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Project 1

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1 Introduction

New York City (NYC) would like to implement a fleet of autonomous vehicles (AV) by 2020 as part of a larger initiative of establishing itself as a world leader in smart city infrastructure. Because of the novel nature of AV technology, there is a considerable amount of uncertainty regarding the impact from its implementation on traffic issues including safety, congestion, energy consumption and environmental impacts. City officials wish to determine the effect of each alternative, while considering uncertainty, on these outcome and optimal strategies moving forward with AV technology within the NYC fleet of vehicles. This study will focus on the alternatives available to implement this technology from AutoMerge, Inc. (AM) specifically in NYC's 40-passenger transit buses. It will compare different alternative strategies by performing a Benefit Cost Analysis (BCA) to assess how these different options impact the general population of NYC, which are the main stakeholders in this issue. Among the factors to be included in the analysis are: safety, energy consumption, air pollution, GHG emissions, weather conditions and traffic flow. Section 2 presents a detailed description of the problem and the alternatives analyzed. Section 4 presents the analysis of each alternative and the results found. In section 5 a sensitivity analysis is performed for some inputs. Section 6 discusses the results of the analyses and section 7 presents the conclusion and recommendations of this study.

2 Problem Description

2.1 Alternatives

Broadly, NYC must consider the following three alternatives.

Alternative 1: Do not implement AV.

This is the reference alternative. AV is not implemented and the benefits and costs are the ones already incurred to the population. There is relatively little uncertanty associated with this outcome because there is historical data to project the effect of this alternative on outcomes.

Alternative 2: Implement AV in the NYC bus fleet.

In this alternative, the city implements the AV technology in the bus fleet directly (without performing any pilot tests). Because this is an emerging technology, it is unclear how AV will perform in each outcome so uncertainty analysis will help determine the expected value for each outcome using the risk information currently available.

Alternative 3: Perform a pilot test with an amount of n buses before deciding to implement AV.

In this alternative, the city performs a pilot test with a predefined amount of n buses. The pilot test has an associated cost directly proportional to n. The potential benefit of running a pilot study is the additional information gained on risks associated with congestion and other outcomes. It will be necessary to calculate the value of imperfect information for each n for this alternative.

2.2 Benefits, Costs & Uncertainty

Although public transit systems are essential to any urban area, they also incur several costs to the general population. Implementing AM in the bus system will impact these costs in different ways.

1. **Capital and Operating Costs of implementing AM.** The most obvious costs are the capital and operating costs of implementing and operating the AM system in the buses. Ordinary capital and operating costs related to the bus operation will not be considered in this analysis since they will be incurred in all alternatives. Estimates for capital and O&M costs for the AM system were informed in a per bus basis, conditioned on the age of the bus. We used this data to compute these costs.

Table 1: Capital and O&M costs of the AM system

	Variable	Value	Notes
(a)	# buses with age < 5 years	2313	Source:
(b)	# buses with age 5-9 years	1296	Source:
(c)	# buses with age 10-20 years	1437	Source:
(d)	Capital Cost per bus age < 5 years	$ 5000	Source:
(e)	Capital Cost per bus age 5-9 years	$ 6500	Source:
(f)	Capital Cost per bus age 10-20 years	$ 8500	Source:
(g)	**Total Capital Cost**(*)	**$ 45.7 Million**	**=(a)*(d)+(b)*(e)+(c)*(f)**
(h)	Annual O&M Cost per Bus	$ 1500	Source:
(i)	**Total Annual O&M Cost** (**)	**$ 7.6 Million**	**=[(a)+(b)+(c)]*(h)**

(*) Capital costs are considered to be incurred only in the first year

(**) O&M costs begin to occur in the fifth year of the analysis (when AM starts operating)

2. **Traffic Congestion.** Being a part of the transit system, buses have an impact in the traffic congestion of NYC. This traffic congestion incurs in a social cost due to longer commutes, wasted hours for the general population and additional fuel consumption. The use of AM can have an impact in the traffic flow and potentially decrease these costs. To calculate congestion costs, we only consider buses, cars, light duty vehicles, and trucks. While walkers and cyclists do experience travel times, we do not believe that they will change with the different alternatives and do not need to be included for comparison purposes. Table 2 presents the computation of the traffic cost for the reference case

Table 2: Estimate of social costs due to traffic congestion in NYC

	Variable	Value	Notes
(a)	Annual Cost per Commuter	\$ 300	Source:
(b)	Annual hours in congestion per commuter	4 hours	Source:
(c)	Cost per minute	\$ 13,400	$(a)/[(b)*60]$
(d)	Total time person trip per day (*)	40,000 minutes	Source:
(e)	**Total annual congestion cost**	**\$ 27 Million**	**=360*(d)*(c)**

(*) considers only Light Duty Vehicles, Motorcycles and Buses

3. **Fatalities & Injuries.** Another cost are traffic related injuries and fatalities. Using AM in the bus system can have an impact in traffic safety and decrease these costs. The cost of each death is estimated using the standard Value of Statistical Life (VSL in \$). The cost of each injury was estimated using data from CDC for injuries costs for each type of victim (motorist, passenger, pedestrian, etc.). Using historical data of number of mortalities and injuries in transit accidents in NYC (N_{mort} and N_{inj}), we computed total cost of traffic mortalities (Cost$_{mort}$) and injuries (Cost$_{inj}$).

Table 3: Estimate of social costs due to traffic mortalities and injuries in NYC

	Variable	Value	Notes
(a)	VSL (2015 \$)	\$ 9.2 Million	Source:
(b)	Number of fatalities per year	4	Source:
(e)	**Total annual mortality cost**	**\$ 27 Million**	**=360*(d)*(c)**
(c)	Average Cost of Injury	\$ 13,400	$= 12*(a)*(P\|U, 5\%, (b))$
(d)	Number of injuries per year	40,000	Source:
(e)	**Total annual injury cost**	**\$ 27 Million**	**=360*(d)*(c)**

(*) considers only Light Duty Vehicles, Motorcycles and Buses

4. **Emissions.** Another major external cost of the bus system is the one related to the emission of air pollution gases and greenhouse gases. These emissions result in major

health hazards for the general population and can affect future climate. Implementing AM can have an effect of changing these emissions by improving traffic flow. Because at this point we have emission data available only for buses, we focused our emission cost estimate only on buses. Emission factors for buses differ for when buses are in movement (ef_m in g/mi) and when buses are idle (ef_i in g/min). Using these factors, the marginal cost of each type of gas emission (mc_g in \$/ton), the total vehicle travel time (T in minutes), the total vehicle distance (D in miles) and an estimate of the share of travel time that the vehicle is idle (s_i in %) we can compute total emission costs for each type of gas.

$$\text{Cost} = \text{Cost}_{\text{run}} + \text{Cost}_{\text{idle}} = D \times ef_m \times mc_g + s_i \times T \times ef_i \times mc_g$$

We assume that improvements from AM will only affect emissions as a result of idle time (i.e., as congestion decreases, vehicles spend less time in idle status but still travel the same distance).

In addition to the costs listed above, there are also uncertainties associated with the implementation of AM. One of the uncertain factor is what will be the effects of AM in the congestion and safety of NYC transit system. Another source of uncertainty is how bad weather will affect the operation of the AM system. These two types of uncertainty are included in our analysis.

2.3 Assumptions

1. The number of riders using each mode of transportation will remain stable for all three alternatives.

2. Changes in congestion will affect motor vehicles (buses, cars, light duty vehicles, and trucks) but not bicycles or walkers.

3. All travel minutes across persons and modes of transportations are worth the same and includes fuel costs, \$22 per hour per individual.

4. Weather patterns remain consistent.

5. Any travel time, even fast ones, incurs a time cost. This means that for each alternative, there will be a time cost added which is associated with it.

3 Methods

For this analysis, we use a decision tree with standard expected values to assess alternatives one and two and the value of imperfect information to assess alternative 3. Figure 1 shows

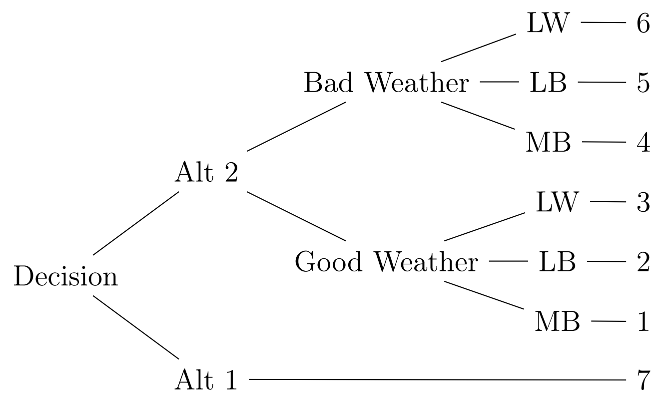

Figure 1: Partial decision tree

our decision tree for the first two alternatives. This same paradigm will be used to compute the expected value of imperfect information.

Each cost listed in Table **??** was estimated using data from different sources:

4 Analysis and Results

4.1 Alternative 1: Don't Implement AV

4.2 Alternative 2: Implement AV

4.3 Alternative 3: Pilot test

Figure 2 presents the resulting NPV for each alternative. For alternative 1 (reference case) we can observe that the component that results in the largest cost is air pollution. Total present value of costs is approximately \$ 31.4 Billion. Implementation of AM (alternative 2) results in a decrease of the expected present value of costs of approximately \$ 0.2 Billion or 0.7%.

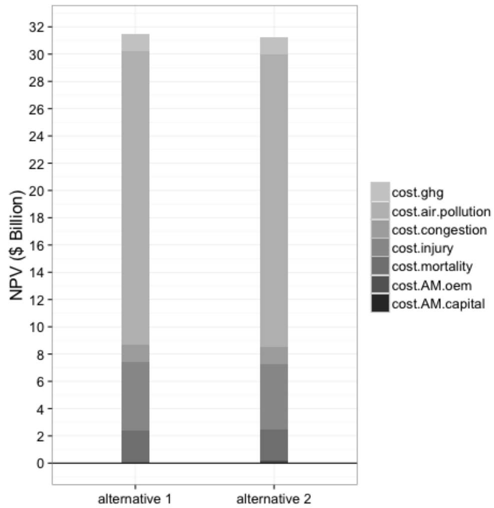

Figure 2: Expected NPV (in Billion \$) computed for each alternative

5 Sensitivity Analysis

6 Discussion

7 Conclusion & Recommendations