The effects of autonomous buses to vehicle scheduling system

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Abstract

We are more and more close to the time when a higher number of autonomous vehicles are appearing in road traffic. The number of unanswered questions does not diminish but grow. One such issue is the role of autonomous vehicles in public transport. When talking about autonomous vehicles we often think of only cars and we think less about self-driving buses. But the economic potential inherent in autonomous buses is huge. In the Hungarian vehicle and crew scheduling practice (and also in other countries) the one driver-one vehicle control is typical. This method closely links the vehicles and the drivers. Vehicles should therefore adapt to the rest time of the crew and the employment rules. Unused reserves are generated in the system. Autonomous vehicles can release this overcapacity. Thanks to that, fewer vehicles can carry out public transport tasks and we can save extra rides. It also provides a solution to the lack of drivers, which is a basic problem in many countries. In our study we show the reserves that can be recovered from the system in the case of three Hungarian cities (Eger, Dunaújváros, Győr). We show how much savings can be achieved by running autonomous buses in European cities with a population of 45 000, 54 000 and 130 000 inhabitants. The results are promising. In smaller cities we could achieve about 20% of economical savings but in bigger cities 40% is also realistic. Our statements are based on only rough calculations and they try to help in preparation for the future.

Keywords: Public transport, Autonomous vehicles, Vehicle scheduling, Transport modelling

1. Introduction

Nowadays, there are more and more words about autonomous vehicles. Many researchers and examinations discuss the chances and opportunities of the age of self-driving vehicles, which is expected to come in the next 10-15 years. We can read a lot about autonomous vehicles and their potential. Some researchers state that with autonomous vehicles the traffic will be lower than now [1]. Others predict the opposite of that [2]. Some examination expects more and more free public spaces, other researches state that they need additional capacity. Despite these studies, there are only a few research studies which examine what self-driving vehicles can do in public transport despite the fact that this technical solution is not the future but rather the present as Sion, Vienna and Helsinki are already operating their autonomous buses with test runs. Some research focus on real time schedule adjustment [3] or based on the passenger demand, use special time table optimization [4], maybe examine the case of mixed systems where the operator employ bus drivers but there are some autonomous vehicles too on the roads [5].

Our study is a smaller slice of a larger scale research, where we examine the vehicle scheduling operation opportunities, costs and line route optimization of autonomous public transport service, based on the passenger’s traveling behavior. In this paper, we try to give some answers to the following question: what kind of consequences could the appearance of self-driving vehicles have in the schedule-based Hungarian public transport service? We examined the public transport of three Hungarian cities, with different population, historical development and geographical aptitude. In this study we focus on work organization, we mention the other aspects only briefly.

We can observe this question in two aspects. We can examine the system as work organization (in this study we focus on this), on the other hand we can talk about the effect of autonomous vehicles on passengers. The new service could alter user preferences, since it will be more reliable and accurate but also the journey will lose the human side without the bus driver. Just like in the case when ticket machines displaced the ticket offices.

2. Autonomous Vehicles in Public Transport

We can examine the public transport systems usually in three ways: user (passenger), customer (usually the local government), operator (transport company). These two latter aspects are often fused, which is not a big mistake as these two create the system as a whole service. According to this idea we
are approaching the issue of self-driving vehicles from two sides in this paper. [6]
What kind of differences can passengers expect when using autonomous vehicles? In the case of a self-driving vehicle service, the passengers could expect to receive a more accurate service compared to the current service (i.e. an autonomous vehicle will not hurry home after the last run). The service may be much more standardized as there are no different driving styles nor good or bad drivers. The vehicles always drive in the same way. On the other hand, this service is machine-only, there is no personal attachment. There is no driver, no one can oversee the passengers. This could disturb some passengers, even if the distant oversight of the vehicles is solved. There is less emotion on the operator side, rather the cost of implementing the service.
But which cost elements will change?
The most important factor is the wage cost of bus drivers which is practically eliminated when autonomous vehicles are used. However, it does not cease completely as it may require smaller movements and occasional runs in case of failure. However, this is only a small part of the original costs and it will appear in service costs. Another important element is the fuel cost which will not disappear but it is changing as according to today's trends the autonomous vehicles usually have electric engines. It also raises the possibility that the operator can even think about power generation (thinking about solar panels). The third important issue is the amortization. The price of self-driving vehicles will be much higher than the price of conventional buses. Also the maintenance will require more sophisticated solutions.
Another important question is the scheduling system. With ceasing the constraints of the crew and the vehicles (which is very tight in Hungarian practice), we can use our vehicles more efficiently and we can save costs. In this paper, we focus on this aspect of the appearance of autonomous vehicles.

3. Limitations of Vehicle and Crew Scheduling in the Hungarian Practice

The vehicles are maybe the most expensive parts of the system but according to Hungarian practice the vehicle and the driver are connected to each other in most cases. If the driver decides to rest, then the vehicle rests too. It is a luxury as it is the most expensive item of the system as mentioned before. The efficient use of vehicles would require that the vehicles always have to do useful activities but this does not happen. The vehicle scheduling utilization does not exceed 70% but in some cases, it does not reach 60% either. It means that the vehicle does not generate income in one third of its working time simply because the crew is spending its obligatory rest period. If we recall the definition of vehicle scheduling: "a daily program of a vehicle" there is not a word about the driver, so it is possible to organize vehicles and drivers separately which means more efficient use of vehicles. The goal is not 100% efficiency obviously, as it is still necessary to use spare time for technology and traffic reasons but it is much more efficient than today's practice. Keeping in mind the basic principles of vehicle scheduling, we can also create a driverless program for the vehicle where we only need to pay attention to the technological times and to spare times (to compensate delays caused by traffic).

4. The Impact of Autonomous Buses on Vehicle Scheduling through some Examples

In addition to the theoretical approach, we also dealt with practical cases. In our previous study, we examined the city of Eger (Hungary) [7]. In this paper, we observed the vehicle scheduling system of another two Hungarian cities (Dunaújváros and Győr). From earlier, we knew the vehicle schedules of the buses and the timetable was also known in these cities. The data table contains all of the vehicle schedules, the boarding and alighting numbers in each bus stop and we also know the number of passengers between the bus stops. We used Microsoft Excel to examine the datasets since the task was not complicated. We sorted the data by vehicle schedule ID and by time and we got the results. We also examined the utilization of each of the vehicle schedules.

4.1. City of Eger

In the city of Eger, a review of the local public transport system took place in 2011. At that time, the city had the following line network as seen in Fig.1. [8] The city has a population of about 54 000 inhabitants and the street network is based on historical roots. The transport of the city is highly influenced by the geographical relief. In 2011, the city’s bus network and timetable were served by 40 blocks. That means that there were 40 buses in the system. However, due to sometime overlaps and part-time work, 37 buses were physically sufficient to provide the service. (The question of reserves is not discussed here.) These 37 vehicles complete 5005 useful kilometers with 130 empty km (useless extra km).

![Fig. 1. Public Transport Lines of Eger in 2011](image_url)

Based on our previous papers [9], in our research we were interested in the effects self-driving buses could have on this network. Autonomous buses were considered as not requiring inter-job breaks and can be used from the start to the end of the service time. This does not appear in current Hungarian practice as the vehicle is typically set aside during the rest time of the driver.
Our calculations were made using the software PTV VISUM which is able to create block systems under specified conditions [8]. Before we did our calculations, we examined the theoretical vehicle minimum with the current timetable. It was 33 vehicles which means that having fewer than 33 vehicles, the city is physically unable to solve the timetable. Assuming that the autonomous vehicles can operate continuously, we have the result that 35 vehicles are enough to provide the service. Figure 2. shows a sample of the block versions.

In addition to significant savings in human resource (about 90 drivers), this intervention saves two vehicles resulting significant investment and lower operating costs. In contrast, the useful km is the same (5005) but the additional runs are growing from 130 km to 1590 km. This high amount of empty run km growing is because of the optimized vehicle schedule system. In the current system the vehicles need to rest because of the driver’s rest time, but in autonomous case the buses can make runs in these times too. The vehicles drive to other stop points with empty runs in order to perform new runs.

Examining the timetable, we concluded that the current minimum 33 vehicles can be reduced with minor changes to the schedule. If we change the timetable with a few minutes (up to 5 minutes) in the case of some runs then we can reduce the number of vehicles to 32. However, it is important to emphasize that the timetable has to be changed for this but in this case, we could reduce the number of additional runs to 1323 km. We took into consideration these extra empty runs in our financial calculations.

### 4.2. City of Dunaújváros

In the Hungarian city of Dunaújváros, the population is about 45 000. The former country town significantly transformed in the 50’s to an industrial town. It lies next to the Danube river. The public transport system was examined in 2008. This investigation was our data source, which showed 89 stops on 43 lines to serve forty thousand inhabitants of the city. That time the service needed 27 vehicles with a performance of 5466 km on every workday.

If we imagine a self-driving bus fleet – as described previously – 17 vehicles would be enough to serve the city. On the other hand, it would lead to a drastic improvement in empty runs (from 172 km/day to 1519 km/day). Although it is a huge amount, the range is similar to the city of Eger and here the decline in the number of vehicles is much higher.

Similar to the previous city, we investigated the optimized timetable. It would lead to saving an extra vehicle, so just 16 buses would be needed. However, it is very interesting that the amount of empty runs would also decrease from 1519 km to 1340 km.

### 4.3. City of Győr

As the third city, we studied Győr which is a lowland town. The traffic is influenced by the city’s rivers and bridges. This town is on another scale, it has a mass transit system (not “just” public service) since this is a city with 130 000 inhabitants (officially) or more. It means that Győr is an economically very important city that is 3 times bigger than the cities investigated previously. We had a dataset from 2012, it was our starting point.

In 2012, the city had 46 lines with 451 stops. On this network, 87 vehicles served the city. These 87 buses performed 14 787 km on every workday. As you can see, these numbers between this city and the other ones are also three times bigger. Due to the fact that this service is much more systematic and periodic, the proportion of empty runs are much lower: it is just 353 km per workday.

If we would have a similar self-driving system, the needed number of buses would decrease to 78 and the number of empty runs would increase just a little bit to 405 km.

The effect of timetable optimization is also remarkable: it is further 3 buses (total 75 vehicles needed), and the empty runs increase to 471 km per workday.
5. Financing Questions

The big question is whether such an intervention is worthwhile since self-driving vehicles are more expensive so their amortization is also higher. We made some economic calculations to decide this issue.

We used the following assumptions to make the economic calculations. The basis of these values was the cost level of the local public transport operator. The running cost were calculated from the cost of the drivers (projected value based on the salary of the drivers and on the running distances); from the average fuel consumption and fuel cost in Hungary; and from the local company other costs, projected to one km.

Due to the high purchase cost of autonomous vehicles, we count amortization separately.

- total run cost: 2 €/km*
  - o driver: 0.8 €/km (projected cost)
  - o fuel: 0.35 €/km
  - o other (direct and indirect): 0.85 €/km
- total running cost in future: 1.05 €/km*
  - o driver: 0 €/km (self-driving vehicle)
  - o fuel: 0.2 €/km
  - o other (direct and indirect): 0.85 €/km
* without amortization of the vehicles

One element is missing from this list: the amortization of the buses. We used linear amortization for ten years. The estimated price for a traditional bus is 200 000 €, while the price for a self-driving bus is as high as 400 000 € (We changed the price of the autonomous buses based on our recent estimation). Detailed calculation can be found in the paper of Nagy and Horváth [10]. The most important numbers of the cost calculation are the following.

### Table 1. The most relevant numbers of the cost calculation

<table>
<thead>
<tr>
<th></th>
<th>Eger</th>
<th>Dunajváros</th>
<th>Győr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of vehicles (present)</td>
<td>37</td>
<td>27</td>
<td>87</td>
</tr>
<tr>
<td>Number of vehicles (self-driving)</td>
<td>32</td>
<td>16</td>
<td>75</td>
</tr>
<tr>
<td>Loaded runs [km/day]</td>
<td>5 004,9</td>
<td>5 466,1</td>
<td>14 787,1</td>
</tr>
<tr>
<td>Empty runs (present) [km/day]</td>
<td>129,8</td>
<td>172,1</td>
<td>352,6</td>
</tr>
<tr>
<td>Empty runs (planned) [km/day]</td>
<td>1 322,7</td>
<td>1 339,7</td>
<td>470,8</td>
</tr>
<tr>
<td>Yearly operating cost (present) [EUR/year]</td>
<td>3 080 820</td>
<td>3 382 920</td>
<td>9 083 820</td>
</tr>
<tr>
<td>Difference in yearly costs [EUR/year]</td>
<td>-547 626</td>
<td>-1 139 093</td>
<td>3 017 582</td>
</tr>
</tbody>
</table>

Although we have at every case extra cost for amortization, the savings in running costs and staff costs are much higher, so the total costs of the system were lower than in the original situation in all three cities. It is very important to note: all calculations are based on estimated and average cost elements. The calculations are simplified, e.g. there is no cost for charging stations and special service stations for this kind of new buses. Also, the fare collection system will change since in many cases the bus driver sells the tickets, or at least the ticket control is the driver’s task. The maintenance staff’s cost could be higher as well.

![Fig. 3. Amount of present (total) and estimated (blue) yearly operating cost](image)

The appearance of self-driving vehicles is expected to have a major impact not only on private transport but also on public transport. In our paper, we pointed out that the use of autonomous buses may lead to concrete savings compared to current Hungarian practice as savings can be achieved both in vehicle numbers and in the number of the drivers, which was shown in three cities of Hungary.

We can say that based on these three cities, the results are promising. The different type of cities behave differently. The smaller city’s have less common mass traffic. Therefore, these cities have less potential on the field of savings. Both of the cities have opportunities. Maybe the original system has too much waste, which could be corrected. On the other hand, the bigger cities have more to save, as can be seen in the case of Győr. In smaller towns, the empty runs increased drastically but in Győr this change is not considerable.

In the future, we would like to do the same calculation for other Hungarian cities, as well as for other European cities. It would lead to more general statements based on more examples.

6. Conclusions

Despite these uncertainties, we still believe that the estimated cost savings of 20.9 % (Eger), 36.2% (Dunajváros) and 39.5% (Győr) are not unrealistic, although we know that in reality, it would be a bit lower than calculated, due to the listed uncertainty factors. Let us hope the range of the savings is true, then the extra costs of the new vehicles in the first year would come back in 3-5 years. Figure 3. shows the savings in the case of each city.
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References


