validate through checking if these modes are likely. For example, for a participant who has been shown to occupy a parking space on campus, a self-report that states being dropped-off would not be accepted by the platform. In this case, the platform would record the mode used for this participant as driving alone.

### 4.5.2 Saliency of the Options in the Incentive Scheme

For commuting trips, people rarely go through the whole process of choosing travel mode, as discussed by Aarts and Dijksterhuis (2000). To influence one's travel habits, it is necessary to make the lottery incentive salient enough so that people will rethink their daily mode choices. There are two methods to increase the saliency of options developed in section 4.4: provision of personalized travel information and presentation of the benefits associated with each travel option.

#### *Personalized Travel Information*

One way to achieve an increase in saliency is to provide personalized travel information on the platform. For example, every participant will have a personal travel account. When a participant enters his origin and destination, which is set to be places within MIT by default, to the platform, all possible mode choices will be displayed with estimated travel time. Information on credits earned for each mode choice, and potential carbon emissions saved will also be displayed. Private shuttles, such as Tech Shuttle and EasyRide, could also be included as carpool option. However, as these shuttles usually only serve as the last mile of a commuting trip for people who live off-campus, credits assigned would be based on the major mode used.

For participants who hope to participate in carpooling, one feature the platform can have is to help assign carpooling partners. The platform would gather information on departure locations and time to give recommendations on possible carpooling options for participants who want to give or share rides.

#### *Monetary and Non-utilitarian Benefits of Each Option*

Another way to increase the saliency of the lottery incentive is to display credits that can be earned and non-utilitarian benefits associated with each mode and at an aggregate level for each participant. For example, the same commuting trip using different modes would have different credits and carbon emissions, and thus impacts on the environment. When displaying all options for the same commuting trip on the personalized travel information page, the carbon emissions and health benefits, such as calories burnt, can also be displayed. In addition, the aggregate carbon emissions saved and health benefits accrued compared to driving alone everyday are summarized on the homepage of the participant's account. To further assist people's process of making sense of these data, comparisons of their performance with their peers can be made. It is also possible to provide example of these data in terms of concrete impacts on the physical environment and one's physical well-being, among other things. For example, 1 kg of carbon emissions saved can be interpreted as a square foot of the Antarctic iceberg saved; or 100 calories burnt from walking can be visualized as one cup of coke or 15 minutes running on the treadmill.

### 4.5.3 Gamification Features

The gamification features are mostly concerned with the implementation of rewarding promoted behaviors; specifically, how the credits can be exchanged for rewards. As discussed in section 4.4.2, three reward structures targeted for different levels of risk aversion among participants are recommended for the case of MIT.

For the first reward structure, where credits are exchanged for cash at a pre-determined rate, the platform is expected to provide the function where participants can easily "cash out" their credits.

Under the second reward structure, a participant can use the credits to enter lotteries with small to medium payoffs. One approach to facilitate these lotteries is through fun online games. A participant can use the credits to "buy" chances of playing these games. In each game, the participant has certain probabilities to win prizes. The total amount of prizes given out everyday is fixed, but the winning probability per game is randomly assigned by the system. For example, assume $100 is provided as rewards everyday and a treasure hunting game is implemented to facilitate these lotteries. For one game, small prizes ranging from $1 to $10 are hidden on map; a player can use his or her credits to purchase steps to navigate the map in order to find those prizes. If players find prizes too hard to find, they can also use credits to purchase hints that would let them know if they are near or far away from prizes. In the case where the player is close to some hidden prize but run out of credits and steps, the game process can be saved for some period of time to allow participants to earn more credits to continue playing. The purpose for providing the option of continuing a game utilizes the behavioral anomaly that people are impatient in the short run (Mullainathan and Thaler, 2000).

For the third reward structure with a large-prize lottery, every participant with positive credits can enter the drawing. The winning probability is proportional to the credits one has in each lottery. The process of the drawing can be designed in a game format, such as "wheel of fortune".

Whichever reward option the participant chooses, the reward would be reflected in this participant's virtual prize account immediately when won. The participant can choose to cash out these prizes through the MIT payroll system or perhaps in the form of TechCash, the on-campus debit card.

# Chapter 5
# Conclusions

## 5.1 Summary of Research Findings

This thesis aims to develop a framework for designing lottery-based incentive schemes that influence commuting behaviors. An extensive review of the research literature has been conducted to examine how lotteries can incentivize behavior changes in the fields of transportation and beyond. Based on the commuting data collected at MIT, a lottery-based incentive scheme is proposed as a tool to manage parking demand. In this proposal for MIT, alternative commuting modes (i.e., walking, biking, transit and carpooling) are promoted and eligible participants would be rewarded for using these modes.

Chapter 2 examines both the theoretical models and empirical evidence on the impacts of the lottery-based rewards on behaviors. In theoretical models (Morgan, 2000; Lange, List & Price, 2007 and Loiseau et al., 2011), lotteries are proved to increase the total contributions from participants at equilibrium under a set of simple assumptions. The model developed by Loiseau et al. (2011) is modified in this thesis to prove that under lottery prizes there would be positive shifts to alternative modes among commuters who currently drive alone to work. Theories from Behavioral Economics suggest that the main appeal of lotteries is a result of the behavioral anomaly of non-linear weighting of probabilities. Specifically, people tend to believe they are luckier when facing small probabilities. The empirical evidence where lotteries were used to incentivize promoted behaviors comes from fields of public economics, survey methodology, public health, education, transportation and marketing. From the reported results of these experiments, the influence of lotteries on behaviors varies. One key factor, proposed by Fryer (2010), that can be relevant to the effectiveness of the lottery incentives is whether people know how to change their behaviors. An example given by Fryer is as follows: rewards that incentivize students' reading books were more effective than the same rewards incentivizing improvements in grades. One analogy of this example in shifting mode choices is that reward incentives would be more effective on commuters who have easy access to alternative modes compared to those driving alone is the only reasonable mode. Another important factor that is related to the effectiveness of the lottery incentives, derived from comparing results from different experiments, is that the participants can benefit directly from the promoted behaviors. In experiments where lotteries are used to increase the response rate, the reported results show varying degrees of effectiveness (Singer, 2002). Nonetheless, in experiments where lotteries are used to incentivize health goals, such as weight loss and adherence to prescribed medicine protocols, the impacts of the lottery rewards on behaviors are significant (Volpp et al., 2008 and John et al., 2011).

The framework developed in Chapter 3 for designing the incentive schemes depends on all parties involved and how they interact. Generally in an incentive scheme, there would be planners who design the incentive and the participants. The planners decide on the promoted behaviors and the reward structure. If participants exhibit the promoted behaviors, they would earn rewards. Theoretically, the planners would need to consider how people choose under different incentives, and devise the incentive scheme accordingly so as to achieve planners' objective(s). Under the assumption that all parties behave in a self-optimizing way and all objective functions and constraints are known, such interactions can be modeled as a bilevel optimization problem. However, from an implementation point of view, it is usually the case that the mechanism behind people making specific choices is unclear, and sometimes even contradictory. Therefore, instead of making highly simplified assumptions on how people react to incentives and building optimization models to derive the parameters for the incentive, the framework proposed in this thesis takes a different approach.

The framework proposes several factors that planners should consider in a lottery-based incentive scheme and features the scheme should have. First, planners should determine the goal of the incentive scheme. In other words, the behaviors that are promoted need to be specified. Second, planners need to identify the stakeholders whose welfare can be affected by the incentive scheme and therefore determine the eligibility for the incentive scheme. Third, the constraints on the incentive scheme should be specified. There are two types of constraints. For financial constraints, planners need to consider both the amount of budget needed and the amount available from sponsors. Though theoretical models predict higher rewards would induce more behavior changes, there would be some maximum amount from the total budget that can be allocated to the rewards in an incentive scheme. The second type of constraints considers how best to implement the designed scheme given the financial constraints. Under the second type of constraints, planners need to identify technologies available and select those which are most implementable. Fourth, since the incentive scheme is ultimately presented to participants as options, planners should consider how to frame and present each option. The options need to include sufficient information on the value of potential rewards for promoted behaviors. If there are any non-utilitarian benefits associated with promoted behaviors, they can be presented with each option as well.

For a specific incentive scheme, several features can be implemented to attract and engage participation. First, an online or app-based platform can be built to facilitate the implementation of the scheme. This platform should have the functions of data collection and rewards distribution so as to minimize active efforts from participants. Second, gamification features can be added to this platform, as the platform is the key interface with participants. Third, regular feedback features that inform participants on their performance can be implemented to encourage consistent efforts. A variety of examples have been given to explain each factor and feature in Chapter 3.

In Chapter 4, a detailed lottery-based incentive scheme, developed based on the framework presented in Chapter 3, is proposed as one of several tools to manage the parking demand within the MIT community. The process for deriving the proposal can be found in Chapter 4. The recommended design of the incentive scheme for the case of MIT is described as follows.

First, all benefit-eligible MIT employees who work half-time and more are eligible for the incentive scheme. Eligible employees would be offered an opt-out option. Second, participants would be awarded credits, which can be exchanged for rewards, for their commuting modes used. The number of credit awarded is calculated from each commuting trip's distance and mode(s) used. The details of the credit allocation mechanism can be found in Table 4-7. Third, credits accrued can be used to exchange for three reward options—deterministic cash, lotteries of medium prize value and a less frequent lottery with a large prize. These three options are designed for participants with different levels of risk aversions. The deterministic cash option provides participants with a certain payoff that can attract initial participation. The second reward option where participants can play lottery games with medium payoff is designed to motivate participants to continue to earn credits in order to keep playing the game. The third option of a grand lottery is based on the behavioral anomaly of non-linear weighting of probabilities and is expected to attract and engage participation by people who are less risk averse.

The proposed incentive scheme at MIT is designed to be implemented and administrated through an online software platform. The major functions and features of the platform are described as follows. First, the platform would present personalized available options to participants; these options include information on mode choices, credits that can be earned and non-utilitarian benefits (such as carbon emissions saved and calories burnt) associated with each option. Second, the platform can query into relevant external databases to identify and validate the mode(s) used by participants and assign credits accordingly. Third, the platform administrates the process of exchanging credits for rewards. Fourth, the platform provides feedback to participants on their performance in terms of credits and rewards earned and non-utilitarian benefits accrued; and furthermore how they perform compared to their peers. Details of the platform can be found in section 4.5.

## 5.2 Future Research Directions

Since there has been no implementation where a lottery-based incentive scheme has been used to influence commuting mode choices, if the proposed lottery-based incentive scheme is implemented at MIT, the data collected would be very helpful in addressing the following research issues.

First, a longitudinal comparison between participants' previous travel habits, their mode choices during the experiment and their behaviors following the experiment could be used to show whether behaviors induced by the incentive can be sustained. In other words, by analyzing whether the behavior changes under the lottery incentive are permanent, researchers can have evidence on whether the mode choices are more influenced by habits or rational economic optimization.

Second, how commuters choose among reward structures (deterministic cash prize, lotteries with small prizes, and the lottery with large prize) could be studied to identify which reward structure is more likely to influence mode choice. Furthermore, it would be interesting to study whether a larger lottery prize would be more effective as different, and sometimes contradictory, conclusions were reported on this question in the prior literature reviewed (Morgan, 2000 and Donovan, 2010).

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