Towards Autonomy: Cost-effective Scheduling for Long-range Autonomous Valet Parking (LAVP)

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***Abstract*—Continuous and effective developments in Autonomous Vehicles (AVs) are happening on daily basis. Industries nowadays, are interested in introducing less costly and highly controllable AVs to public. Current so-called AVP solutions are still limited to a very short range (e.g., even only work at the entrance of car parks). This paper proposes a parking scheduling scheme for long-range AVP (LAVP) case, by considering mobility of Autonomous Vehicles (AVs), fuel consumption and journey time. In LAVP, Car Parks (CPs) are used to accommodate increasing numbers of AVs, and placed outside city center, in order to avoid traffic congestions and ensure road safety in public places. Furthermore, with positioning of reference points to guide user-centric long-term driving and drop-off/pick-up passengers, simulation results under the Helsinki city scenario shows the benefits of LAVP. The advantage of LAVP system is also reflected through both analysis and simulation.**

I. Introduction

Our mobility is largely dependent on transportation system. Some people uses their own auto-mobiles while other rely on public transport. Public transport on road can be found in the form of buses and taxis. Each form has its own pros and cons. Buses are considered less costly source of public transport. Although buses follow a specified path, and sometimes people need to travel long route for a location nearby. Usually people prefer to use transport system when destination is not within walking distance. With the increase in human population, an upward trend has also been seen in number of car purchased each year. Besides, the capacity of traffic infrastructure in the city remains almost the same. Parking, in public places is one of the highlighting issue that discourage self-driving.

In most of the times private driving is discouraged by parking issues. Where main concerns are cost, convenience, and safety. It is staggering to know that a driver wastes 2,549 hours of life in total, moving around in streets searching for a car space. On an average in UK, it takes over 6 minutes to find an appropriate parking space, as per survey by JustPark [1]. Commuters also find it a difficult job searching for parking spaces. Around one-third of commuters usually chooses other modes of transportation rather than driving to work. Parking a car in a defined space itself a headache for most of drivers. On the other hand, 20% of all auto accidents happen in commercial parking lots, as per report of Insurance Institute for Highway Safety (IIHS).

Parking is considered as a severe headache while driving. These days car parking in urban areas, congested zones, business areas and tourist spots is a major concern due to increase in vehicles ratio. Usually in urban areas, very limited number of parking spaces are available. Besides limited space for Car Parks (CPs), skill required in tight spaces, high cost and circular driving are the reasons which needs immediate attention.

For each of the problems explained above, various techniques have been proposed. However, the following aspects must be considered to making parking task easy and effective.

- How to overcome congestion in urban areas?
- How can we ensure the hassle to park safely?
- During long term parking, how cost can be reduced?
- How efficiently can be parking lots utilized?
- How reliable will the parking be?

The advancement in machine vision system and autonomous car-manoeuvring techniques has made Short-range Autonomous Valet Parking (SAVP) a mature technique. These techniques have solved many problems of parking in limited and narrow spaces. SAVP is specially designed to offer services in already trained scenarios. In SAVP, autonomous parking in already visited areas and area with simple layout can be achieved through machine learning techniques. In initial step, AV performs training with driver inside AV and driver parks AV at least once for supervision. In the next step AV learns to park itself without a driver. Advanced AVP system scans for available parking lots, slot by slot and floor by floor in case of multi-story CPs. It is capable to park AV in full autonomous mode [2]. Systems that are proposed in [3] provides valuable recommendations on parking lots status and results in saving time. In [4] studies about coordination of AVs to avail parking facilities in Vehicle-to-Grid (V2G) has been carried out, where most of vehicles are assumed as electric.

Though solution presented above are enough for basic parking, but still AVP needs a proper mechanism for parking by considering lot availability, cost, Quality of Experience (QoE) and fuel consumption. AVP related advanced automation techniques allow us to extend its functionalities. Here, Long-range AVP (LAVP) became possible due to advancement in fundamental techniques of AVP, like precise detection [5], path generation [6], [7], [8] lateral control [9], cloud-based distributed Vehicle-to-Everything (V2X) architecture [10] and precise localization [2].

As the value beyond most of efforts on SAVP, this paper studies LAVP solution that works for **large-scale** (e.g., city wide) scenarios, integrating Information Communication Technology (ICT) into automated control for valet parking. The primary deliverables of this paper are as follows:

- Design of LAVP integrated with ICT to provide best driving experience.
- An optimized solution for LAVP is demonstrated mathematically, via: 1) recommendation of the best location for drivers to drop-off/pick-up their AVs; and 2) recommendation of the most cost-efficient remote CP.
- Analysis developed to follow simulation study under the Helsinki city scenario.

II. Background on AVP

AVP is delivering astonishing services with the help of modern automation technologies. It improves overall user experience and provides safety as well. AVP is evolving along with automation technologies and ICT. It provides services at different levels [11], as presented in Fig. 1.

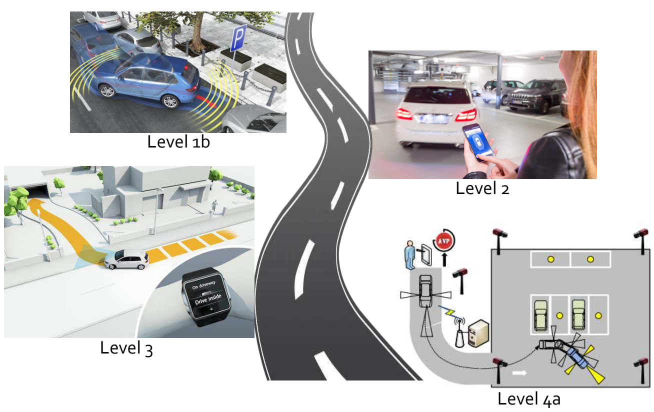

Fig. 1. The Development of AVP at Low Autonomous Levels

In the starting days, AVP was used to provide a limited parking assistance. Automatic parking is used while driver remains in the AV. Which is not fully autonomous as driver can intervene in the process. In this process the whole parking activity is fully supervised by driver, referred as "Level 1b" in Fig. 1. In this process, the driver use to driver the AV to a vacant parking and lot and set its position at a certain distance from obstacle and other AVs. Once AV is in heading position towards parking lot, it automatically detects the lot and AV is parked. This mechanism is mostly useful for less experienced driver and it has minimum chances of hitting an obstacle or other AV.

In the following years, AVP developed wireless operations. It enable the driver to stay out of the car, perform and monitor parking process through their specified handset or smart phone, which is referred as "level 2".

In the later stage which is shown as "Level 3", 3D mapping and sensing technologies are used. This is a more advanced level of AVP then previous one, where AVs travel to parking lot from a specific spot. Usually in this technique an AV is trained at least once with driver inside AV [12].

In the state-of-the-art AVP system, path generation [6] and precise detection [5] techniques has extended AVP's scope to large scale areas. In this scenario referred as "Level 4a", a driver leaves AV as CP entrance and navigate AV towards vacant lot [13]. The disadvantage of this system is that driver must approach CP and drop AV over there, however it saves time to find lot and park autonomously in CP.

III. Design for LAVP

The exponential increase in number of vehicles has raised parking difficulties in urban and congested areas. LAVP is specifically designed to overcome parking issues and provide intelligent transportation services in urban areas. LAVP respond to parking call by providing whole city CPs status to vehicles.

A. Big Picture of LAVP

LAVP provides the possibility to take AVs from drop-off spot to selected CPs autonomously, as depicted in Fig. 2. Usually drop-off spots are deployed near congested areas, like city centre, shopping mall, hospitals, and stadiums while CPs are deployed in less congested and remote areas which is usually on border line of the city. In LAVP, driver may any time request for a parking lot in remote CPs and drop AVs at a selected drop-off spot. Scheduling Centre (SC) has an important role in scheduling parking operation and provide optimized solution towards journey time, fuel consumption and parking fee. The process of LAVP start with a parking request with an outbound trip, e.g. office or Work Place(WP). It suggests an efficient selection of drop-off spot to AV. It helps the driver in leaving the AV at nearest spot as well as to WP.

B. Communication Signallings in LAVP

In Fig. 3 communication framework is shown for both inbound and outbound journeys, where vehicle and infrastructure is denoted by "X" in V2X systems.

"Drop-off" spots for inbound trip are regarded as "pick-up" spots. The "Drop-off/Pick-up" (D/P) and well-suited parking locations are scheduled by SC keeping in view live traffic updates. SC consider the cost of driver towards D/P and that consumed on delivering AV to/from CP.

Design presented in Fig. 3 is based on cloud system, while Mobile Edge Computing (MEC) [14] may be integrated in future. It will replace the operation of SC. These edges collect traffic and vehicles data and performs intelligent data

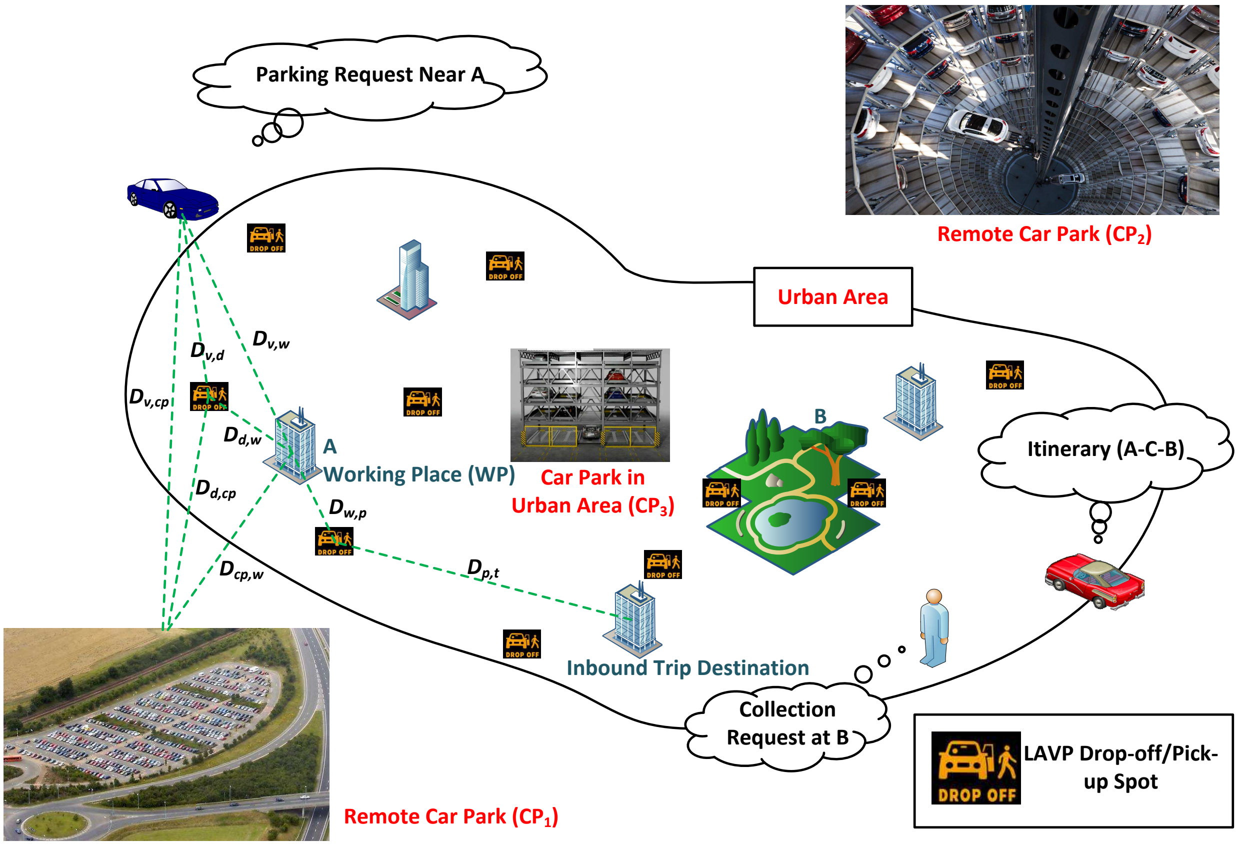

Fig. 2. The Framework for LAVP

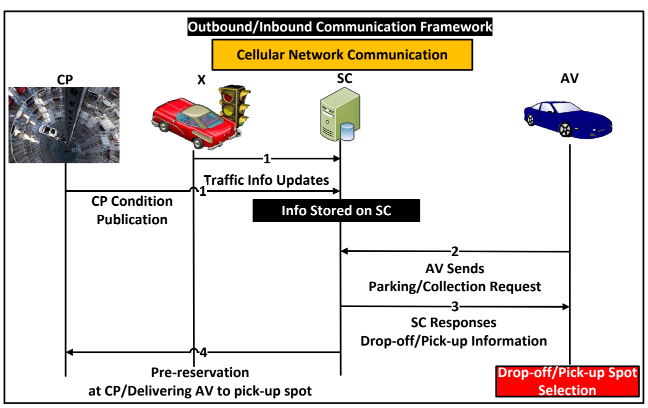

Fig. 3. The Communication Framework for Outbound/Inbound Trips

calculations at its end. These results are then shared with other edges as well as the centralized cloud. An edge directly respond to AVs upon parking request as local edge can be directly accessed by AVs. These edge's helps in taking decision instantly and does not require handshakes/signalling.

C. LAVP System Cycle

In Fig. 4 five stages of LAVP has been described.

Travelling Phase: In this phase AV travels in urban city.

Drop-off for Outbound Trip: Moving towards WP, when AV is in certain range towards WP, it sends a parking request to SC.

Working in Office & LAVP: As soon as SC receives parking request, it suggest a feasible drop-off spot to driver. The driver then proceeds to suggested drop-off spot, leave AV and start walking towards WP. In the meantime, AV starts moving towards CP and get parked.

Pick-up for Inbound Trip: After work in WP, driver send inbound trip request to SC. The SC schedules AV delivery to pick-up spot depending upon time driver will leave WP and time driver will take from WP to pick-up spot. SC suggest the best available pick-up spot. The driver pick up AV and then turns to **Driving Phase** by driving towards destination.

IV. Scheduling Scheme of LAVP

A. Problem Definition

Mathematically transportation's network can be considered as multiple optimization problems. The network can be interpreted as follows; D_0 can be indicated as start of journey or some other point in the city while D_T shows the target location or location where a person work like WP. In transportation network there are multiple factor that need consideration but, for the instance the goal is to minimize the time spend from D_0 to D_T. Lets suppose x denotes possible locations of traffic network. Let $f(x)$ be the shortest path connecting D_0 and x and let $g(x)$ be the shortest path connecting x and D_T. Let

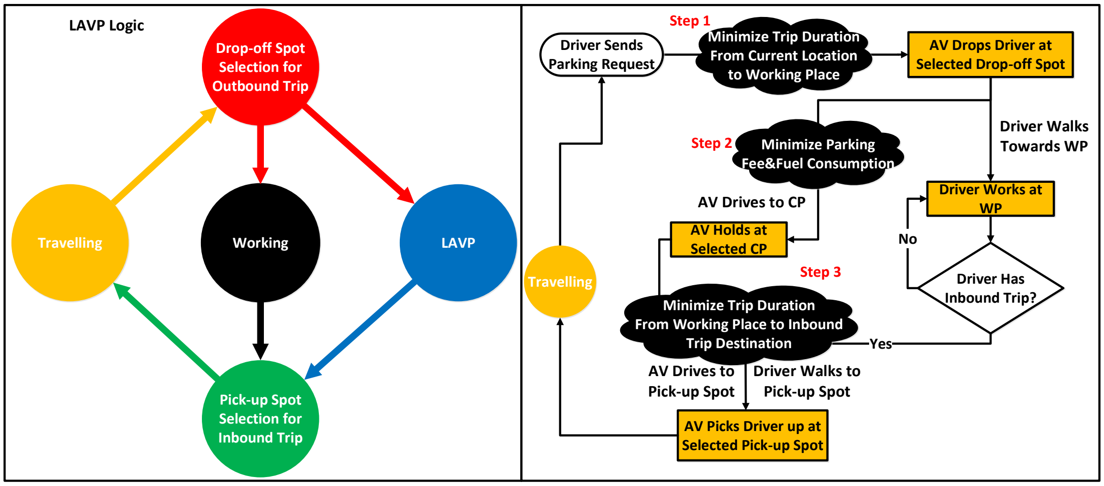

Fig. 4. System cycle of LAVP procedure

the set of M drop-off points be

$$\{drop_i\}_{i=1}^{M}. \tag{1}$$

To make it simpler, the speed of AV S_v and person walking S_h is kept constant. Hence the first optimization problem is

$$x^* = \underset{x \in \{drop_i\}_{i=1}^{M}}{\arg\min} \left(\frac{f(x)}{S_v} + \frac{g(x)}{S_h} \right). \tag{2}$$

Main theme is to minimize the time spend on the way from D_0 to D_T, when AV is used. After dropping the person at x^*, the AV will autonomously move toward one of the pre-defined CPs in the remote area. The CPs locations and vacant parking slots at time t as a set

$$Cap(t) := \{park_i\}_{i=1}^{N}. \tag{3}$$

The capacity of CPs should be updated regularly. Let the time when the vehicle drops the person at x^* as t_0 and denotes $l(t_0, x)$ the shortest distance between x^* and a car park $x \in Cap(t_0)$. The aim is to minimise the parking cost and expenses on the way to CPs, namely

$$\min_{x \in Cap(t_0)} \left(a \times \frac{l(t_0, x)}{s_v} + b(x) \times \omega \right). \tag{4}$$

Where the cost of electricity or gas is denoted by a While $b(x)$ denotes parking cost of one hour in each CP. The total time of parking there is denoted by ω, which is assumed to be constant now. At time t, we consider

$$\min_{x \in Cap(t)} \left(a \times \frac{l(t, x)}{s_v} + b(x) \times \omega \right). \tag{5}$$

The $l(t, x)$ function is to connect the location of vehicle at time t and CP $x \in Cap(t)$ through shortest distance. Although it is difficult to do it at time t, we may discrete time t and update capacity information of CP, like every five minutes.

Here, it is worth noting that If any reservation function is used for parking AV the optimization problem may be considered (4) and find out the best CP in $Cap(t_0)$, to confirm reservation.

B. Generic LAVP Computation Logic

The computation logic in LAVP is developed to make appropriate selection of drop-off spot for outbound trip and pick-up spot selection for inbound trip. It will minimize the trip duration with a trade-off between fuel consumption/parking cost. Here, $d/p \in \mathcal{D}$ is shown as a set of D/Ps, and $cp \in \mathcal{P}$ as a number of CPs in network.

- **Step 1:** In the initial step SC select a drop-off spot, considering the minimization of travelling time. The selection of drop-off spot depends on current location of AV. It can be achieved by $\underset{d \in \mathcal{D}}{\arg\min}(\frac{D_{d,w}}{S_h} + \frac{D_{v,d}}{S_v})$, here $D_{d,w}$ is the distance[3] between a Drop-off spot and WP, while $D_{v,d}$ is considered as distance between Drop-off spot and current location of AV as presented in Fig. 3. Besides, S_h (where h stands for human) and S_v are assumed as average walking and driving speeds, respectively.
- **Step 2:** It is responsibility of SC to determine a suitable CP for the AV left by driver at drop-off spot. Usually CPs with vacant slots are considered for this process. In this step, fuel consumption for return trip to drop-off spot and parking fee for which AV will be parked, are taken in consideration. In case of same parking fee, CP with shortest travelling distance will be selected, can be achieved by $\underset{cp \in \mathcal{P}}{\arg\min}\, D_{d,cp}$.
- **Step 3:** In step 3 driver needs to collect AV from pick-up spot. The SC select pick-up spot keeping in view current location of driver. A pick-up spot will be selected on certain criterion like minimum travel time and travelling expense if driver is using public transport towards pick-up

[3] Although we only illustrate the geometric linear distance for the simplicity of presentation, in case study the actual path consisting of segment coordinates of road map is considered to calculate the distance.

spot. It can be achieved by $\arg\min_{p\in\mathcal{D}}(\frac{D_{w,p}}{S_h}+\frac{D_{p,t}}{S_v})$, where the distance between pick-up spot and WP is presented by $D_{w,p}$ while $D_{p,t}$ is the distance between the Pick-up spot and inbound trip destination.

C. Analysis

1) LAVP vs Benchmark : An analysis has been provided here to show the advantage of LAVP, here inbound and outbound trip are same. We are taking only inbound trip into account. There are no D/P spots involved in benchmark. In fact, the driver need to drive all the way to CP, get their car parked and walk back towards WP.

In case of LAVP, the outbound trip, T^{out}_{lavp} is given by:

$$T^{out}_{lavp}=\frac{D_{v,d}}{S_v}+\frac{D_{d,w}}{S_h} \tag{6}$$

That for benchmark is given by:

$$T^{out}_{bck}=\frac{D_{v,cp}}{S_v}+\frac{D_{cp,w}}{S_h} \tag{7}$$

As S_v is much larger as compared to S_h (e.g., 13.9 m/s vs 1.5 m/s), mainly $D_{d,w}$ and $D_{cp,w}$ dominate how advanced the LAVP is. In general, the deployment of D/P reflects the efficacy of LAVP, while large CPs are usually expected in the remote areas of each city, rather than near the city centre as the example given in Fig. 2. With a large number of Drop-off spots, it is possible to find a $d\in\mathcal{D}$ to hold $D_{d,w}<D_{cp,w}$.

2) Convenience vs Fuel Consumption: Regarding the deployment of D/P, let us assume a simple case, with one CP what $|\mathcal{P}|=1$ and one WP. Particularly $D_{d,w}=0$ means the Drop-off spot is co-located with WP. Here, a triangle is formed by $D_{v,d}$ (note that $D_{v,d}=D_{v,w}$, since $D_{d,w}=0$), $D_{v,cp}$ and $D_{cp,w}$. Obviously, we can obtain $D_{v,w}<(D_{v,cp}+D_{cp,w})$ according to Euclidean geometry. Note that $D_{v,cp}+D_{cp,w}$ is actually the travelling distance spent in benchmark solution. This analysis provides an insight that the Drop-off spot should normally be set close to the WP, which certainly follows the vision of LAVP system to the benefit of users in terms of driving experience.

As the fuel consumption is proportional to distance an AV travels, the distance $D_{v,d}+D_{d,cp}$ is traversed in case of LAVP. In benchmark, $D_{v,cp}$ is traversed. Obviously, the LAVP will result in much fuel consumption given in above simple case, as there is only 1 CP. However, with more CPs built in city, the fuel consumption of LAVP can be potentially reduced, by diverting the AV towards a CP that is more closer to the Drop-off spot (as the CP selected in LAVP and benchmark does not need to be same).

V. Case Study

The case study is implemented under Opportunistic Network Environment (ONE) [16], a Java based simulator originally used for DTN routing research. The default scenario with 4500×3400 m^2 area is shown as the down town area of Helsinki city in Finland. 300 AVs running at speeds in the range $[30\sim 50]$ km/h are initialized in the network.

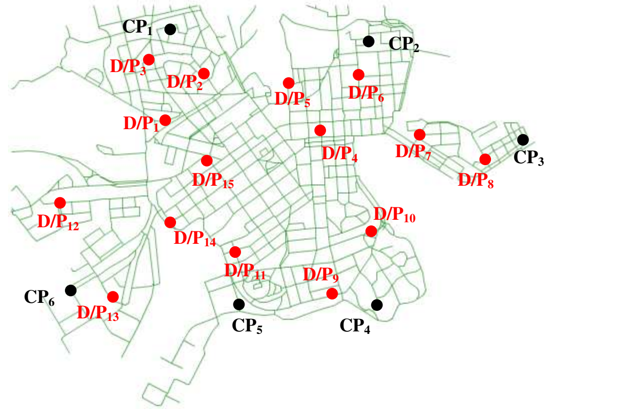

Fig. 5. The Helsinki City Scenario for Case Study (6 CPs, 15 Drop-off/Pick-up Spots)

Shown in Fig. 5. A total of 6 CPs in remote area are deployed while 15 Drop-off/Pick-up spots (depicted as 'D/P') in total are deployed in main city centre. By default, the time for drivers to start requesting for drop-off spot is 3600s while 7200s is set as working period. The simulation runs for 12 hours. Here, the power demand (P) of AV can be calculated in [17].

The duration of AV to experience in Outbound and Inbound trips can be denoted by $\mathcal{H}$, while fuel consumption in (J) can be given by $\int_0^{\mathcal{H}} P$, when acceleration is enabled.

For the proposed LAVP, results are shown given different deployment of D/P spots. In case of 4 D/P spots, D/P$_4$, D/P$_{10}$, D/P$_{11}$ and D/P$_{15}$ are deployed. 10 D/P spots means D/Ps other than (D/P$_4$, D/P$_{10}$, D/P$_{11}$, D/P$_{14}$ and D/P$_{15}$) are considered. 15 D/P spots means all the D/Ps are deployed. For fair comparison purpose, parking fee of all CPs to set to same, as the main interest is to compare LAVP with benchmark based on of following performance metrics:

- **Average Walking Duration (AWD)** - The average period for drivers to move from Drop-off spots (in LAVP)/CPs (in Benchmark) towards WPs for outbound trips, plus that for inbound trips.
- **Average Trip Duration (ATD)** - The average time that drivers experience for their trips, from the time they request drop-off until reaching the WPs for outbound trips. That for inbound trips include the time for drivers to reach the Pick-up spots from WPs, until they reach the inbound trip destinations. Result accumulates the ATD of these two periods.
- **Total Fuel Consumption (TFC)** - Total fuel consumption for all AVs, including both outbound and inbound trips.

Results are presented with normalized value.

In Fig. 6 the outcome of deploying large number of D/P spots can be observed, which helps driver in reducing AWD.

Besides, the ATP is reduced, as certain D/P spots can be selected close to drivers' WPs. While in case of 4 D/P spots, both LAVP and benchmark achieve a close AWD and ATD. Here, although the ATD is reduced comparing to the

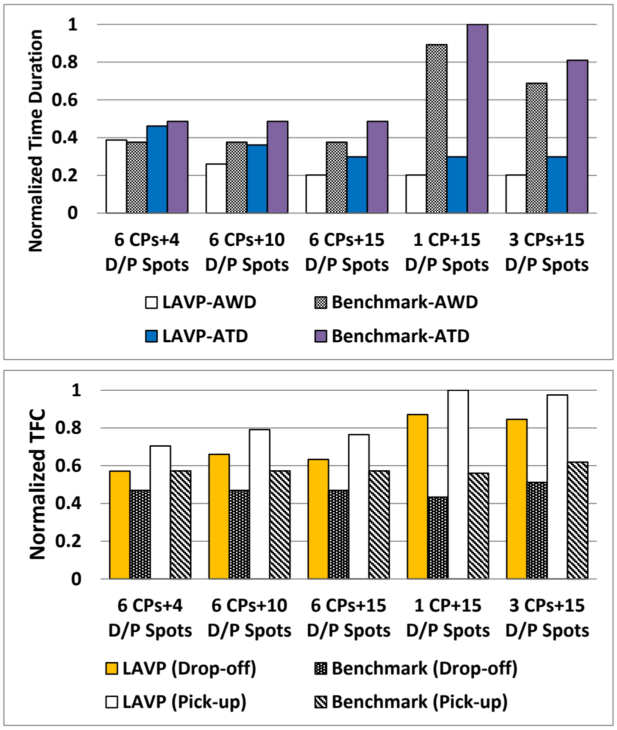

Fig. 6. Evaluation Results

benchmark, the AWD cannot get reduced due to the limited number of deployed D/P spots (which do not benefit to drivers to walk to their WPs). The results demonstrate that the proposed LAVP has the capability of improving user QoE (in terms of shorter journey time), and the more deployment of D/P spots the more benefits it achieves. If only keeping CP_1 in network, the benchmark suffers from the highest AWD and ATD, as the fundamental analysis in Section IV-C. While, with 3 CPs (CP_1, CP_3 and CP_6 included), Benchmark obtains lower AWD and ATD.

In case of LAVP, the TFC is increased when more D/P spots are deployed. This is because AVs would firstly drive towards D/P spots (which primarily benefit to drivers) and later heading to the CPs/inbound trip destinations. In particular, deploying 4 D/P spots is able to uniformly cover the needs around central city, compared to 10 D/P spots case. Therefore, the latter case achieves a higher TFC. Further deploying D/P spots from 10 to 15, TFC is reduced as AVs can find convenient D/P spots for drivers working around central city. If increasing 1 CP to 3 CPs, LAVP obtains reduced TFC compared to the Benchmark.

VI. Conclusion

This paper proposes the LAVP system, which relies on the support from both ICT and autonomous driving. With a number of deployed D/P spots and pre-trained track routes to/from remote CPs, LAVP reduces the walking time for the drivers to walk between WPs and total out/inbound trips duration. With a trade-off at fuel consumption, the highly improved QoE makes the LAVP promising in the future intelligent transportation systems. Our ongoing work will conduct reasonable pricing and reservation system.

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