Introduction of Autonomous Driving Bus System

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Abstract

Autonomous driving bus system is a big issue today, no matter in which aspect - technology, feasibility, or acceptance. Firstly, We will introduce the developing history of autonomous bus in the world; secondly, we have surveyed some related previous works. Most of them show a result that the driving speed and the high cost are the main issues which the technology of autonomous driving bus is facing. One of the researches is talking about an autonomous driving modular bus system, where the goal is to decrease the cost - including the facility cost and time cost, and so on. We analysed and explain the formula and try to implement it and do more experiments.

1 Introduction

"Autonomous" is considered an important part when it comes to modern vehicle technology; the combination of self-driving and public transportation also becomes a popular issue, in the era that people pay much attention to not only technology development but also environmental protection. It seems that the technology of autonomous driving buses nowadays can cover both of the above, but still has room for improvement, apparently. Therefore, researchers try to design new modules not only based on "traditional buses" to improve the performance of autonomous driving bus system. After read a research, we try to implement the algorithm it provides, then analysis the model's performance.

2 History of Autonomous Driving Bus

The first autonomous vehicle appeared in 1980s, and the technology of autonomous vehicles is still developing today. Also, people try to combine "self-driving" and "bus" together. Below are some samples of autonomous driving buses recent year.

- 2014, Softbank

  Japanese company Softbank has developed an autonomous driving bus in 2014, but it can only drive in a low speed and in a certain small region.

Figure 1: Softbank's autonomous driving bus.

- 2016, IBM - *Olli*

  This is the most commercially used autonomous driving bus nowadays. *Olli* has been used in many university campus in America and Europe.

Figure 2: IBM's autonomous driving bus: *Olli*.

- 2018, Gatik & Walmart

  This is the first autonomous driving bus which can really serve in urban traffic.

Figure 3: Gatik & Walmart's autonomous driving bus.

- 2020, Ligier & Easy Mile - *EZ-10*

  It is designed as a "Mini shuttle" to serve in regions subway or tramway do not reach.

Figure 4: Ligier & Easy Mile's autonomous driving bus: *EZ-10*.

The newest technology of autonomous driving bus can already reach level-4 in autonomous level.

3 Previous works and relative researches

We have surveyed some papers talking about autonomous driving buses. We sort them into two categories: user experience and system design/analysis.

3.1 Researches about user acceptance of Autonomous Driving Bus

As a type of public transportation, autonomous driving bus has to deal with not only technology issues but also user acceptance and user experience to attract more and more users. Below are three researches which discuss those issues.

3.1.1 Kostas Mouratidis, & Victoria Cobeña Serrano (2020), Autonomous buses: Intentions to use, passenger experiences,and suggestions for improvement

[MC21] This paper focuses on the use of recently established autonomous buses running along a regular public transport line in a residential area of Oslo, Norway. The conclusion shows that users *passengers* have high intention to use autonomous bus in the future, and also feel good of safety. But the speed of autonomous buses is generally considered a little slow.

3.1.2 Bae, Moon, and Seo (2019), Toward a Comfortable Driving Experience for a Self-Driving Shuttle Bus

[BMS19] This paper focuses on the accelerations and jerks of vehicles to reduce the risk of motion sickness and to improve the driving experience for passengers, by using some physics model to compute passengers' feeling in the autonomous bus.

3.1.3 李柏萱等(2021), 無人自駕巴士使用接受模式分析

[李21] This is a Mandarin research. Since there are several project of autonomous driving bus. The team did a survey about user experience and willing to use autonomous driving bus in the future, and analyzed the coefficient of questions mentioned in the questionnaire.

3.2 Research about autonomous driving bus system

According to the researches above, the costs (including facilities cost and time cost) is a big issue which autonomous driving bus is facing. Below is a research about a modular autonomous driving bus system in order to decrease the costs. Our final project mainly focus on this research.

3.2.1 Guillem Romea, & Miquel Estrad (2021), Analysis of an Autonomous Driving Modular Bus System

[RE21] This paper provided a modular autonomous driving bus system because one of the main complaints about the performance of the bus systems is the time lost at recurrent stops along the route, especially autonomous driving buses which are usually drive more slowly. Also, they built a mathematical model to analyze the improvement by the modular system. In sections below we are going to introduce the model and show the result of our implementation. The model developed is applied to low and high demanded routes in the current Barcelona Bus Network, so the implementation of this new system will be analyzed. The less demanded line corresponds to the V5 (Zona Franca-Avinguda Pearson), while the crowded one to the H10 (Plaça de Sants-Olímpic de Badalona).

The modular bus system is with the keyword ”convoy”. Each convoy of the modular bus consists of several pods, when a convoy arrives a bus stop, the pod(s) waiting at the bus stop will join this convoy; only the tail of the convoy will drop and stop, instead of all the convoy. Apparently, time of waiting at a bus stop and acceleration will be saved in this way. Then, ”how many time and other cost is saved in total” can be the indicator of the module's performance. Shown as Figure 5 below.

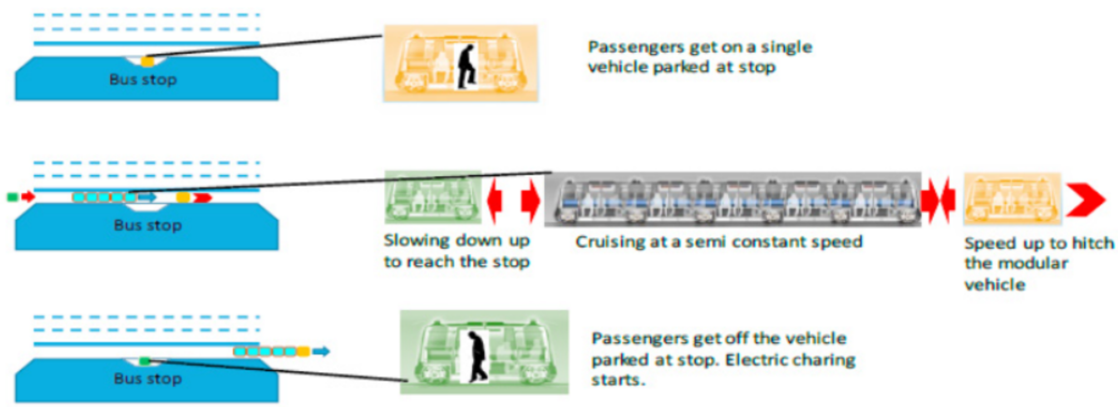

Figure 5: Operational scheme of the autonomous driving modular bus system

4 Model of the Autonomous Driving Modular Bus System

The model separates costs into *agency's costs* and *user's costs* with notation Z_A and Z_U, respectively. The sum of them is the total cost of the system Z_T (Eq. 1).

$$Z_T = Z_A + Z_U, \tag{1}$$

4.1 Agency's Cost

The all cost incurred by the agency can be computed as following equation (Eq. 2).

$$Z_A = €_L{\cdot}L_T + €_V{\cdot}V + €_M{\cdot}M + €_{ER}{\cdot}M + €_B{\cdot}C{\cdot}M, \tag{2}$$

The meaning of each term will be shown below respectively.

4.1.1 Infrastructure cost ($€_L$) and Route Length (L_T)

The proxy $€_L$ represents the infrastructure deterioration, expressed in [€/km-h], and the variable L_T is the route length expressed in [km].

4.1.2 Unit Vehicle Distance Cost ($€_V$) and Distance Covered by the Fleet (V)

The unit vehicle distance cost represents the energy cost per kilometer to run each pod plus its maintenance cost. It is expressed in [€/veh-km], and a pod energy consumption will be considered **0.30 kWh/km**. The distance covered by the fleet per hour (V) [veh-km/h] is calculated with the following equation (Eq. 3):

$$V = \frac{L_T}{H}{\cdot}\#_{pods/convoy}, \tag{3}$$

where H represents the headway [hours].

4.1.3 Unit Vehicle Temporal Cost ($€_M$) and Number Vehicles (M)

The third term of the sum corresponds to the agency expenses related to temporal units, expressed in [€/veh-h], and the number of pods serving the line (M) are found with Eq. 4:

$$M = \left[\frac{V}{v_{Net}} + n{\cdot}\frac{L_T}{s}\right]^+, \tag{4}$$

where n is the number of pods stopped at each bus stop (considered 1 through all this model), v_{Net} stands for the commercial speed [km/h], and s is the separation between two bus stops [km] (considered the same for each pair of adjacency bus stops)

4.1.4 Unit Vehicle Charging Facility Cost ($€_E R$)

The charging of pods will be performed during the 10 hours per day that they do not run; lifespan of each charger should be 30 years, 300 days/year and 10 hours/day. This parameter is expressed in [€/veh-h].

4.1.5 Unit Temporal Battery Cost ($€_B$) and Battery Capacity (C))

First, the term $€B$ represents the battery cost expressed in [€/kWh-h]. It is estimated to be a value of 0,021 €/kWh-h, if the pod runs 300 days/year and 14 hours/day. The Battery Capacity C expressed in [kWh]. The pod's energy consumption per day is found in Eq. 5, and it satisfy the Battery Capacity (C) requirement.

$$Consumption = v_{Net}\left[\frac{km}{h}\right] \cdot f_{consumption}\left[\frac{kWh}{km}\right] \cdot 14\left[\frac{h}{day}\right] \cdot (1+S_{factor}) < C, \tag{5}$$

where the consumption factor is 0.30 kWh/km, the pod runs 14 hours/day, and a 20% safety factor has been taken. Finally, the net speed is approximated with the following equation:

$$v_{Net} \approx \frac{L_T}{\left(\frac{L_T}{v_{Cr}}\right) + (H+\tau) \cdot \left(\frac{L_T}{s} \cdot \frac{1}{\#_{pods/convoy}+1}\right)}, \tag{6}$$

where v_{Cr} represents the cruising speed of the pod [km/h], and τ is the time lost by each pod for breaking and accelerating at a bus stop in comparison with a non-stopping one [hours]. We pick $\tau = 0.025$ in our implementation.

4.2 User's Cost

The other part of the cost is user's cost. Here, time spent on the bus will be considered and then transformed into monetary units, that is, *Value of Time*. It can be calculated as below:

$$Z_U = \Lambda \cdot \beta \cdot (A + W + IVTT). \tag{7}$$

4.3 Hourly Demand (Λ) and Value of Time (β)

Λ represents the hourly demand expressed in [pax/h], and β is the value of time, where its units and value are [€/h] and 12.50 €/h, respectively. This average value comes from considering a salary of 2,000 €/month and working 40 hours per week.

4.3.1 Access and Exit Time (A)

The first and last part of every journey by public transport corresponds to the walking time to the bus stop and to our destination once we get off the transport. the average distance is $s/4$ because of the assumption that distance between any two adjacency bus stops is s. So we can compute it as

$$A = \frac{\frac{s}{4}}{v_w} + \frac{\frac{s}{4}}{v_w} = \frac{s}{2v_w}, \tag{8}$$

where v_w is the walking speed of the pedestrian [km/h].

4.3.2 Waiting Time (W)

To simplify the calculation, just consider a perfect regularity and no use of mobile phones, and with the aid of the same simplification used in *4.3.1*, the expected waiting time is half the headway, that is,

$$W = \frac{H}{2}. \tag{9}$$

4.3.3 In-Vehicle Travel Time ($IVTT$)

In this particular case of the autonomous and modular bus, the user will only perceive an acceleration, travelling at constant speed, and breaking time, so the equation will become:

$$IVTT = \left(\frac{l}{v_{Cr}}\right) + (\tau), \tag{10}$$

where l represents the length travelled by the user inside the pod (which has been considered as $L_{total}/4$ to be conservative) in [km].

5 Implementation

We have implemented the model after reading the paper. Here is our code. We try to implement with parameters provided, with the two testing data, V5 and H10. Unfortunately, we found that there is a conflict between C (battery capacity) and $\#_{pods/convoy}$ because of the constraints in case H10. Therefore, there is a trade-off while adjusting the two parameters. Then we run for 1e7 rounds to approximate the optimal solution.

6 Comparison between the paper's claim and our results

Concept		V5	H10
Headway (H)	min	8.00	1.50
Stop spacing (s)	km	0.73	0.30
Battery Capacity (C)	kWh	63.96	118.03
$\#_{pods/convoy}$	-	2	4
Total Costs (Z_T)	€/h	2,155.03	22,625.27

Table 1: The paper's claim.

Concept		V5	H10
Headway (H)	min	6.77	1.01
Stop spacing (s)	km	0.75	0.72
Battery Capacity (C)	kWh	53.05	172.01
$\#_{pods/convoy}$	-	3	7
Total Costs (Z_T)	€/h	2,052.98	27,535.85

Table 2: Our implementation results.

As the tables shown, our implementation gives a similar result comparing with the paper's claim in case V5, the less demanded line; but has a much different result in case H10 because of the conflict mentioned in the previous section.

7 Conclusion

Technology development, user's intention, and system design of autonomous driving bus are all big issues. Although we finally found that there is a little bug within the modular system designed by the last paper's author, we still think it will be a good way to improve the performance of autonomous driving bus. Nowadays, we can already see autonomous driving buses serve on the road somewhere, including some certain area in Taiwan, so we believe autonomous driving buses will become more strong and be more generally used in the world.

8 Team members' contribution

B07902056: looking for relative researches, recording and editing presentation video, writing the final proposal
B07902142: looking for relative researches, making presentation slides, doing the implementation

References

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