EX24.26

STAFF REPORT
ACTION REQUIRED

Implications of Automated Vehicles for TTC

Date:	March 22, 2017
To:	TTC Board
From:	Chief Executive Officer

Summary

At its July 12, 2016 meeting, Toronto City Council adopted Item EX16.47 whereby the TTC was requested to report to the Executive Committee with respect to the TTC's strategic plan concerning the incorporation of automated vehicle technology within the city's transit system. The motion focused on automated buses operating on public streets.

Staff conducted research on the use of automated vehicles (AVs) in the transit industry and determined that at this time there are too many unknowns to prepare a business case or a strategic plan with regard to AVs. There is, however, adequate information to identify impacts on departments that would be affected, changes to roles and responsibilities, and positive and negative impacts at a high-level. Our approach to this study was divided into two phases. In Phase one we conducted a literature review on the current state of the industry and in Phase two we conducted a roundtable workshop with staff from various departments at the TTC to identify potential impacts.

Recommendations

It is recommended that the Board:

1. Receive this report for information;

2. Direct TTC staff to continue to monitor the technological and legislative progress of AVs and report back to the Board in the future with a recommendation for future use of AVs at the TTC; and

3. Direct staff to forward this report to the City Clerk in response to City Council's July 12, 2016 decision related to Item EX16.47 – Requesting the Toronto Transit Commission to Report on Plans with Respect to Automated Public Transit Vehicles.

Financial Summary
There are no financial implications resulting from this report.

The Chief Financial and Administrative Officer has reviewed this report and agrees with the financial impact information.

Accessibility/Equity Matters
This report, itself, has no accessibility or equity issues.

The implementation of Level 3 AVs (require an Operator) will have no impact on accessible transit services and the customer experience. The widespread implementation of Level 4 AVs where there is no Operator present on board could present challenges for customers who do require Operator intervention and assistance during their transit ride, unless there are further technological advances in this area. For example, mobility device securement and the deployment of ramps for boarding on street. This could increase reliance on Wheel-Trans for customers who can currently use conventional buses independently. This would consequently, drive up demand for Wheel-Trans. These issues will need to be considered if Level 4 vehicles are being considered for adoption at the TTC.

Decision History
Council Motion

> At its July 12, 2016 meeting, Toronto City Council adopted Item EX16.47 whereby the TTC was requested to report to the Executive Committee with respect to the Commission's strategic plan concerning the incorporation of automated vehicle technology within the City's transit system.

http://app.toronto.ca/tmmis/viewAgendaItemHistory.do?item=2016.EX16.47

Issue Background
Innovations in technology have allowed for the advancement of transportation systems throughout history. Arguably the most pivotal breakthrough was the transition from horse to automobile, which fundamentally changed transportation patterns, land development, and human behaviour by allowing for significantly longer and faster travel. In recent decades, the rapid evolution of computing systems and wireless communications has greatly increased the capabilities of tools used to support transportation systems, such as real-time position monitoring.

Faced with rising operating cost, manufacturers sought to automate parts or all of their processes to reduce cost. Automation also exists in transportation applications, demonstrated in automatic train operation or autopilot on airplanes. What remains is the automation of vehicles travelling on road networks such as cars, buses, and freight trucks.

The past decade has seen large investment into the development of a functioning automated vehicle. There are varying criteria for what is considered an AV, but the defining feature is the vehicle's ability to drive independent of human control. In short, a computer system combines static and real-time data feeds to manoeuver around vehicles and pedestrians, abide by traffic laws, and anticipate and prevent collisions.

Major automotive manufacturers such as Ford, Tesla, and BMW are developing prototype AVs. In addition, technology based companies, including Google and Uber, are also investing in the technology. Despite the vast attention and investment AVs are receiving, there is much uncertainty about when the technology will mature, how it will be regulated, and how capable it will be.

Though the specific disruptive effects caused by AVs are unknown, both public and private sector discourse anticipates they will be significant in magnitude, and that it is necessary to start planning management strategies in advance. Different scenarios, such as increased private vehicle trips being made due to the convenience of automated driving, changing parking dynamics, or publicly owned fleets of AVs competing with public transportation both bring massive implications for transportation planning.

The City of Toronto has recognized that there will be a need for adjustments in order to accommodate AVs and taken a proactive approach to mitigating the impact of AVs coming to Toronto. The 'City of Toronto Interdivisional Working Group on Automated Vehicles' – of which the TTC is a member – was established in 2015 to facilitate discussion amongst City divisions in regards to how AVs would affect their jurisdictions, and what could be done to mitigate negative impacts and amplify positive impacts.

At the time of writing, the working group partnered with the University of Toronto to produce a report titled "*Driving Changes: Automated Vehicles in Toronto,*" that explores the far-reaching effects of AVs and what they will mean for Toronto policymakers, and a report is planned for submission to the Public Works and Infrastructure Committee entitled "*Preparing for Autonomous Vehicles,*" that provides background on the topic and summarizes impacts provided by each division/agency in the working group. This will be presented in April, 2017.

A City Council motion requesting a TTC strategic plan for implementation of AVs has caused staff to conduct preliminary research and facilitate high level discussion amongst departments that would be directly affected by the implementation of AVs.

This report serves to respond to the City Council motion. It also establishes a foundation through which the unprecedented subject of AVs can be discussed internally, and provides a preliminary exploration of what TTC implementation of AVs would entail.

Comments

Automated vehicles refer to vehicles, such as trains, cars or buses, equipped with technology that allows either part of, or the entire process of driving to be completed by a computer system rather than human control. The technology has been used in rail vehicles operating in dedicated rights of way for some time, the technology is in its infancy and there are still many unknowns for use on “road vehicles.” Based on the level of interest and investment in autonomous road vehicle technology, numerous industry sources estimate that highly automated vehicles will be commercialized and available for purchase within a decade’s time, thus triggering City Council’s request for this review.

Implementation of automation technology on the TTC’s rapid transit network includes automatic train control on Line 3 and in the future Line1. This report narrows its scope to TTC buses only.

Staff conducted research on the use of AVs in the transit industry and determined that at this time there are too many unknowns to prepare a business case or a strategic plan with regards to AVs. There is however, adequate information to, identify impacts on departments that would be affected, changes to roles and responsibilities, and positive and negative impacts at a high-level.

Study Approach

The approach for this study consisted of two phases:

- Phase One – Research: Professional and academic reports, as well as current articles, were reviewed to understand the current state of AV technology, their projected future, and in particular their implications for public transit.
- Phase Two – Impact Assessment: The research findings were presented to stakeholders from TTC departments that are immediately affected by AV technology. Following the presentation, a roundtable discussion was held to identify potential changes to responsibilities and processes that would occur within each department, as well as positive and negative impacts.

Phase One – Research

A key takeaway from the literature review of AVs is that the relatively recent emergence of the technology and its uncertain future create discrepancies in the terms, concepts, and predictions that are made. The following presents a summary of what we learned.

Levels of Automation

The capabilities of AV systems vary greatly, necessitating a categorization system to understand the varying levels of the technology. The categorization system of AV technology in Canada (referenced in Ontario’s AV framework) is the SAE (Society of Automotive Engineers) Standard J3016. The standard offers six levels of vehicle automation, ranging from Level 0, “No Automation” to Level 5, “Full Automation”, as shown in **Table 1** below.

Level 0-2 vehicles either have no automation, or only a few specific functions. These vehicles are already operating on roads and require no additional legislation because the driver maintains full responsibility for controlling the vehicle. It was concluded that these levels are out of scope for discussion of AVs used by the TTC. By the time a comprehensive study, approval, and procurement is all cleared, the technology would be considered obsolete given the fast pace at which this technology is developing.

Level 3 vehicles denote the change from primarily human control to primarily AV system control. At this level the vehicle is able to monitor the environment and drive accordingly, however it will request human intervention when deemed necessary, so a driver must be ready to intervene at all times. Automated driving allows for more consistent braking and acceleration, and advanced environment monitoring provides superior collision anticipation to what a human can achieve. Level 3 vehicles were considered in Phase 2 as TTC buses that would operate autonomously, but with an Operator present at all times.

Level 4 vehicles no longer depend on human intervention for most driving situations except in emergency situations. They are limited by different ‘driving modes’ (or scenarios) where they cannot operate autonomously, such as in inclement weather, or on particular types of roads. Many operational proposals of Level 4 fleets involve Operators being replaced by a fleet manager remotely monitoring and controlling vehicles to navigate through restrictive driving modes. Level 4 vehicles were considered in Phase 2 as TTC buses that would operate without a driver on board, but rather with the assumption that remote fleet management allows for safe driverless operation.

Level 5 vehicles can be considered autonomous rather than automated, as there are no driving modes they cannot perform in, and human input will never be needed, even remotely. There is some skepticism within the industry towards whether it can actually be achieved or is just a theoretical concept paralleling artificial intelligence. Due to this skepticism, Level 5 was considered out of scope. This is consistent with the City of Toronto’s AV working group understanding.

Table 1: SAE Levels of Vehicle Automation

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

The State of AVs: Present and Future

The most controversial and uncertain element in AV discussion is when and how the vehicles will reach public roads, which is dependent on the capabilities of the technology, affordability and ownership models, restrictiveness of responding legislation, and public perception.

Vehicles in level 0-2 are already commonplace and operate freely on roads in Canada and the USA, with the most prominent example being the Tesla Model S. Level 3 and Level 4 vehicles are currently being tested in designated areas. There is almost always a requirement for a driver to be present to take control should the system fail. As an alternative the vehicles are tested in designated lanes or areas with extremely low traffic. Google's Waymo is currently testing Level 5 vehicles that do not need any method of driver control in a closed environment and has announced it will be expanding its Level 5 testing to public roads after approval from State regulators soon.

Optimistic estimates predict the commercial arrival of AVs as early as 2018, however a vast majority predict within the range of 2020-2025. This range mirrors the dates several major auto manufacturers have announced for their plan to complete development of either Level 3 or Level 4 technology, with only Volvo and Telsa projecting Level 4 before 2020. Predictions for widespread adoption of AVs generally fall within the range of 2030-2040. The arrival of AVs within transit networks is a largely unprecedented subject with very little evidence for a meaningful prediction to be made, but it can be asssumed that it will closely follow that of personal AVs.

Limitations of AVs

While a key argument for AVs is that their ability to monitor their environment surpasses what a human can detect, their ability to understand complex situations is currently lacking. Most of the vehicles presently being tested simply come to a halt when an obstacle comes before them, but in the example of a piece of light plastic waste that has blown onto the road, abruptly stopping could be significantly less safe than colliding with the obstacle. This limitation encroaches on a key unknown of how AVs will weigh factors in cost benefit analyses when a collision with one thing or another is unescapable.

A uniform challenge for AV manufacturers has been managing inclement weather, with snowy conditions being particularly disruptive to performance. Should this barrier not be addressed, it would significantly limit the viability of AVs in Canadian climates. In a similar capacity, bright lights and reflective surfaces have been proven to be capable of disorienting an AV system, as demonstrated with a highly publicized crash of a Tesla vehicle on auto pilot that failed to identify a white truck in its path.

AV technology to date is associated with electrically powered vehicles. In its current state of development if AV technology was to be deployed on buses this would require charging stations at transit terminals. Electric bus technology has yet to reach a point where a full day’s worth of revenue service could be achieved with a single charge. This requirement for recharging may result in increased operational cost and also additional run time/buses would need to offset the time required for charging.

AV Legislation

Being a new and unprecedented technology, AVs have largely been unaddressed by legislative bodies. Policies that do exist occur sporadically throughout North America and the rest of the world. Below is a summary of key steps towards legislating AVs, both locally and abroad.

On October 13, 2015, the Government of Ontario filed Reg. 306/15 under the Highway Traffic Act, permitting testing of AVs on select Ontario highways, provided applicants adhere to all specifications and restrictions set out. This came into effect January 1, 2016, and the first large scale applicants were approved in November of the same year.

In September, 2016, the US Department of Transportation released a federal policy intended to accelerate the implementation of AVs and provide common standards and regulatory tools to be used at state level. The Government of Canada has yet to release a policy for AVs, but it is possible that with the release from the US DOT, a similar policy may be produced in Canada.

On November 10, 2016, the state of Michigan passed four bills that together create a globally leading policy to further the adoption of AVs. The most differentiating component of these bills is that they allow for the testing of AVs that are driverless or completely without a steering wheel and pedals. This is an unprecedented policy that removes a lot of barriers to testing. Equally important is that the policy is passed in the state of Michigan where the US car industry is concentrated.

The City of Toronto currently has no official position or any policies concerning AVs, but is currently directing the AV working group to identify impacts that may necessitate new or modified policies.

AVs in Public Transit

While the contemporary image of an automated vehicle is typically a personal automobile, considerable industry efforts, as well as government-funded research, for higher capacity AVs are being put forth. Transit agencies are refraining from working directly with automated vehicles, instead 3rd party pilots that supplement existing service are most commonly observed. Research into automated transit vehicles is still in its infancy, but a summary of available information follows below.

The majority of larger on-street AVs being developed and tested are shuttles that can hold 10-12 people on average, and operate at average speeds of 20-25 km/h. These shuttles are almost exclusively electrically-powered with lithium batteries. Testing occurs mostly in low-traffic areas like business parks or university campuses, on fixed routes of only a few kilometers. Most instances of testing require a driver to be present and monitoring the system’s performance. Hailing has been tested in a variety of ways, including e-hailing through an app, connected stop infrastructure that signals the vehicle, stopping at every stop along the route, and Operator interpretation, but there is little data as to which have proved effective.

The Mercedes-Benz Future Bus is the only prominent example of a full-sized automated bus and has yet to have had test data made public. Tesla, an industry leader of AVs, has announced plans to expand into public transit vehicles in future years.

Phase Two - Impacts Assessment

Concluding the above research allowed TTC staff to determine which TTC departments would be immediately affected by the adoption of AVs. These departments included: Legal, Information Technology Services (ITS), Finance, Bus Maintenance and Shops, Bus Transportation, Safety and Environment, Engineering, Wheel-Trans, and Strategy and Service Planning; all of whom were invited to a roundtable discussion. Prior to the discussion, attendees were given a presentation summarizing the research findings to ensure familiarity with the subject.

The guiding questions of the discussion asked attendees to consider impacts to their department that would occur from adoption of Level 3 and Level 4 buses.

<u>Impacts of an Automated Bus with Operator (Level 3)</u>

For the purpose of discussion, Level 3 was defined as a vehicle that would by default steer itself – in a safer way than humans can – but request Operator intervention in situations the programming is not prepared. The vision of Level 3 TTC buses therefore has an Operator always present. The following presents a high level summary of what was discussed and by no means is a comprehensive list.

- **Changes to roles and responsibilities:**
    - Increased responsibility and expertise for ITS and Bus Maintenance and Shops required to achieve technical familiarity of AV technology.
    - Increased liability for ITS and Bus Maintenance and Shops with regard to vehicle performance, and there would be some blurring of responsibilities.
    - Increased workload for Legal as a result of any revisions or additions to the Highway Traffic Act.
    - Reduction in claims due to the increased collision prevention capabilities of AVs.
    - Potential need for a new scheduling interface for AVs to be equipped with bus schedules.
    - New training and skill set required in the Engineering department to incorporate AV standard requirements into transit facilities.
    - New processes and extensive training would be needed for Bus Transportation (supervisors and Operators) to allow for joint control between Operators and AV systems.
    - New procedures and policies needed for what follows any incident involving an automated system (a collision, system failure, etc.).

- **Positive effects:**
    - Potential for improved schedule adherence and reliability. This may result in cost savings.
    - Less stress on Operators.
    - Enables Operators to increase focus on customer service. For example, increased assistance for passengers requiring help with boarding, mobility device securement, fare payments, and advising customers when it's their stop etc.
    - Fewer collisions would occur with the application of collision prevention systems; a plus for customer safety, reduced legal claims, and reduced maintenance work. This may result in an operating cost savings.
    - If Level 3 vehicles are widely adopted by private automobiles, the TTC would gain residual benefits of this technology with fewer collisions.

- **Negative effects:**
    - Joint control between an Operator and the system may create ambiguity in determining liability, should a collision occur. Who is liable, Operator, Bus Maintenance and Shops, ITS, or the manufacturer?
    - Operators may develop a false sense of security knowing that the automated system is the primary driver and be unprepared to assume control when the system prompts them.
    - The procurement and implementation of AVs and supporting infrastructure may be expensive.
    - A large upfront capital cost will be incurred for all supporting services (i.e. new maintenance tools – if not facilities – electric charging stations throughout the system, and new ITS equipment that allows for fleet monitoring and data collection).
    - An organization-wide program would be needed to train staff, shift responsibilities, and create new procedures that collectively allow for a successful transition.

<u>Impacts of an Automated Bus Without Operator (Level 4)</u>

Level 4, it was assumed that the capabilities of the vehicles would be strong enough to allow operation without an Operator, and that instead a remote fleet manager would monitor several vehicles at once and take control if warranted. The following presents a high level summary of what was discussed and by no means is a comprehensive list.

- **Changes to roles and responsibilities:**
    - New policies and procedures needed to support the identification of and response to issues that present themselves during revenue service. (For example: additional staff supervising the service may be needed and called upon to respond to incidents across the system as they occur).
    - For all incidents, fleet management would need to have constant visual and mechanical status updates from each vehicle to be able to assess situations. An emergency assistance channel of communication would also be necessary on any vehicle without an Operator.

    - Complete transformation of the Bus Transportation workforce. Staff would need thorough training in fleet management and new procedures and policies.
    - New analytic skillset requirements to interpret the data generated from the automated systems. Extensive consideration would be needed in how the data generated is managed, assuming that there is a constant video feed of on board activity for every route for safety purposes.
    - Simplified scheduling process as crewing of Operators would no longer be a component.
    - New procedures and policies needed in the event of an occurrence preventing the safe operations of AVs. For example, if there is a forecast for heavy snowfall, procedures must ensure that service is maintained during inclement weather.

- **Positive effects:**
    - Potential for significant operating cost savings if vehicles no longer require an Operator on board.
    - Potential to reconfigure seating arrangement on vehicles.
    - Further reductions in the rate of collisions. A fully automated fleet would be the most capable of adhering to a programmed schedule by allowing the vehicles to collectively determine the speeds and timing points needed.

- **Negative effects:**
    - Persons with disabilities requiring minor assistance may no longer be able to travel independently therefore reversing the planned advancements in the family of services concept.
    - New strategies required to deal with providing customer information, responding to questions etc. on board vehicles.
    - Any solution on buses that requires e-hailing or similar technical solutions could be a challenge for many people (seniors, people with disabilities, tourists etc.) if they cannot afford the technology required to request the vehicle.
    - New policies and procedures required as all door boarding and proof of payment would be required on all vehicles.
    - Complete transformation in how revenue service is delivered and how the TTC responds to issues or incidents on board vehicles.
    - Further limitations arise from not having dedicated staff present to identify, report, and solve on board issues as they come.
    - Complete removal of the Operator greatly increases the risk of cyber-attacks on the vehicles, which could be difficult or impossible to recognize through fleet management.

Key Outstanding Questions

The AV workshop generated good discussion as noted above and many questions, some of which currently do not have an answer. The following is a list of key outstanding questions:

- What will be the cost of the vehicles, the services needed to support them, the training to work with them, etc.?
- Will the software running the system be proprietary, or something independent of the vehicle that can be changed?
- How is liability determined between Operators, maintenance, ITS, and the manufacturer?
- What would the overall net change in costs be after considering vehicle and software procurement, new infrastructure, and changes in roles and staffing?
- How will AVs operate in inclement weather?

Conclusion

Though there has been a spike in discourse and attention surrounding AVs in recent years, the future of the technology is still uncertain. Despite this uncertainty, it is clear that significant resources are being invested into the industry to achieve widespread adoption. Many government agencies are beginning to take proactive approaches to managing AVs, further suggesting the likelihood of their commercialization in the coming decade. The future of AV transit vehicles specifically is further from the fore front of current predictions, and even more uncertain, but unquestionably progressing. At present, private automated shuttles on streets make up the majority of prototypes being developed.

This study assessed the impacts of Level 3 and Level 4 AVs only at the TTC. The implementation of Level 3 and Level 4 AVs would prompt changes throughout the TTC, but especially within operational departments.

There are numerous challenges to TTC adoption of AV technology for our conventional bus service. AV technology is still in its infancy but could be realized on public roads in many different ways. There are too many uncertainties in the capabilities of the technology, the cost, the restrictions, and the timing to be able to develop a TTC strategic plan or consider their implementation at anything further than a preliminary level. The TTC by itself does not have the scale to be a leader in this industry. Once the technology has matured in private operations, the TTC would be happy to become a leader with regards to the use of the technology in the public transit industry.

It is imperative for TTC staff to continue to monitor its progress, and assess if a point of maturity has been reached that warrants further study.

The TTC will continue to participate in the City of Toronto's AV working group and contribute to the identification of impacts and development of appropriate response policies through staying informed on the progression of both AV technology and legislation. The TTC will also look for opportunities to join industry working groups on the topic (CUTA, APTA, TRB etc.). Should a point be reached that necessitates action, staff will report to the Board.

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