Assessing the Effects of Automated Vehicles on I-94
APPENDIX T6 -
ASSESSING THE EFFECTS OF AUTOMATED VEHICLES ON I-94

Introduction

This memorandum summarizes an evaluation of the potential effects of autonomous vehicles (AVs) on future traffic conditions in and around the Rethinking I-94.

Autonomous vehicles are expected to be widely adopted in the next 15 to 20 years, as manufacturers gradually introduce more sophisticated sensors and control systems to vehicles. At the end of this development period, we can expect to have fully automated, electric vehicles using our roadway systems. Eventually, market penetration of AVs may approach 100 percent. Figure 1 shows one possible scenario timeline regarding the introduction of AVs into the fleet.

Figure 1: Anticipated Timeline for AV Adoption

Source: Morgan Stanley
A significant or total market penetration of AVs will likely have a substantial effect on our transportation system. While there remain significant unknowns regarding the effect of AVs, this exercise seeks to assess a possible range of system responses based on how AVs could change the access and mobility for the population and with respect to behavioral responses to these changes. These changes were evaluated using the Twin Cities Activity-Based Model (ABM), which modified some assumptions to represent potential changes due to AVs and quantify the traveler responses in a way that is useful for evaluating AV effects. In Section 2, we will describe the specific factor adjustments that were tested to reflect AV market penetration.

One of the key unknowns about AV adoption is what the mix will be between the percentage of privately owned AVs (similar to how most passenger vehicles are owned today), and the percentage of AVs that will be shared and paid for on a per trip basis (similar to how taxis/Uber/Lyft are currently used). These scenarios were first identified in a research report prepared for MnDOT¹ and termed the “OUT” and “UP” scenarios, as defined below:

- **“OUT” Scenario**: in this scenario, the current individual car ownership model largely remains intact. Since AVs can return to the household independently, household auto ownership levels may drop as many households make greater use of their vehicles. For the purposes of this report, and for clarity, we will refer to this scenario as the OWNED Scenario.

- **“UP” Scenario**: in this scenario, the advent of connected and autonomous vehicle (C/AV) technology leads to a dramatic shift in the car ownership model, resulting in extensive use of on-demand AV “taxis” as opposed to private vehicle use. Further, these AV taxis serve to support last-mile transit connections. For the purposes of this report, and for clarity, we will refer to this scenario as the SHARED Scenario.

It should be noted that between these two scenarios there is a wide range of outcomes that could each be modeled. The most likely future outcome will be a combination of owned AVs and Mobility as-a-Service (MaaS), based on trip patterns, density and affordability. However, for the purposes of this analysis, the outlier scenarios were modeled in an attempt to bracket a range of possible outcomes, each with the assumption (based on best current industry projections) that commercial AV introduction occurs in the mid-2020’s and achieves near-full market penetration by 2040. The modeling was done assuming a 2040 horizon year.

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Methodology

This section describes the process used to model these factors and scenarios, using the Twin Cities ABM.

GEOGRAPHIC SUMMARY

The modeling results are summarized for three geographic areas, shown in Figure 2. These are a half-mile buffer around I-94, a one mile buffer around I-94 and a wider “subarea” approximately 4 miles north of I-94 and 2 miles south of I-94. The measures included:

1. Vehicle-Miles of Travel (VMT)
2. Vehicle-Hours of Travel (VHT)
3. Congested Vehicle-Miles of Travel (defined as VMT above 0.9 volume/capacity (v/c))

Figure 2: I-94 Subarea, One Mile and Half Mile Summary Areas

FACTORS

Four factors were tested as inputs to the model. The following subsections describe these factors and how they were implemented into the model.

Capacity

The widespread use of AVs will improve roadway capacity in two ways. First, smaller vehicles will allow for narrower lanes and additional lanes on freeways and expressways, and generally permit higher
vehicle densities as operating headways are reduced. Second, the vehicles will be able to maintain higher speeds and avoid breakdown conditions under higher volumes than conventional vehicles due to greater inter-connectedness and faster response times. Based on a consensus from the literature, the network specifications were adjusted to increase capacity by 50% for freeways and expressways (limited access facilities) and increase capacity by 10% for arterial roadways. The volume-delay function was also modified to be more “forgiving” of higher v/c ratios. Figure 3 shows this change graphically. The actual adjustments were made by modifying the “alpha” and “beta” parameters in the Twin Cities ABM.

**Operating Cost and Parking Cost**

The second factor represents the anticipated change in auto operating cost and the removal of the necessity to use paid parking. The default model auto operating cost is $0.15/mile. This cost is intended to represent the variable cost of operating a vehicle that might influence trip length or the use of that vehicle versus another mode. Primarily, this can be thought of as fuel cost and does not include items such as vehicle depreciation, insurance or the cost for regular vehicle maintenance. In the model, this cost is interpreted as “real” dollars adjusted for inflation to 2010. Both an increase and a decrease in the auto operating cost, as defined above, were tested. This included a $0.10/mile and a $0.30/mile price. The Twin Cities ABM has a user-accessible global parameter for auto operating cost, so this was modified for these model test runs.

In addition, AVs are assumed to be able to avoid traditional paid parking by simply returning home (in the OWNED scenario) or to a free parking lot located in a low-density area of the metro. Parking cost was adjusted by setting all zone parking costs to zero for the work tour parking cost field (PARK_COST) in the zone data set. Non-work tour parking costs (NONWRKPRK) were not changed.

**Figure 3: ABM VDF Adjustments to Represent AV Performance**
Auto Availability

The widespread use of AVs are assumed to allow segments of the population that otherwise have been unable to use vehicles alone to make use of them. This includes elderly, disabled and child populations. From a modeling perspective, this effectively increases the auto availability for each household, beyond what the Twin Cities ABM would otherwise estimate. Two auto availability levels were tested, including:

1. Set 95 percent of households as having at least as many autos as adults
2. Set 50 percent of households as having at least as many autos as adults for the lowest income group and set 95 percent of households as having at least as many autos as adults for the remaining income groups.

The second test was a result of a refinement of the first, and was used in the final combined tests. Test number 1 above results in 30 percent more “vehicles” in the vehicle fleet and test number 2 above results in 26 percent more “vehicles” in the vehicle fleet, compared with the no-build condition. Note that the model treats this as autos available only, and in the context of AV tests, this simply represents the ability of any household to have largely sufficient autos available for travel for any household member. It will primarily affect the trip generation rates in the model, as well as influence the mode choice. This change was made to the household vehicle file and the person files that include household auto availability. A random number between 0 and 1 was generated for each household, and using this random number the household’s autos were adjusted, as necessary to cause the autos to be at least as large as the number of adults or “auto sufficient.” If a household was already forecast to be auto sufficient, no change was made.

Vehicle Positioning/Driverless Vehicle Flows

The fourth factor estimates the number and flows of driverless vehicles. For this factor, there is a different approach between the SHARED and OWNED scenarios.

For the OWNED scenario, we used the Twin Cities ABM’s household trip records to estimate driverless trips that would be needed to serve all the estimated auto trips made by all household members. These trips were conditioned on the AV’s ability to serve a household member by the desired start time. If this was not possible, a new household AV was “created” to serve the household. The number of required AVs was recorded for each household. A 30 percent reduction in AV vehicle fleet was estimated.

For the SHARED scenario, an aggregate set of all occupied auto trip ends (driverless trip starts) and all occupied auto trip starts (driverless trip ends) for each half hour time frame was developed. Given these driverless trip starts and ends by time period, driverless trips were distributed in order to serve all modeled occupied vehicle trip requests. This distribution was also conditioned on available trip time and available AVs. When not needed between serving trips, the AVs were assigned a waiting area in a low-density (by total employment/area) zone at either the start or end of the driverless trip to be accomplished. A subsequent refinement of the SHARED scenario driverless trips limited the maximum trip length to 30 min, which had a significant effect on driverless VMT. The resulting vehicle fleet was estimated by identifying the number of vehicles in motion plus the number of waiting vehicles for the maximum half-hour period.
Once the individual tests were run, two composite scenarios were developed and tested. The composite scenarios both included the following factors:

1. **Capacity** – increase freeway capacity by 50% and arterial capacity by 10%. Also apply adjusted volume-delay functions. This is applied in all highway assignments.
2. **Costs** – set the auto operating cost to $0.30/mile and zero-out all work tour parking costs by zone.
3. **Auto Availability** – for the lowest income group, make 50% of households auto-sufficient. For all other income groups, make 95% of households auto sufficient.

The regional model was executed with these changes and run with 4 feedback iterations. After this, the SHARED and OWNED Scenarios used separate methodologies to include driverless trips.

**OWNED Scenario** – estimate driverless vehicle trips to serve each household's members with their own vehicles.

**SHARED Scenario** – estimate driverless vehicle trips to serve any auto-person travel need with a limit on long-distance/long time trips nominally at 30 minutes.
Results

This section describes the results of the test of the model factors. It is important to note that the individual factors are tested with only that one individual effect of AVs and are isolated from the other factors. For each of these factors, refinements were made subsequent to the initial tests. The results of all initial and subsequent tests are described below in terms of percent change from the base, which does not include any AV factors.

CAPACITY TESTS

Figure 4, Figure 5 and Figure 6 show the effects of increased capacity on system operation. Predictably, the VHT decreased for all tests due to the increase in capacity. The VMT shows a very small change, which is also expected since the input vehicle trip table did not change so travel flows from origin to destination has not changed. Path changes result in relatively small changes in travel distance. Finally, the congested VMT show the greatest change for the 50%/10% capacity change. Changing the volume delay function (VDF), only results in greater VMT over 0.9 v/c since the AV volume delay curves accommodate higher volumes operating over 0.9 v/c ratios. It is also observed that the effect of a small (10%) increase in capacity on freeways and expressways offsets the effect of the VDF change.

Figure 4: Capacity Tests: Change in Vehicle-Hours of Travel
Figure 5: Capacity Tests: Change in Vehicle-Miles of Travel

Figure 6: Capacity Tests: Change in Congested Vehicle-Miles of Travel (congested defined as v/c>0.90)
COST TESTS

Figure 7, Figure 8 and Figure 9 show the effects of adjustments to the auto operating cost and work-tour parking costs. Overall, the changes are very small relative to the no-AV scenario. The model was not very sensitive to either auto operating cost or parking cost changes.

Figure 7: Cost Tests: Change in Vehicle-Hours of Travel

Figure 8: Cost Tests: Change in Vehicle-Miles of Travel
Figure 9: Cost Tests: Change in Congested Vehicle-Miles of Travel (congested defined as v/c>0.90)

AUTO AVAILABILITY TESTS

Figure 10, Figure 11 and Figure 12 show the effects of two auto availability tests, as described in the methodology. Both the VHT and VMT, as well as congested VMT increased since the auto availability changes increased the number of auto trips made. Congested VMT increased at a greater rate than the VHT or VMT since the increase in trips impacted congestion by adding to already congested facilities. The auto availability tests also showed a decrease in transit trips by 38 to 40 percent.

Figure 10: Auto Availability Tests: Change in Vehicle-Hours of Travel
DRIVERLESS VEHICLE FLOWS TESTS

Figure 13, Figure 14 and Figure 15 show the results of assigning the driverless vehicles for both the SHARED and OWNED AV tests. These were post-model assignments which assigned the driverless trips as a separate class that did not influence the v/c ratio. The resulting VMT and VHT is thus reflecting the
added driverless vehicles but not their effect on the rest of the vehicles. In spite of this conservative approach, VHT increased by about 60 to 80 percent, VMT by about 30 to 40 percent and congested VMT by over 100 percent. The initial SHARED scenario driverless vehicle flow test did not constrain the trip lengths of the driverless vehicle trips, and as such could be considered a scenario that is not optimized. Note that the original SHARED scenario resulted in 88 percent more vehicle trips (driver plus driverless) and the distance-restricted SHARED scenario resulted in 77 percent more vehicle trips. The OWNED scenario resulted in 67 percent more vehicle trips and a smaller vehicle fleet by about 30% compared to the no-AV base.

Figure 13: Driverless Vehicle Flows Tests: Change in Vehicle-Hours of Travel
Figure 14: Driverless Vehicle Flows Tests: Change in Vehicle-Miles of Travel

Figure 15: Driverless Vehicle Flows Tests: Change in Congested Vehicle-Miles of Travel (congested defined as $v/c > 0.90$)
Figure 16, Figure 17 and Figure 18 show the results of composite tests that combined all four individual factors, as described in the methodology section. The effect of added driverless vehicles and additional trips from greater auto availability more than offset the effects of greater capacity in the system, resulting in quite high VMT, VHT and congested VMT. Transit shares also decreased by about 38 percent. Note that in these tests, the added driverless vehicle flows were allowed to influence overall delays on the system.

**Figure 16: Composite Tests: Change in Vehicle-Hours of Travel**
Figure 17: Composite Tests: Change in Vehicle-Miles of Travel

Figure 18: Composite Tests: Change in Congested Vehicle-Miles of Travel (congested defined as v/c>0.90)
Conclusions

The goal of this series of tests was to evaluate, in broad terms, the general transportation system effect of a range of automated vehicle fleet assumptions on the I-94 corridor. Key metrics were summarized including vehicle-hours, vehicle-miles and vehicle miles during congested conditions on a daily basis for three subareas surrounding the I-94 corridor, as well as regionally. Impacts that were not measured include:

1. land use changes,
2. changes that might occur with regard to transit access and egress and
3. basic behavioral travel changes resulting from a decreased disutility of travel.

MODEL LIMITATIONS:

Note that for the driverless vehicle demand estimation, the analysis of the ownership scenario used discrete vehicle trip records from each household, while the sharing scenario analysis used aggregate trip tables. The results of aggregate approach will vary, though not greatly, the degree to which the matrix procedures are balanced.

Sensitivity of demand to cost and auto availability is based on the regional model's implied elasticities, which are derived from current observed behavior. This may change somewhat for populations that currently do not drive.

The modified volume-delay curves used in this analysis are asserted, and while they generally correspond to simulated AV behavior, it is unknown at this time what the precise AV response to congestion will be.

FINDINGS:

The conclusion is that AVs would likely increase the impact on the key metrics, compared to a condition without AVs. The specific magnitudes of the results may vary depending upon assumptions used, but the general trend, indicating an increased burden on the transportation system, seems consistent regardless of whether SHARED or OWNED scenarios are assumed. It is also concluded that the same trend would apply for any ownership mix between the SHARED and OWNED scenarios tested.

To simulate a condition with AVs, the modeled capacity on the freeways and arterials was increased by 50 percent and 10 percent, respectively, to account for the efficiencies of AVs. Also, parking costs were removed from the model. Because the widespread use of AVs is assumed to allow segments of the population that otherwise have been unable to use vehicles alone to make use of transportation, multiple auto availability levels were tested. Two basic auto ownership scenarios were tested. The “owned” scenario assumes individuals continue to own vehicles as they do today. The “shared” scenario assumes individual ownership of vehicles is greatly reduced as more people rely on a form a shared
vehicle use. While actual conditions would likely fall in between these two points, these two scenarios allowed the team to consider two extremes.

The study concluded that AVs would likely impact key transportation metrics like Vehicle Miles Traveled (VMT), Vehicle Hours Traveled (VHT), and congested VMT as compared to a condition without AVs. Modeling of potential AV scenarios showed increased congestion, VMT and VHT due in large part to travel by driverless vehicles (assuming that no new constraints were placed on AV trip-making). The specific magnitudes of the results vary depending on the assumptions used, but the general trend indicated an increased burden on the transportation system regardless of the specific AV scenario and without introduction of policies or pricing to manage demand.

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