Dynamic Scheduling for the Autonomous Public Transportation Era
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Autonomous driving is here. A few more technical enhancements, a little push on regulation, some more emphasis on education. But it’s coming, faster than we realize. However, with the introduction of this technology many tend to focus on the impact it will have on personal cars, where in fact public transportation may be the segment leading the way of adopting the new technology. The question this paper discusses is whether the implementation of autonomous driving in public transportation, mainly buses, will have a real substantial impact on passengers. Will taking the driver off the equation have any impact on how passengers use buses? And if so, what other technologies are needed to make it happen?

Autonomous bus driving technology brings hope for significant improvement in service quality on public transport. It can provide a much better solution for two main challenges: Automatic implementation of dynamic control strategies to counteract the effects of bus bunching in passenger’s waiting times and its variability, and, automatic planning for demand responsive service to improve service reliability. Improving service quality of public transport using autonomous bus driving technology should bring a change in achieving the target of modal split in favor of public transport.

Dr. Robert Ishaq (PhD in Transportation Engineering, Technion)
Has something fundamental changed in transportation in the last century?

The way passengers use public transportation did not change much in the last century. Buses traveling over fixed routes, according to fixed schedule, and passengers waiting in predefined stations for them to arrive.

Look at the picture on the right taken in NYC in the 1950’s. Much has changed since then. Cars these days are nicer, bigger, and more economical, and with much better accessories. However, if you were to take a driver from that picture and put him/her through a time machine all the way to 2016, the driver will probably have no problems finding his/her way around town and handling driving and traffic. The reason is that nothing fundamental has changed in how we drive our cars around town and how we use our vehicles.

Now take a look also at the pictures of buses below. Those take us even further back in time to the first buses from the 1800’s. Compared to the buses today, which are bigger and nicer, these buses look ridiculously old and inconvenient. But think again. Was the way passengers use those buses in the 1800’s so much different than today? Public transportation is all about moving people from Point A to Point B. The first horse drawn bus started to run in 1820. The first motor bus started to run in 1895. The modern buses today are faster and much more convenient, with Wi-Fi, video and passengers’ real-time information. But for passengers, the fundamental way of using the buses - waiting in the station for the bus to arrive according to pre-defined timetable - that did not change and so the benefit from using the bus system is about the same. That could also be the root cause which prevents many people from using public transportation – It’s fixed, static, and does not respond to changes and passengers’ demand.
Autonomous driving technology development and status

Autonomous driving technology has come a long way since the first visionaries started imagining what it would be like. For now, autonomous cars can only drive in specific road conditions (good weather, fully mapped area, etc.), but this is about to change very soon. Technology is developing fast, and crucial components such as newer chips analyzing sensors’ data, and lasers used in sensors, all become available and in much lower prices. Mobileye (www.mobileye.com), a market leader in the area of Driver Assistance Systems (DAS), recently announced launching the kit for a semi-autonomous car next year (2016), and a fully autonomous one in just 5 years.

The transition is already beginning to happen. Elon Musk, Tesla Motor’s CEO, says that their 2015 models will be able to self-drive 90 percent of the time. The major automakers aren’t far behind – according to Bloomberg News, GM’s 2017 models will feature “technology that takes control of steering, acceleration and braking at highway speeds of 70 miles per hour or in stop-and-go congested traffic. Both Google and Tesla predict that fully-autonomous cars – what Musk describes as “true autonomous driving where you could literally get in the car, go to sleep and wake up at your destination” – will be available to the public by 2020.

Autonomous transportation is already a reality in areas like airports or campuses. Autonomous cars are already successfully tested in highways throughout the US, Sweden, and other countries, driving millions of miles with very few accidents, none so far related to the lack of a driver on board.

Adoption rate predictions and early adopters

Morgan Stanley’s research shows that cars are driven just 4% of the time, which is an astonishing waste considering that the average cost of car ownership is nearly $9,000 per year. A panel of Silicon Valley technology leaders recently polled by The Atlantic Magazine, expected the first fully autonomous models to roll into our highways in 2022. In September 2014, California joined Nevada in granting autonomous licenses, and within hours Audi and Mercedes-Benz squeezed ahead of Google in securing permits. They were merely the first in line. General Motors’ Cadillac division announced in August that it would offer limited autonomy by 2017, and Tesla Motors CEO Elon Musk recently unveiled the Model D, an electric sedan with its own semi-autonomous features. Ford CEO Fields predicted in 2015 that driverless cars will be on roads within 5 Years. Carlos Ghosn, CEO of Nissan, said in 2013: “I am committing to be ready to introduce a new groundbreaking technology, autonomous drive, by 2020, and we are on track to realize it”. Dr. Alexander Hars, an industry expert, estimates the timeline for the transformation to autonomous cars, where in 2025 Fleets of autonomous vehicles operate in most cities of developed nations. The common prediction is that by 2030-2040 at the latest, autonomous cars will become the standard. Dr. Hars, like many others, predicted (in 2014) a big shift in the way we use cars, where car sharing will gradually replace private car ownership. Dr. Hars estimates
that in **2030** Car ownership will decline dramatically and only 20% of the US population will own cars, vs. about 44% today. 90% of all trips will take place in fully autonomous mode. Traffic accidents and fatalities will decline dramatically. Many industries are expected to change, including: insurance, dealerships, parking, and more.

Anthony Foxx, Secretary of Transportation, recently was quoted to say: “I am very optimistic with respect to driverless cars and expect to see them in use everywhere in the world within 10 years”.

“Anyone who focuses solely on the technology has not yet grasped how autonomous driving will change our society,” emphasizes Dr. Dieter Zetsche, Chairman of the Board of Management of Daimler AG and Head of Mercedes-Benz Cars.

Chinese bus manufacturer Yutong achieved a world first at the end of August when it successfully trialed a driverless bus on an intercity road from Zhengzhou to Kaifeng. Encountering busy traffic as it navigated the 32.6km route, the bus arrived at its destination having completed a series of complex driving acts without human assistance, including automatic lane change and overtaking. It also successfully responded to 26 traffic lights on its journey.

Once personal cars autonomous driving technology becomes commonly used, car sharing platforms and public transportation may very well complement each other. Some researchers predict a scenario where there will be a BRT (Bus Rapid Transit) or large buses connecting the different neighborhoods and the major transit lines, while smaller buses/vans, or shared cars are used within the neighborhoods to “feed” the major bus lines.

### The case for autonomous buses

#### Public bus service in the autonomous transportation era

In dense urban neighborhoods and job centers, especially with the expected growing trend of urbanization, public mass transit will still be much more effective to transport the masses than small autonomous vehicles. However, it will undergo transformation with the advent of autonomous driving technology, which makes it much easier to dynamically change and adjust the original schedule. Buses, compared to railway, tram, or metro, present the most flexible modality to address on-demand services, as they don’t drive strictly in fixed routes.

Personal cars autonomous driving acceptance and implementation face challenges and barriers. However, for public transportation, some of these challenges are far less problematic, which make it a more likely segment where autonomous driving will kick in earlier. Here are some of these barriers, and why they have no-to-little effect on public transportation, which leads to the conclusion that autonomous driving technology may very well be implemented in buses prior to personal vehicles, thus making this segment lead the whole autonomous driving revolution:
- **Incentive** - Bus operators spend more than 60% of their operating expenses on drivers’, and they will push aggressively to find ways to eliminate this cost
- **Regulation** - Public transportation is a limited and professional segment which is much easier to regulate and enforce new rules
- **Education** - Passengers are more likely to ride a bus without a driver, as many are already used to such modalities in airport and theme parks
- **Navigation** – Public buses use mostly fixed routes in a specific geographical area and do not have to navigate across unpredictable numerous regions

Therefore, there are some very good reasons for buses to be the segment that will spearhead the autonomous driving revolution, and we may see it starting in just a few years from now.

**Autonomous public bus service cost savings**

“Money makes the world go round”, and it is the cost savings that will provide the biggest push for autonomous buses. Other than the obvious savings of drivers’ cost, there are additional areas where autonomous buses will generate cost savings:

- Big transformations require a trigger, usually a financial trigger, and public transportation companies today face a big challenge: About 60% of operators’ Operating Expenses (OPEX) is dedicated to drivers’ paychecks. In an era where operators struggle to maintain profitability, while bidding for new tenders becomes much more competitive, reducing OPEX is what drives decision makers to look for new solutions, and they finally appear in sight.
- A study by Princeton University showed that autonomous buses on the bus lanes of the Lincoln Tunnel, connecting New York City to New Jersey, could accommodate over 200,000 passengers per hour, more than five times today’s throughput. This shows how public space and budget can be saved (less road construction, etc.)
- The average spending on transportation (per household) will also decrease. Car ownership is expected to decrease to 20% in the US (see above). As personal car ownership decreases, the demand for public transportation will increase and a combination of personal/shared/public transportation modalities will present the most cost-effective option.
- Reduction of resources (time and buses) as a result of the elimination of drivers work limitations, like:
  - Reduction of millage, which will not be needed anymore, like: driving to relief points, where drivers must get a break, following regulatory requirements
  - Elimination of mandatory breaks between trips for drivers to rest
- Last but not least, autonomous driving will drastically reduce road fatalities. Other than the human loss, fatalities have a huge financial impact, and once reduced – the insurance premiums will go down, and other businesses will flourish
The three pillars of successful autonomous buses transformation

The transition to buses autonomous driving will be a major transformation for bus operators and passengers. For this transformation to succeed, autonomous driving has to be an enabling technology, vs. an objective. Autonomous buses should present a new value for passengers. Such value will be replacing the current fixed routes/timetable characteristics of the current system with a new concept of a dynamic on-demand system that is constantly adjusting according to passengers’ needs. Today’s system, based on human drivers, cannot accommodate the on-demand requirement, as human drivers cannot adjust to new routes, lines, or driving patterns quickly enough, and they have to comply to very strict regulation of rest times. Therefore, to enable the transformation for both operators and passengers, three major pillars need to be in place:

1. **Autonomous buses technology**
   Autonomous buses technology, as described before, is advancing very rapidly. There are already autonomous buses driving in trial mode in some local routes, like: China and Switzerland. The technology is almost ready and most experts and researches outline a timeline where the technology will mature to be used in production in 5-10 years.

2. **Real time information and big data**
   Replacing the human driver with an automated one makes the system much more flexible and dynamic. With the objective of improving the service to passengers and making the bus ride as predicted and responsive service as possible, autonomous driving will enable what passengers need so much, which was not possible before: bus transportation that is demand-driven and flexible to accommodate the changing needs and conditions. To enable all that, real time information will provide the following information, and more (some of this information is already available today):
   - Buses GPS data, providing data about location and possible delays
   - Passengers’ on-demand information, which will be provided usually through smartphones’ apps, like Moovit (www.moovit.com). This information includes: desired destination, current location, expected time, etc.
   - Passengers’ ticketing and attendance data
   - Real time traffic status, arriving from multiple sources, like: sensors, police reports, social apps like: Waze (www.waze.com) or Google Maps (maps.google.com)
   - Weather reports which may affect traffic and road availability, accessibility, and speed
   - Electrical buses charging systems status, indicating when they should be recharged.
   Additionally, big data information will be accumulated and used:
   - Traffic historical and periodic data
   - Passengers ridership trends and patterns
   - Buses service and maintenance data
   All the above data will make the new era of public transportation much more cost-effective, while providing a far better passenger service, which means: Less waiting time and more time saving as the bus could avoid or bypass obstacles, or skip unneeded stations. Eventually, it may serve as the motivation for more people to use public transportation.

3. **Dynamic Scheduling System (DSS)**
   Real time scheduling software that uses all the real-time and big-data information, translating them into dynamic changes to the schedule, so that passengers actually see the difference in service and the system operates in the most cost effective way. The next chapter elaborates on
the critical role and characteristics of the DSS.

A closer look at the Dynamic Scheduling System (DSS)

Autonomous driving technology by itself will not make a big difference for passengers and will not have the desired revolutionary impact. Without a DSS, bus operators will save the cost of the drivers, but passengers will not be impacted by the use of autonomous driving technology or having the real-time information available. DSS plays the critical role of using all the feeding data of real time information and big data, to make dynamic changes to the buses schedule, thus providing the best and most cost effective service. Today, a DSS system is difficult to find, as the pre-requisite is operating in real time, responding to real time events. Unfortunately, almost all scheduling systems today take hours or even days to complete the scheduling and optimization process, making them unfit in the real-time environment, such as the one needed here. When defining the requirements for a DSS, the following are the most important ones in chronological order/flow:

- **Planning:**
  - **Schedule creation:** Based on service requirements, together with demand prediction, DSS calculates basic/tentative schedule of buses to the different assignments. This can be performed ahead of time to prepare the necessary resources for operating the schedule.
  - **Optimization:** This schedule is optimized for resources optimizations and savings (vehicles and energy) in ‘regular/standard’ situation.

- **Real time:**
  - **Real-time adjustments:** DSS constantly evaluates data received from the real-time information systems, calibrating it with big data information. In case changes are needed, DSS adjusts the schedule in real time, so that within seconds a new updated schedule is ready.
  - **Operator control:** The transportation control room operators are constantly updated on the events and changes and can manually override changes to the schedule.
  - **Optimization:** Before communicating the changes to the buses, the updated schedule is optimized again, to assure maximum cost effectiveness of the new schedule.
  - **Integration:** Changes to the schedule are communicated to other systems, like: dispatching, fleet management, etc. – to assure all systems are updated with the trips information as they actually took place.

The DSS plays the critical role of using available data (real-time and historical), and translate it to changes to the schedule. Changes can range from adding more buses to service, to dispatching a replacement bus to make up for delayed buses. The changes immediately take place, as there is no human driver to receive and interpret the changes. Based on DSS, passenger experience will be completely transformed and improved.

**DSS market overview**

Currently there are no such systems available yet. The main barrier for having a DSS system in place is the optimization speed. DSS requires that schedule creation and optimization will be performed in real time (seconds/minutes) and almost all the available scheduling solutions are using old technologies which take hours, or even days, to perform.
Optibus is a leading vendor with the core technology of Optibize™, which performs schedule optimization at a blazing speed. The Optibize™ proprietary technology uses special patent pending algorithms that were designed specifically for the transportation industry. It is used in the Optibus OnTime™ solution, which helps bus operators, in real time, overcome delays, by re-adjusting the schedule, finding alternative buses to take over the following trips, thus improving on time performance (OTP) of the buses. Optibus OnTime™ can be considered as the baseline core technology of the future DSS. Optibus plans on using the Optibize™ technology as the core for the future DSS.

Summary
Autonomous driving can be just another technology in the evolution of transportation technologies, or it can play a key role in revolutionizing this market, by making a significant impact on how people use transportation and consume transportation services. To have such an impact, we need to add to the two existing pillars of autonomous driving and real time information, a third pillar of Dynamic Scheduling System. The DSS will feed off the real time and big data information, and adjust the buses schedules and routes in real time, so that public transportation actually works for the passenger. A pre-requisite for DSS is a real time scheduling technology, such as the one Optibus developed for the use of its OnTime™ solution. In 2-3 decades, the transportation world will operate completely different than today, and the DSS will be the core technology to enable it all.

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