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16. ABSTRACT

Transit ridership data come from automated passenger count (APC) systems. APC systems are electronic machines that count the number of passengers that board and disembark at every bus stop. Currently, their cost varies between $2.5K and $10K per bus, but, combined with automatic vehicle location (AVL) systems, aggregation and analysis software, the cost may jump up dramatically.

APC systems are supposed to generate robust ridership information on a stop-by-stop basis and to enable assessment of bus occupancies on different segments of bus routes. APC data can be used to assess bus utilization, to determine schedule adherence and whether bus routes need more or less running time to get between endpoints. In the mid- and post-COVID environment the real-time APC data can help travelers plan their trips to avoid overcrowded transit. To summarize, accurate APC data are critical for effective transit planning, efficient operation, and traveler comfort.

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Working Group to Address Automatic Passenger Counting (APC) Problem

Prepared for Caltrans by California PATH and Prospect Silicon Valley

June 2022

Table of Contents

Introduction

Transit ridership data come from automated passenger count (APC) systems. APC systems are electronic machines that count the number of passengers that board and disembark at every bus stop. Currently, their cost varies between $2.5K and $10K per bus, but, combined with automatic vehicle location (AVL) systems, aggregation and analysis software, the cost may jump up dramatically.

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This report addresses these questions:

- What would incentivize transit agencies to cooperate – provide access to passenger counting? How to overcome their reluctance to share ridership numbers?
- What should be a feasible integrated end-to-end solution: starting from non-intrusive passenger counting, to real-time reporting, to data aggregation and storage, to open APIs for data access?
- What technologies, primarily for passenger counting, must be considered? One of the obvious candidates is a video detection, but people are concerned about "Big Brother". Are there other candidates?
- Who would be invited to participate in the challenge, and what will be the role of transit agencies?
- How to ensure that APC data end up in the public domain? This is needed to enable a competitive ecosystem for application development.
- Is there a commercial value of APC data, what is it, and how to monetize it? This is needed to get private industry to invest.

The report has two major parts:

1. The memo summarizing APC vendor and transit provider engagement (Tasks 2-3 of the project); and
2. APC state of practice, use cases and recommendations (Tasks 4-6 of the project).

Report for Tasks 2-3: APC Vendor and Transit Provider Engagement

Approach

There were several tasks associated with the overall market research assignment:

1: Technology Provider & Designer Engagement
The Task 2 objective was to build on existing research to provide a profile of the APC technology provider market for public transit, with a specific focus on providers for buses and shuttles. To achieve this, we conducted interviews with companies that provide APC solutions, either stand-alone or within a technology set.

2: Transit Vehicle Operator Engagement
The Task 3 objective was to engage regional transit agencies and operators to better understand adoption barriers and potential points of coordination. We approached this through the lens of the agencies' organizational structure and roles, their purchasing policies and budgets (broadly), and the technology they employ in operations that would interface with APC. We achieved this through conducting surveys, interviews, and organizing a focus group of transit agencies.

Background Research

ProspectSV conducted background research on APC technology and applications. APC is used for multiple purposes, including for transit vehicles (such as buses, trains, shuttles, etc), as well as in buildings (such as retail stores, offices, and grocery stores). For the APC market research study, we focused on transit vehicles. There are many types of APC technologies, but the most common types are Infrared, Thermal, Video, and Bluetooth. As outlined in the table below, each has several advantages and disadvantages. Unfortunately, there is no one technology that is low cost, simple to use, and also highly accurate.

Table 1: Types of APC technologies.

People Counting Technology	Advantages	Disadvantages
IR break beam	Low cost, simple operating concept	Low accuracy (~85%) Sensitive to alignment
Thermal	Highly accurate (> 95%)	Expensive Sensitive to environmental conditions
Video	Highly accurate (~98%) Image processing software generates rich data sets	Expensive Can suffer from inconsistent lighting May incur data protection and privacy issues
Bluetooth	Low cost, simple to install	Low accuracy (80% - 90%). Passers-by must have a mobile phone in order to be counted

Source: FierceElectronics

Survey

ProspectSV surveyed transit agencies to understand if they currently use APC technology in their transit vehicles, and if so, what vendors they worked with, how they manage their APC data, and if they allow real-time passenger data publishing. We received 17 total responses from 15 Agencies. 9 were in California, and 6 out of state. Questions that were asked:

1. Do you currently use APC technology in your transit vehicles? (If No, please, skip to the end of the survey)
2. If yes, what APC vendor(s) do you work with?
3. Does your APC solution allow real-time passenger data publishing?
4. How do you manage your APC data?
5. Is there anything else you'd like to share with us regarding APC?

Table 2: Survey responses.

	Do you currently use APC technology in your transit vehicles?	If yes, what APC vendor(s) do you work with?	Does your APC solution allow real-time passenger data publishing?	How do you manage your APC data?	Is there anything else you'd like to share with us regarding APC?
Agency	**Response**	**Open-Ended Response**	**Response**	**Response**	**Open-Ended Response**
AC Transit	Yes	UTA	Yes	Internally	APC technology is big investment but it is valuable data collection for both real-time passenger count streaming and ridership reporting.
Antelope Valley Transit Authority	Yes	InfoDev APC/Avail	Yes	Internally	The APC are verified everyday before bus goes into service and the count can be adjusted manually in case of miscount.
Blacksburg Transit	Yes	Dilax, Iris-IRMA; Hella	Yes	Internally	These system are not plug and play, they need a maintenance plan and staffing.
LA METRO	Yes	IRIS	No	Internally	there needs to be these two critical elements in using APC: 1. A reliable hardware/software infrastructure to collect, transmit and store the APC data automatically as much as possible. 2. A rigorous computer programming process to validate and clean the raw APC data, correlate the valid data to the schedule, apply treatment to the curable data inaccuracy, impute the missing data with statistically tenable methodology and data, and eventually bring the data to a state agile for business analysis and reporting use.
Marin Transit	Yes	APCs are provided through our AVL vendor (GMV Syncromatics). Not exactly sure of the vendor	Yes	Internally	We use them as a "relative count" recognizing they are not 100% accurate. We have them installed on roughly 75% of the fixed route fleet.
Napa Valley Transportation Authority	Yes	UTA Transit	Yes	Other third party vendor	Our APCs are certified for NTD reporting purposes

Salem Area Mass Transit Agency	Yes	Indev	Currently working through issues with our CAD/AVL vendor (GMV Syncromatics) to make this possible	Other third party vendor	Having real time APC data published is a goal of ours that we're working with GMV syncromatics at this time.
Salem Area Mass Transit District (Cherriots)	Yes	Indev is our APC vendor	Not currently, we're working with our CAD/AVL vendor (GMV Syncromatics) to create that.	Other third party vendor	We're in the process of verifying our APCs and are interested in sharing our data as we gain more confidence in it.
Santa Clara Valley Transportation Authority	Yes	Iris/INIT; Note: the Iris/INIT equipment is integrated with the Clever Devices application.	Yes	Internally	The VTA setup is unique. APC equipment is with Iris/INIT but the application (ie management of data) is Clever Devices' -- As part of the CAD/AVL project, the CAD (ie Clever Devices) integrated with the Iris/Init equipment to centralize software application use. Note that a LOT of background activities/effort occur to manage the APC data: from cleansing/balancing to performance/maintenance monitoring. Providing raw passenger information is only a small portion of the effort to manage the APC data. We need to be mindful of the requirements FTA impose on transit agencies when APCs are used for passenger counting.
SEPTA	Yes	Infodev Electronic Designers Intnl. (InfoDev) Urban Transportation Associates (UTA)	Yes	Internally	APC technology has evolved for over 3 decades and it has a potential to provide TSP, Wheelchair & Bike usage, Real-time Seat availability on buses and trains, NTD Reporting, and even futuristic origin and destination (O&D) data, and much more. Creating a complete Intelligent Transportation System (ITS) is very much possible with a fleet-wide APC retrofit project that is currently underway. I have been involved with APCs and ridership data at SEPTA since 1988 and have been instrumental in bringing an innovative one-stop solution (design+manufacturing+hardware+software+support) APC technology by InfoDev at SEPTA in 2016. In this digital age, data is everything and APC acts as the powerhouse of a big data source for transit that fulfills almost all data needs for small and big projects, and it helps us provide enhanced

					customer services in real-time via API, phone apps and website. We have manual Traffic counts, standard AVL data, and Fare Box data, but they all play a very limited role in filling data gaps for routes that currently do not have APC vehicles. Within 2 years, SEPTA will have a fleet-wide vehicles equipped with APCs on all modes that will enable us to improve scheduling, planning, and customer services. APCs vary by vendors (most of them are resellers), and therefore it is necessary to invest money, time, and talent in the right product that is dependable and consistently gives accurate results. It is a very small investment of less than \$10k/bus and \$20k/train car that will give complete transit data set 24x7 during the life-time of a vehicle. Shift the paradigm by staying away from industry standard Integrated APCs and instead go with the Standalone Independent Cellular APCs is a bit of advice I would give to the transit agencies and the decision makers. Thank you for giving me an opportunity to briefly share my views on APCs via this survey.
SMART	No				We are kicking off an APC procurement currently.
Union City Transit	Yes	Dilax	Yes	Internally	
Utah Transit Authority	Yes	Urban Transportation Associates, INIT	It is possible and requires us to change how we process data. We are hesitant to provide raw/unvetted data to the public due to data inconsistency/anomalies as well as the benefit to the riders and what decisions riders can change based on this information. We are doing more research on this topic.	Internally	Data availability and quality are critical to the success of the APC system. We put quite a bit of effort on to monitor and ensure data are available and in good quality.
Valley Transit	Yes	We purchase equipment and receive support from DoubleMap.	No	Internally	We have APC equipment on all buses.

		The APC equipment is manufactured by Dilax.			
Washington Metropolitan Area Transit Authority	Yes	Our bus APC system is provided by CleverDevices, with a mix of CleverDevices dual beam and Hella overhead camera hardware. We use Ridecheck Plus for data processing and official APC ridership reporting.	Real-time data is available but requires extensive processing and cleaning before being published	Internally	
Western Contra Costa Transit Authority	Yes	Hanover and Iris	Accuracy is not there yet to permit this	Internally	Validation process for National Transit Database is fairly difficult, with a long lead time
Western Contra Costa Transit Authority	Yes	IRIS - incorporated through our AVL vendor - Hanover HAWK	No	Other third party vendor	

- All but one Transit Agency we interviewed currently uses APC technology (Figure 1).
- Eight agencies use more than 1 vendor. The most common vendors were: UTA (Urban Transportation Associates), InfoDev, IRIS, INIT, Dilax, Clever Devices (Management of data)
- Eight agencies allow real-time passenger data publishing, while 3 do not. 3 others commented that their APC system was not accurate enough, working through issues to create, or the data is available but requires extensive processing (Figure 2).
- Twelve agencies manage their data internally, while 4 manage it through a 3rd party vendor (Figure 3).
- Other comments included:
    - Critical elements for APC: data availability and quality, reliable infrastructure to collect and store data, and rigorous process to validate and clean the data.
    - A lot goes into APC beyond providing the raw data - maintenance plan and staffing required

- Big investment, but valuable data collection for real-time passenger count streaming and ridership reporting
- Need to be mindful of requirements FTA impose on transit agencies when APCs are used for passenger counting.

Figure 1: APC Survey Question 1 Results

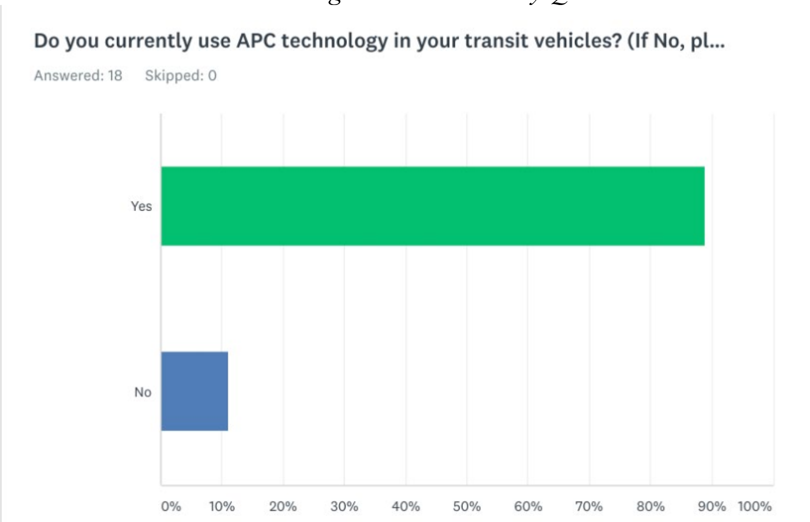


Figure 2: APC Survey Question 2 Results

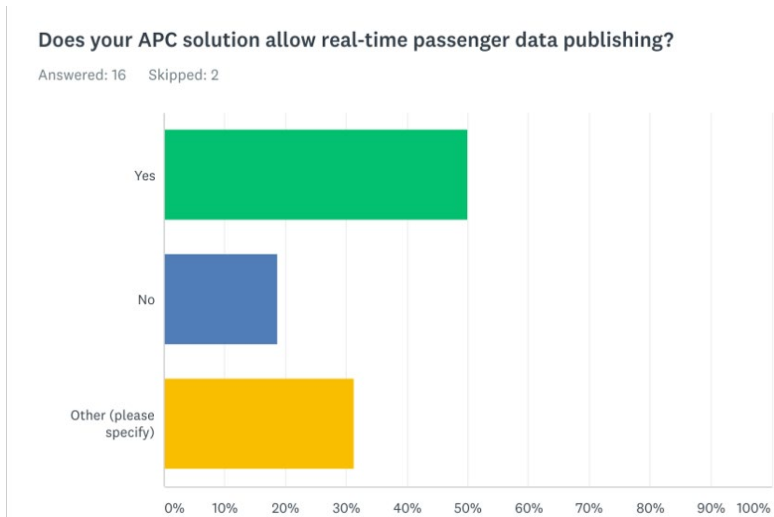
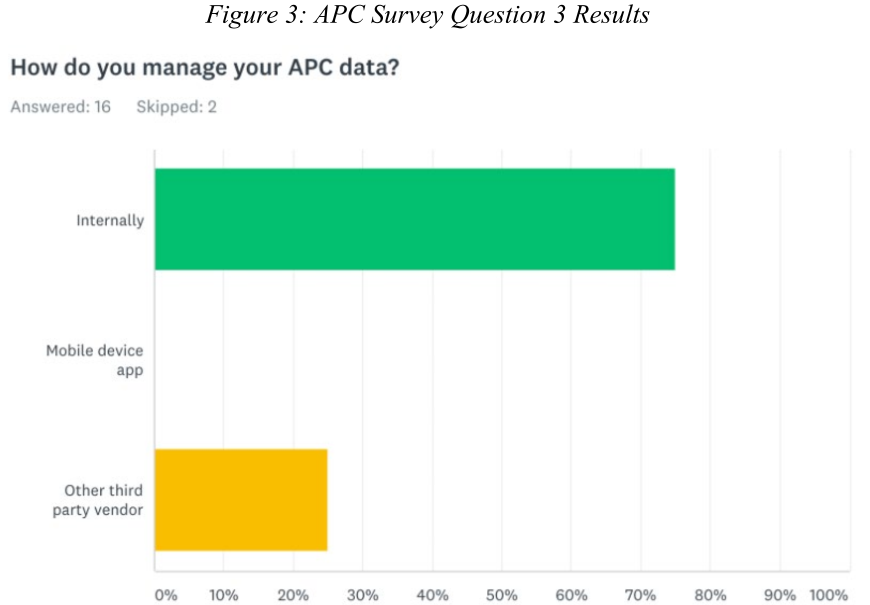


Figure 3: APC Survey Question 3 Results



Transit Agency Interviews

Out of the transit agencies who responded to our survey, ProspectSV conducted follow-up interviews with five agencies (one from California, the others out of state). Questions that were asked:

1. Who is your APC vendor(s)?
2. Who manages your APC data – upload, storage, cleanup & validation, reporting?

3. Which parts of your current APC solution could be improved?
4. Does your APC solution allow real-time passenger data publishing?
5. Are you willing to make your APC data public? If not, what are the main [up to] 3 reasons?

Table 3: Transit agency responses.

Agency	About	Outcome/Feedback
Utah Transit Authority (UT)	The Utah Transit Authority is a special service district responsible for providing public transportation throughout the Wasatch Front of Utah, in the United States, which includes the metropolitan areas of Ogden, Park City, Provo, Salt Lake City and Tooele	o Vendors: UTA/INIT – 15 years, 80-90% of buses running APC o Main issue is troubleshooting hardware repairs, need to train staff o Count on vendors for software data downloads
Blacksburg Transit (VA)	Blacksburg Transit, or simply BT, is a local government-owned urban-suburban bus line based in Blacksburg, Virginia. The system originated in 1983 with six buses, but has since expanded its operation to 53 fixed-route buses and 18 body-on-chassis vehicles	o Vendors: Dilax, Iris-IRMA, Hella – 20 years o Main issues are with accurate passenger data and sensor calibration o Covid disrupted plans to make data public o Would like to see interoperability of APC systems
Union City Transit (CA)	Union City Transit is a public transit service in Union City, California, in the San Francisco Bay Area. As of March 2021, Union City Transit operates 5 bus lines that connect riders to local destinations, such as schools, shopping centers, and the Union City BART station.	o Vendor: Dilax, CAD AVL service contact through MV Transit- 3 years o Data validation is a barrier (using currently as internal validator), operationally they care about alightment counts instead of boarding o Would like to see different use cases for APC: ex: expand to microtransit, count passengers based on seats instead of the door
Valley Transit (Appleton, WI)	Valley Transit is a city bus and paratransit commission operated by the city government of Appleton, Wisconsin. It has operated as a bus system since 1930, and has been fully operated by the city since 1978.	o Vendor: Dilax, equipment and support from DoubleMap o Small agency, with 30 vehicles in their fleet, all have APC o Use APC data and analyze it in GIS for planning purposes, not for reporting (they use fare box data for this). o There are some accuracy issues - passenger count inflation at transit centers. o No issues with the equipment itself, no maintenance issues. o Main issue is that they can't analyze the data quickly enough.
Washington DC Metro	The Washington Metropolitan Area Transit Authority, commonly referred to as Metro, is a tri-jurisdictional government agency	o Vendor: Bus APC system is provided by CleverDevices, with a mix of CleverDevices dual beam and Hella overhead camera hardware. Use

	that operates transit service in the Washington metropolitan area.	Ridecheck Plus for data processing and official APC ridership reporting. o Real-time data is available but requires extensive processing and cleaning before being published (In house analysis, processing software is clunky). Reports to NDT, uses data for juridictions and consultants o Data provides value - different counts from the fare box (alightments vs boardings) o Maintenance of sensors and accuracy could be improved.

- Although the agencies' bus fleets ranged from small to large, all had APC installed on 80-100% of their buses.

- APC technology has been used by the agencies for between 3 and 20 years.

- Common uses for APC data:
    - Some agencies only used APC data internally for planning purposes, while others used it for National Transit Database (NTD) reporting, and shared with jurisdictions and consultants.
    - The APC data provides a potentially more accurate depiction of ridership than other sources (for example, the fare box).

- Issues or challenges with APC:
    - Maintenance of the sensors: some agencies had difficulty troubleshooting hardware repairs, especially with limited staff bandwidth and training capacity. However, one agency had no maintenance issues with the APC equipment itself.
    - Sensor Accuracy: agencies reported inaccurate passenger data due to the sensors, for example passenger count inflation at transit centers.
    - Data validation: most agencies only use data for internal purposes, as data needs extensive processing and cleaning. However, most cannot analyze the data quickly enough due to staff limitations and the processing software is clunky.

- Other comments:
    - COVID-19 disrupted one agency's plans to make data public.
    - One agency would have liked to see different use cases for APC; for example, expand the technology to microtransit, and be able to count passengers based on seats instead of through the door.
    - Another would like to see interoperability of APC systems.

Peer Forum Focus Group

ProspectSV conducted a focus group to discuss APC technology and survey more transit agencies who are members of the Transit Innovation Peer Forum. The Peer Forum consists of 85 Members and 45 Agencies, composed primarily of Transit Agencies and Transportation Authorities in California and 8 other states. There were 9 responses to the live poll during the peer forum. They were asked three questions about their APC systems and use cases.

- Five Agencies currently had an APC system, while 4 did not.

- Three agencies managed their APC data via another vendor, while 1 managed their data internally.

- The most important use cases to the agencies were (in order from most to least important):
    - Self-assessment for operations planning and reporting (3 Agencies).
    - Connection protection - extend waiting time based on real-time passenger counts (2 Agencies).
    - Inverted "Next Bus" - Next Stop: passenger count and expected destination (2 Agencies).
    - Coordination of connections with other transit agencies and TNCs (2 Agencies).
    - Enable signal priority based on real-time passenger counts (2 Agencies).
    - Real time transit occupancy information for travelers (1 Agency).
    - Combination of APC and Clipper card data to improve transit ridership (1 Agency).

Technology Vendor Interviews

ProspectSV conducted extensive background research on technology vendors of APC hardware and software. ProspectSV conducted outreach to request interviews with the technology vendors. However, the team was only able to set up interviews with two vendors. Both vendors were quite established in the industry, having worked with hundreds to thousands of transit agencies in California for 20-30 years. Questions that were asked:

1. Can you tell us a bit about the products/solution sets you offer and how they are configured? (e.g., hardware, software, data service, backend services)
2. What partners or outside providers do you work with? (CA?)
3. Do you offer different levels of service/packages with different support or products?
4. Do you offer different price points for one vehicle, or vehicle-specific packages?
5. What are your future product plans (e.g., visualization, dashboards, etc.)?

Table 4: Technology vendor responses.

Vendor Name	Vendor/Technology Description	Area Covered	Company Origin	Website/Source

INIT	INIT is worldwide leading supplier of IT solutions for public transport. We understand the specific needs and challenges our customers face each day. To provide them maximum support, we cover all operational processes within a fully integrated ITS system and offer a wide variety of services to make their life easier.	Worldwide	Germany	https://www.initse.com/ende/home/
UTA (Urban Transportation Associates)	Urban Transportation Associates, Inc (UTA) provides transit authorities throughout North America with a mature Automatic Passenger Counting (APC) system consisting of proven APC hardware, APC software, and APC support.		Cincinnati, Ohio	http://www.utatransit.net/
UTA (Urban Transportation Associates)/Clever Devices	Approximately 80% of AC Transit's fleet is equipped with automated passenger counting (APC) sensors that feed into our data—providing real-time rider capacity information for all AC Transit bus lines on most trips. This data is refreshed every 15-seconds, providing riders with up-to-date trip planning information. The rider capacity feature is already embedded into AC Transit's existing real-time trip planning tools. For some trips, rider capacity information is not yet available, but we are working to equip all buses in the fleet with APC sensors.			https://www.actransit.org/rider-capacity
Infodev Electronic Designers International Inc	Since 1993, INFODEV EDI has been developing and installing Automatic Passenger and People Counting systems. We are considered one of the world leaders in this industry. All hardware and software are designed, manufactured and assembled in our headquarters here, in Canada. We are also proud to provide our customers with the best support in high-tech electronic products and software in terms of design, manufacture and sale. INFODEV EDI is a Canadian-based company with more than 30 years of experience. INFODEV EDI's APC can provide you with crucial data, information and insight that gives you an accurate picture of your ridership. We are proud to have delivered the world's first real-time compartment occupancy based on passenger counting technology.		Canada	https://www.infodev.ca/transit/automatic-passenger-counting/
IRIS Infrared & Intelligent Sensors	Supplier of the Infrared Motion Analyzer (IRMA) Automatic Passenger Counter (APC) systems for rail, light-rail and bus. IRMA uses the latest "Time-of-Flight" technology to provide 3D images of the detection area and passengers. Used by major systems integrators, IRMA works in both stand-alone APC systems or integrated ITS solutions. More than 80 transit agencies and airport authorities throughout North America count their passengers with		Germany	https://www.iris-sensing.com/products/automatic-passenger-counting/

	IRMA.'			
DILAX Systems Inc	Specializes in the design, delivery and support of customized or turn-key-type automated passenger counting (APA) and trip analysis solutions including sophisticated data management and reporting software.	over 200 transit agencies across Europe and North America, over 30 OEM partners	Germany	
HELLA Aglaia Mobile Vision GmbH	full subsidiary of HELLA GmbH & Co. KGaA and specializes in innovative software solutions. Our portfolio is based on extensive expertise in image processing, embedded software and machine learning as well as 20 years of experience in series development in the automotive industry. Our innovative public transport product is at the forefront of the next generation of automatic 3D passenger counting sensors. The APS-R-PoE is specifically designed to meet the rigorous standards of the transportation industry. And, as one of our premier products, it acts as a gateway to new methods of analyzing of ridership structure and flow.	over 125 locations in some 35 countries	Germany	https://people-sensing.com/public-transport/
Clever Devices Ltd.	CleverCount® is an automatic passenger counting (APC) solution that provides insights that allow you to plan based on the actual ridership demands of your customers, improving efficiencies and increasing rider satisfaction. Our sophisticated methodology combines sensor data with best in class reporting tools that result in passenger count accuracy levels of over 95% so you can plan better and operate more efficiently. Onboard sensors collect APC data		US	

	that is transmitted via Wifi as vehicles return to the yard. Passenger counting data is automatically correlated to Run, Block, Trip and Stop and stored in a SQL server database for reporting. Optionally, ridership data can be made available to dispatchers and passengers in real-time using cellular or radio networks			
Avail Technologies	The myAvail Enterprise Transit Management Software (ETMS) automates much of what drivers need to do on the bus, so they can focus on driving. With a single login, drivers can initiate automatic ADA announcements, fare collection, passenger counting and more — leaving them free to spend their time focused on driving safely and providing your riders with a good experience.		Las Vegas	https://availtec.com/
	Tri Delta Transit riders will see nearby options and departure times in big text and bright colors. Users can easily navigate Tri Delta Transit service, aided by accurate real-time bus ETAs, trip planning, step-by-step navigation, and crowdsourced real-time information with Transit's GO feature. In addition to providing trip planning and real-time bus information, the app also allows riders access to bus crowding information for their trip, an important tool during the COVID-19 pandemic when deciding which bus trip to take. Tri Delta Transit's fixed route fleet is outfitted with automated passenger counter (APC) sensors. APC data is supplemented with crowdsourcing data which allows riders to report the current passenger bus load for their trip. Crowding levels are described as Crowded, Some Crowding, and Not Crowded. These standards are based on the temporarily lowered crowding threshold to accommodate social distancing			https://trideltatransit.com/pdf/PR-Transit-App.pdf
NextBus	Automatic Passenger Counting (APC) is used to quantitatively monitor passenger use of Metro's bus network and provide the agency with a critical component of the information needed to enhance and improve its bus services.Sensors mounted in bus doorways count passengers boarding and exiting at the same time the corresponding information on bus stop location and time is acquired from the AVL system. At the end of every day, the WAN is used to transfer the accumulated data from each bus to Metro's central computer system for processing and reporting.			https://www.metro.net/projects/atms/

Ridecheck Plus	This is Clever Devices			
DoubleMap				
NextBus	Nextbus Information Systems, Inc., a subsidiary of Cubic Transportation Systems NextBus provides a real-time passenger information system for all routes for several major transportation agencies including the San Francisco Municipal Railway, Los Angeles County Metropolitan Transportation Authority, the Massachusetts Bay Transportation Authority, and the Toronto Transit Commission. The system is also available in many other smaller universities and public transportation agencies for a total of approximately 100 systems.			
Hitachi	The most advanced solution is to deploy automated people counters for 24/7, real-time traffic and occupancy monitoring. These counters utilize IoT solutions like sensors, thermal devices, and video technology to keep track of and control the flow of people throughout brick-and-mortar operations, thus complying with CDC recommendations on occupancy limits		Japan	https://global.hitachi-solutions.com/blog/automated-people-counters
Eurotech	Eurotech is a global company with a strong international focus: born and still headquartered in Italy, it has operating locations in Europe, North America and Japan. Eurotech offers an open, integrated and managed IoT architecture - Everyware IoT - that provides on-board intelligent devices and software and off-board tools to setup a cloud-based Automatic Passenger Counting (APC) system.		Italy	https://www.eurotech.com/en/page/automatic-passenger-counting-system

- One vendor focuses on configurations of hardware that suit the agency's individual needs instead of a standard plug and play system. Their software works with the existing sensor and hardware on the bus. They are looking at improving functionality and flexibility of the software.

- Another APC vendor specializes in data collection and communication. They are also working on interesting future applications for object recognition and tracking/classifying passengers while maintaining their privacy.

- The vendors noted some barriers/challenges as well:
    - hardware and software are currently expensive to replace
    - the sensors should be standardized for integration purposes

- There is a need to train/empower teams at agencies to overcome the knowledge gap.
- reporting should be agnostic/modular.

APC Adoption

From our survey and interview findings, we have identified potential benefits and barriers to APC adoption, from the transit bus/route, transit agency system, and integrated system levels.

Table 5: Potential benefits and barriers.

	Potential Benefits	Potential Barriers
Transit Bus and Route	• Capacity/passenger crowding data • Maintaining occupancy limits for COVID-19 • Alightment data • Route demand analytics for service changes • Improve route efficiency e.g. dwell time reduction and increased punctuality • Respond to excessive demand • Extend stop connection times based on real-time passenger counts	• Calibration • Sensor Reliability • Sensor Accuracy • Small sample size (fewer people riding public transit due to COVID-19) • Passenger traffic flow and door configuration of sensor • Each type of APC technology has advantages and disadvantages (see table below) • Route variability
Transit Agency System	• Demand dynamics and demand response for fleet optimization, such as coordinating route stops or adjusting schedules based on passenger needs. • Improved communication and coordination within an agency for planning and scheduling purposes • More cost effective long-term to invest in an accurate APC system that provides valuable data • Provides higher data counts than manual counting or fare box data	• Agency staffing and training (bandwidth/experience) • All buses would need APC • Data issues: gaps, storage • Cleaning of the data: lack of balancing algorithms for passenger loads • Highly accurate systems are expensive
Integrated System (Across Transit Agencies, the State, General Public, and the Private Sector)	• Standard APC data validation and quality assessment • Intermodal integration dynamics • Inter-agency comparison of ridership performance • GTFS-ride capabilities: Standardized data format across transit agencies to make data sharing easier	• NDT Reporting sufficiency and requirements: benchmarking and maintenance plans, accuracy tests & backup counting systems • Data limitations (files and formats) • No current standardization to compare across data sets • Not recognizing full potential of the data • Integration challenges with technologies

	• Improve quality and availability of APC data from various providers • Provides deeper insight than NTD reports • Inter-agency comparison of ridership performance • Juxtapose with land use and Census data – the goal is to solve spatial mismatch problem • Real time transit occupancy information for travelers • Vendors sell their APC solutions • Enables integration with private mobility providers – e.g., TNCs	

Source: Smartech

While APC technology currently has several barriers to adoption for some agencies, the benefits it could provide (to transit agencies, the private sector, and the general public) surely outweigh the challenges. We know that transit ridership is suffering due to COVID-19 impacts, and recovery is essential. There are vast opportunities to improve transit ridership that need cooperation from both the private and public sectors. Accurate ridership data, standardization, and affordable APC systems could help.

- Accurate APC data are necessary for transit performance assessment, proper planning, tactical optimization of operations and traveler comfort. In addition, making APC data available would give a tremendous boost to a variety of mobility services.

- Standardization of data collection and processing approaches makes it more attractive for the private industry to participate in transit projects. Standardization would also make it easier for transit agencies to clean and process their data either for reporting or planning purposes.

- APC hardware and software must be affordable, highly accurate, and easily maintained by internal staff. APC systems must be more accessible to transit agencies looking to understand and improve their ridership.

Report for Tasks 4-6: APC State of Practice, Use Cases, Recommendations

APC Technology and How it Works

Automated Passenger Counters (APC) are essentially dual people counting sensors that count the in and out numbers and are installed on transit vehicles. APCs accurately and automatically count and log the numbers of people on buses, trains, rail networks, ships, etc., as they get on and off at each stop or station.

APC is critical for automatically collecting data on passenger activities that were previously collected manually. Depending on the fleet penetration of APC, an APC system can provide so much more data, richer data that agencies once either could not afford to collect or could not manually collect the data (e.g., average peak load) but also what they could not do or could not afford to do with traditional manually collected data (e.g., the 95th-percentile value of peak load). Furthermore, large APC data allows agencies to estimate the aggregated ridership or passenger miles traveled with more precision than what is feasible with manually collected data.

The transit industry has realized the critical importance of having APC. One indication is that the transit industry is quickly moving towards 100% fleet penetration of APC, at least for bus systems. Twenty years ago, few agencies had APCs and, when they did, had deficient fleet penetration levels. According to APTA's 2020 Public Transportation Vehicle Database, about 60% of all bus vehicles of the 325 responding APTA members had APC. This percentage was less than one-half of that just ten years ago. An important role for an APC system is to monitor and report changes in transit ridership at various levels of spatial and temporal resolution. Given the dramatic changes in travel behaviors caused by the pandemic, APC-generated ridership is essential to monitor changes in ridership and adapt service accordingly.

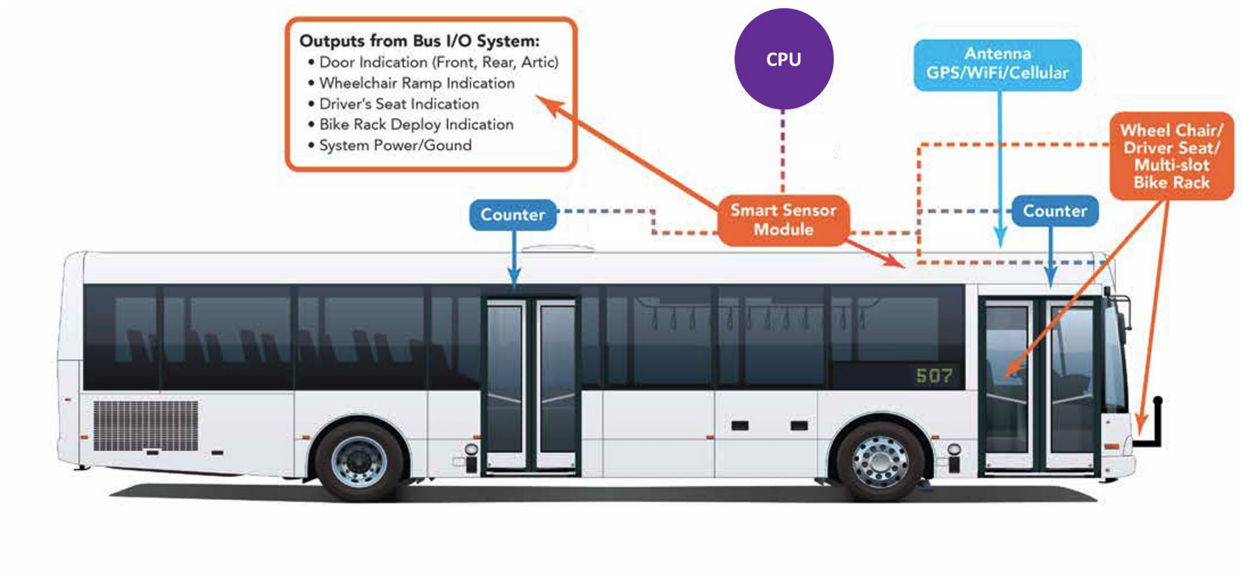
Traditionally agencies who did not have 100% saturation of APC presence on their fleet relied on other ways to reconcile the data to determine operating costs and passenger boardings. One way to do this is to cross-reference passenger boardings with fare collection. Since the COVID-19 pandemic, many agencies have forgone fare collection to limit transmission of the virus and protect both operators and customers. Safety measures from the pandemic have meant that agencies do not have fare data to cross-reference, thereby relying specifically on APC or manual passenger counts. Since agencies depend on ridership for funding subsidy calculations, and ridership had already dipped dramatically during the pandemic, it became increasingly important to collect automated boarding data.

Another potential benefit of APC ridership is identifying passenger load. Social distancing is a primary strategy to reduce viral transmissions, and transit agencies needed to account for accurate passenger spacing during the pandemic. Accurate ridership load tracking was required to monitor passenger crowding and maintain safe practices by dispatching a second vehicle during high use periods.

Passenger counting works by installing a people counter sensor over each door. The sensors detect the passengers as they enter and exit. Passenger counts can then be instantly transferred to the cloud platform as actionable reports, enabling instant real-time access to ridership information and data-based decision-making. With the reporting screens, instantaneous data can trigger real-time actions on a vehicle or route basis. At the same time, historical reports constitute the most important data used for route, vehicle, and stop optimization.

Figure 4 shows the components of the APC system. The centerpiece of the system is the network of sensors (smart sensor module) that count passengers. Depending on the configuration, in addition to in/out passenger counts, sensors can track the driver, bike rack usage and wheelchair users. Sensor data is aggregated by the central processing unit (CPU), which augments it with geo location coming from the GPS, timestamps it and sends it to the cloud via a WiFi or a cellular communication link.

Figure 4: High-level APC system configuration. Source: Urban Transportation Associates, Inc.



An APC system has four components:

1. Sensors that can be queried by a CPU;
2. CPU that adds GPS coordinates and timestamps to data obtained from sensors;
3. Communication link – WiFi and/ or cellular;
4. Software or services for data processing, data quality control, analysis, reporting and data dissemination.

Here, components 1 and 4 are APC specific, whereas components 3 and 4 can be provided by a system integrator. Some APC vendors (e.g., UTA) provide the full-stack APC solution consisting of all four components, as well as each component – sensors or software – separately. Others (e.g., Iris), sell only sensors, whereas the other components should be provided by the system integrator.

APC Sensors

APC sensor technologies include:

- **Infrared lights**. These are active sensors, which have a transmitter and a receiver. It creates a series of rays of infrared light, forming a beam. These lights are placed above the doorways of the vehicles. When these rays shine down, they form a beam of light. With every person entering or exiting the vehicle, the beam gets broken.

- **3D time-of-flight cameras**. Mounted above the doors and facing down, this camera works as a LiDAR – by illuminating the scene with a modulated light source and observing the reflected light. The phase shift between the illumination and the reflection is measured and translated to distance.
- **Light beams inside the doors**. A way to measure the number of people in the vehicle is to install a light barrier in each door. Depending on the deviation from the undisturbed state, the system recognizes whether a person has entered or left the vehicle. Measuring in and outflow at each stop the total number of passengers can be measured during a journey the vehicle.
- **Treadle mats**. These are floor mats with pressure sensors built in them. They are placed on the floor or access steps at the entrance/doorways of the vehicle. The mats sense the pressure difference when someone steps on it. However, the data collected using Treadle Mats might be incorrect when the vehicle becomes too crowded.
- **Security cameras inside vehicles**. Security cameras are often already installed for safety reasons in public transport vehicles. The primary use case of the cameras is to provide evidence in crime investigations and to prevent crime. However, with modern image processing the video data can also be used to evaluate vehicle occupancy. Unlike cameras inside doors, which count inflow and outflow, the number of people is directly captured by the camera. This has the advantage that measurement errors do not accumulate over time.
- **Pressure sensors inside the seats**. One can measure occupancy using pressure sensors in the seats. If a seat is occupied, the sensor sends a signal to the associated control unit. Disadvantage of this method is that only the load of the seats is considered, while at peak times the majority of passengers are standing. Furthermore, the cost of such a system is relatively high because each seat must be equipped with a sensor.
- **Measuring mobile signals**. Most people carry mobile devices such as smartphones which are emitting signals such as WiFi, Bluetooth or LTE. Measuring these signals one can infer the number of people inside the vehicle. However, some people carry multiple devices or no devices at all, which reduces the accuracy.
- **Ticket apps**. Ticket applications on smartphones of customers can be used as a source of information for passenger counting. However, in rural areas as well as in tunnels internet connection and GPS location might be bad or distorted making it hard to measure the occupancy of single vehicles. As long as there is analog ticket distribution, the information obtained from ticket apps remains incomplete.

- **Weigh-In-Motion**. The Weigh-In-Motion or the WIM system is another way of using Technology in counting passengers. This system counts passengers by calculating the weight difference in the vehicle before and after stops. One must know the vehicle's overall weight, including the driver's weight and the weight of the fuel in the tank. With these, the actual difference in weights at different stops can be computed, using which, one can find out how many people alighted and got off from the vehicle.

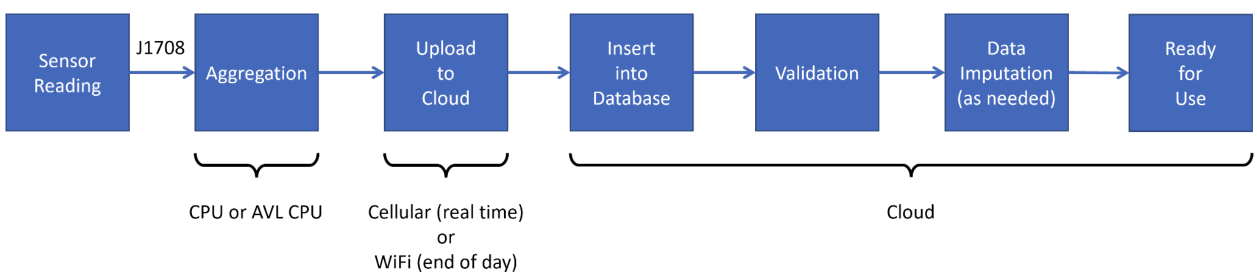
The first two from this list constitute the current state of practice and are estimated to be 98% accurate. Both technologies are well developed, and the vendors compete not over a better accuracy, but rather over convenience of installation, adjustability, angle flexibility, integration options and technical support.

Light beams are considered to be an outdated technology, which, however, is still widely used. Its accuracy is also quite high – above 95%. Treadle mats are considered to be an obsolete technology, although still widely used. The use of security camera footage for passenger counting is hindered by privacy concerns. And, the remaining sensor technologies can provide only estimated passenger numbers – these are good enough for qualitative comparison of certain transit stops or routes, but are inadequate for precise passenger count collection.

APC Data Flow

Figure 5 shows the APC data flow.

Figure 5: APC data flow diagram.



CPU collects data from sensors via a serial communication bus through polling. Polling can be done at regular time intervals, e.g. 30 seconds; or at bus stop locations for the time period, during which at least one door was open. An APC data record consists of:

- Begin time;
- End time;
- Door number;
- In count;
- Out count.

There is no standard defining the format of this record. Data may come as text strings with comma-separated values (CSV) or in some vendor-specific JSON format.

CPU snaps the APC data record to a GPS location and either uploads it to the cloud right away or stores it for a later upload. Real-time upload occurs through a cellular modem. Some transit providers, however, save money on cellular plans and upload APC data to the cloud once a day, when the bus returns to the garage – through their WiFi link.

After reaching the last stage – "Ready for Use" – the process usually stops. It does not have to, though: APC data could then be packaged using General Transit Feed Specification (GTFS), more precisely, GTFS Real Time (GTFS-RT),[1] standard format and made public.

Caltrans division Cal-ITP is working with transit providers to reach universal coverage of publishing transit information via GTFS and GTFS-RT. Cal-ITP is helping providers publish high-quality GTFS feeds for both GTFS Static – which includes schedule and stop location information – and GTFS Realtime – which includes up-to-date arrival and departure information – so riders can easily access complete, accurate, consistent, and timely mobility data for their trip through popular mapping applications such as Google Maps, Apple Maps or Transit App.

To reach universal GTFS Realtime coverage, Cal-ITP is assisting transit providers in negotiating with their existing vendors to upgrade their services and has also developed an open-source smartphone app that allows transit providers to easily publish real-time information with minimal upfront costs or technical expertise required. Cal-ITP is currently offering this innovative software program, called GTFS-RT as-a-service (GRaaS), for free to interested transit providers. GRaaS could potentially be used to provide passenger counts together with bus locations in real time. Looking forward, GRaaS could also include bicycle rack occupancy, wheelchair occupancy and stroller count.

Essential Elements of an Effective APC System

According to Urban Transportation Associates, Inc. (UTA), an effective long-lasting APC system with real-time capabilities depends on six essential elements listed below. Weaknesses or deficiencies in any of these elements will have a direct negative impact on the performance of the APC system.

APC On-Bus

1. **Accuracy**. APC on-bus equipment (passenger counting sensors, GPS receiver, CPU) must provide accurate information. Evaluation of each of these on-bus sensors should take place at the initial implementation. Passenger counting sensor accuracy should be within +/- 5% of manual observations with significant sample sizes. Time and location should be thoroughly checked. Typically, a disproportionate amount of focus is placed on APC sensors. Generally, however, APC sensors achieve above 95% accuracy. It is identifying and resolving the unique failure modes of each APC sensor that determines the level of system effectiveness.

2. **Reliability**. On-bus APC equipment needs to operate reliably over the life of the vehicle. Requirements for APC system reliability are typically missing in APC procurement specifications. It is common, however, for APC sensors to perform well in an initial acceptance test but begin to malfunction shortly after the acceptance testing.

[1] It must be noted that Oregon DoT is developing the GTFS-ride standard – specifically to encode ridership information. However, as of 2022, GTFS-ride is used only by a few transit agencies in Oregon.

APC Cloud

3. **Analytics**. A successful APC system implementation must provide local transit staff with a comprehensive set of analytic reports, plots and APC file exports. The APC analysis software should utilize local schedules and geo-coding with minimal setup effort. The APC analytics should be easily auditable and provide substantiated transparency. All APC data and analytics should be easily accessible throughout the organization. Software tools should be adaptable for ad-hoc analytic requests which include all possible spatial and temporal levels of resolution. The design of the APC data architecture should allow for flexibility in responding to non-routine analytic tasks.

4. **Administrative control**. APC systems should contain self-monitoring capability that provides the users with an accurate assessment of the performance of the APC system including specific conditions which require repair/resolution. The Administrative control software should include the quality check of APC reference files such as schedules and geo-coding. APC diagnostics should provide daily actionable information on any APC-related malfunctions that impact APC data quality/quantity.

APC maintenance

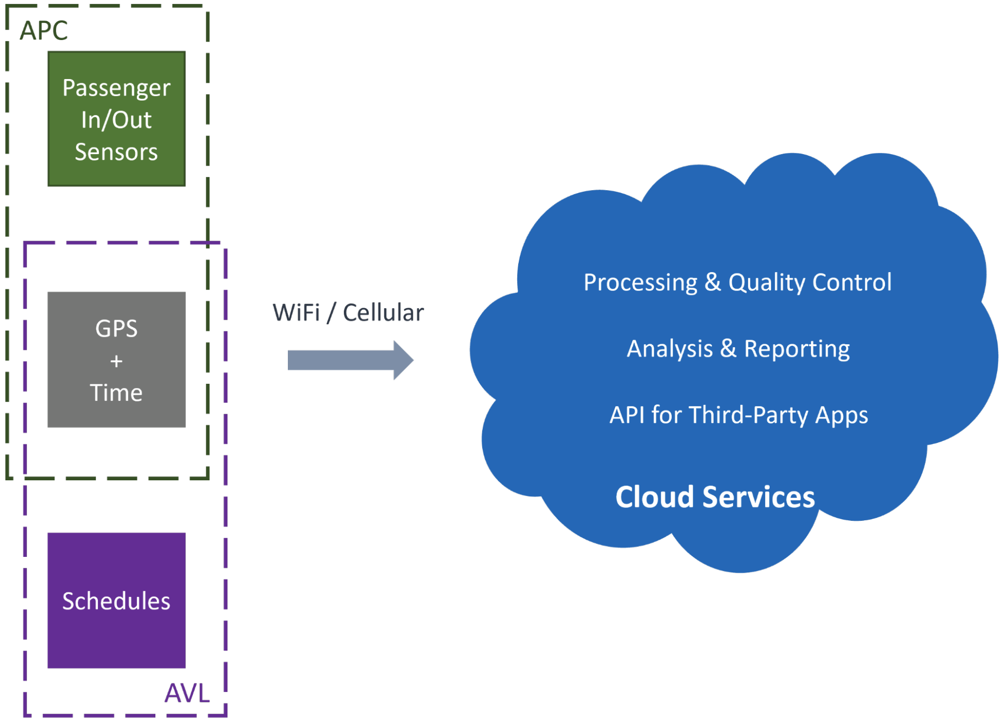
5. **Promptness**. Any APC-related malfunction identified from the APC administrative control process should be promptly addressed to minimize the negative impact on APC data.

6. **Effectiveness**. The corrective actions for APC failures identified from the APC administrative control, such as: equipment malfunctions, reference file errors, data processing interruptions, etc., should be successfully corrected. Detailed APC training and documentation addressing APC problem resolution should be present.

Deployment of APC – Use Cases

Transit providers install APC and automatic vehicle location (AVL) systems in their vehicles. Figure 6 shows the combination of data needed for both.

Figure 6: APC and AVL data.



APC systems can be deployed in two ways:

1. Standalone – when APC data are aggregated and uploaded to the cloud separately from AVL, and the subsequent processing, quality control, analysis and reporting is conducted on APC data separately from anything else.

2. As part of an AVL system – when an AVL vendor acts as a system integrator incorporating APC into their solution. In this case, a CPU in Figure 4 is a CPU of an AVL system.

Availability of Real-Time APC Data

About 30% of California transit providers upload their APC data to the cloud via WiFi once a day when buses return to their garages. The others do it directly from bus stops via cellular communication, and thus, have a capability of reporting their passenger counts in real time. Yet, none of the agencies provide their APC data in real time. The main reasons cited are:

- Not all buses are equipped with APC, and APC data is lacking on 15-25% of the bus fleet.
- Some buses report incorrect APC numbers due to malfunctioning equipment.
- Data processing pipeline (the cloud part) is very involved and takes up to several days to perform clean-up.
- Different parts of the bus fleet are equipped with APC/AVL systems from different vendors with different data processing pipelines.

These can be summarized as: **APC data quality concern**. Agencies are unwilling to publish APC data that may have errors. The sources of these errors are:

1. Malfunctioning on-bus equipment – sensors, GPS or CPU – and a failure to detect malfunctions.

2. Software bugs on the level of on-bus CPU or cloud processing routines. This is common when APC is present as a component of a larger AVL system. There is plenty of anecdotal evidence of AVL software skewing APC data. Similarly, proprietary in-house software maintained by transit providers or their consultants may skew the original APC data.

Both reasons can be eliminated through tight **APC data quality control**, which is lacking in most deployments.

APC Data Quality

Transit providers are governed by National Transit Database (NTD) reporting requirements that ensure their APC certification by the Federal Transit Administration (FTA). The APC certification checklist consists in:

- Agency's APC vendor;
- The date APC system was installed (can be approximate);
- The NTD Report Year in which the agency plans to begin reporting APC data;
- The mode and type of service that will use APC data;
- The number of vehicles in the fleet;
- The number of these that are APC-equipped;
- The number of trips agency sampled for your benchmarking study;
- A description of how agency selected the trips to sample;
- A description of agency's survey procedure, including information such as whether agency used video or sent in-person ride checkers, and how many checkers agency had on each vehicle;
- Confirmation that the agency plans to repeat the benchmarking survey in Fiscal Year 2022 (2025, 2028, etc.);
- The percentage of trips during agency's last fiscal year that did not return valid APC data for any reason (can be a reasonable estimate based on a sample);
- A list of common reasons why a trip would not return valid APC data;
- A description of agency's method for using APC data to determine annual totals;
- The total manually collected unlinked passenger trips (UPT) in the sample;
- The total APC-collected UPT in the sample;
- The total manually collected passenger-miles traveled (PMT) in the sample;
- The total APC-collected PMT in the sample.

FTA must approve the following for agencies to report APC data:

- APC benchmarking plan for the first year;
- APC maintenance plan every three years, beginning in 2019.

The APC benchmarking plan and maintenance plans must include:

1. Validation of the APC data for UPT and PMT data against a manual sample:
    a. Agencies operating 30 or fewer active vehicles must sample at least 15 trips.
    b. Agencies with greater than 30 active vehicles should sample, at least, the larger of 15 trips or half of the number of APC equipped vehicles, up to 50 trips. These numbers represent the smallest acceptable sample. Agencies may perform larger samples at their discretion.
    c. The trips sampled for the manual sample do not need to be randomly selected and can be spread out over any period within the same year. The sample should include heavy ridership trips and at least one trip per vehicle type and APC model.

2. A description of the agency's APC system.

3. A description of the agency's sampling procedures.

4. A list of trips that were flagged and rejected from the sample with explanations for each. The explanation cannot be that the trip was rejected because it was different from the manual data.

5. The percentage of trips that do not have valid APC data over the course of a typical year, either because the APC malfunctioned, the data were corrupted, the data failed a validation check, or for any other reason.

6. Descriptions of the differences (if any) in the set of distances between stops (e.g., interstop distances) the agency used to calculate PMT using manual and APC data. Ideally, the agency will use the same set of distances for both calculations.

7. The following metrics, both of which must be less than 5 percent:
    a. Percent Difference of manual vs APC UPT.
    b. Percent Difference of manual vs APC PMT.

Generally, transit providers limit themselves to these requirements and declare the APC question resolved. In comparison, the Association of German Transport Companies (Verband Deutscher Verkehrsunternehmen – VDV) developed a comprehensive guideline for APC system deployment, data collection and maintenance, known as Recommendation 457.[2] This document contains the requirements for APC systems and their data quality.

[2] VDV Recommendation 457: https://dms.vdv.de/mitglieder/Documents/457__V2.1_SES.pdf

In Germany, transit agencies report accurate passenger data to essentially ensure their share of ticket revenue. For example, public transport services in Berlin (and Brandenburg) are provided by around 40 companies organized in the Transport and Tarif Association of Berlin and Brandenburg (VBB), which provides operator-spanning tickets, e.g. single day or monthly passes. Public transit is coordinated through a single, integrated system based on zones. One ticket can be used to travel between multiple zones, no matter which method of transit you take.[3] The tickets are sold by the transport association, and revenue, as well as subsidies, are distributed among the transport companies, which accounted for 12.8 billion EUR in 2017. Since passenger data is commonly used for revenue sharing, it's crucial to provide accurate and validated data, especially since small errors can have a large impact. To illustrate, even though passenger counts would account to only 10% of the shared revenue, if just one of the above-mentioned companies somehow systematically counted 1% too few, and another one 1% too many passengers, two million EUR would be distributed inappropriately – every year, for these two companies operating in the Berlin area alone.[4]

NTD reporting does not require high quality real-time APC data. Yet, APC data quality control is what currently suffers, and inconsistency between real time passenger counts and what's later reported to FTA is cited as one of the main reasons why APC data are not made public by transit agencies.

In the United States there currently is no method to validate and incentivize reporting accurate data. Currently, each transit agency in the Bay Area operates separately and therefore each takes on the associated costs. Following the European model, transit agencies in the Bay Area could share the cost of resources with one another, to not only increase their margins, but also provide accurate passenger data. Ubiquitous use of APC data, coupled with standards, protocols, and algorithms, would take billions of dollars of capital expenditures out of the picture.

Accurate, verified APC data opens the door to massive resource efficiencies that are much needed to bring quality of service and ridership to desirable levels in regions like the Bay Area. Demand-based revenue sharing between interconnecting agencies could be achieved. With validated APC data, revenue sharing would be based on ridership levels easily traceable back to the individual vehicle. The cost sharing and inter-agency accounting required for such an approach is already in practice today. Furthermore, the data would allow agencies to eliminate redundant vehicles and sub-optimal routing. For example, three agencies with adjacent popular bus routes could in effect share the cost of a single set of buses run on a single, long route without transfers or additional station infrastructure, thus significantly reducing capital expense and recurring maintenance costs. Furthermore, travel times would be significantly reduced, interconnection delays would be eliminated, at a massive service to the riding public. Enabling long-route "rail like experience" for riders would also provide some leeway to local transit agencies to focus on more dynamic short-route local services that work for commuters, shopping, and other use cases.

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[3] Public transportation in Germany: U-Bahn, S-Bahn, tram & bus.

[4] Sibert & Ellenburger, Validation of Automatic Passenger Counting: Introducing the t-test-induced equivalence test, 2019

Incentives for Accurate Real-Time APC

What could be the motivation for a transit agency to provide real-time passenger counts and maintain a high level of APC data quality? The use cases where real-time APC adds value include:

1. Self-assessment for operations planning, which includes vehicle capacity adjustment, route adjustment and service frequency adjustment; and reporting. It is a current main use case, and generally does not require real-time data.
2. Bus equipment adjustment. Current APC technology provides more information than just passenger counts. APC sensors can reliably distinguish between passengers, baggage, and objects like wheelchairs, bicycles, or strollers. This allows for a more reliable determination of the space required in the vehicle and the implementation of wheelchair access ramps as needed.
3. Real time transit occupancy information for travelers. This use case became widely discussed during COVID-19 pandemic.
4. Traffic Signal Priority (TSP) – signal priority can be given to selected buses based on their real-time passenger counts.
5. Route coordination between transit providers and establishing connection points.
6. Connection protection – extend waiting time based on real-time passenger counts.
7. Combination of APC and fare collection data (e.g., Clipper card) gives a full picture of transit ridership. Fare collection gives travel patterns, while APC gives volumes, which produce the scaling factor. As a result, one can obtain origin-destination (OD) patterns with routes and modes by time of day.
8. Inverted "Next Bus" – Next Stop: how many passengers with what destination to expect at the next stop? This information can also be used for TSP.
9. Coordination of connections with other transit agencies and transportation network companies (TNCs).
10. As energy becomes more expensive, optimization of energy use based on passenger counts will become more and more important.
11. Vehicle maintenance and cleaning can be optimized based on the number of transported passengers.
12. Profits from transport advertising. Transportation companies that provide advertising services on their vehicles can share the passenger counts with ad agencies to encourage

them to advertise on their vehicles and determine their impact. Advertisers can also select specific routes and vehicles with higher occupancy rates to achieve higher impressions.

13. Control over payment systems and ticketing. By comparing the number of sold tickets with the number of people counted, transport providers can cross-check and have more control over ticketing systems to ensure transparency and avoid any discrepancies.

Recommendations

For Transit Agencies

1. It is often the case that an APC system enters as a component of an AVL deployment, so that passenger counts are processed and reported through the AVL system. However, a standalone APC deployment with cellular data transfer and APC software hosted in the cloud provide the highest level of APC system performance in the long-term. This approach enables real-time fault detection in APC sensors and AVL systems. And, in the case of AVL software bugs, it makes it possible to re-process and correct the data.

2. APC systems are often purchased by procurement committees consisting of a maintenance person, an operations person, a finance person, an IT person or an engineer and, maybe, a planning and scheduling person. Yet, planners and schedulers are the main users of the APC data. Thus, it often happens that the main user has a very minor voice in the procurement committee. The actual users of the APC data must oversee selecting the vendor and setting up the requirements.

3. Requirements for APC systems are often copied and pasted from other or previous procurements, especially the requirements concerning the IT portion of the system. This should be avoided. Requirements should be generated by the users of APC data, not by the IT personnel.

4. Ask your APC vendor what their biggest concern is should they win your contract.

For Government Agencies

5. Technical capabilities of current APC and AVL technologies far exceed the present requirements of the NTD reporting. FTA could consider demonstration projects addressing improved service productivity and data quality reporting.

6. Strategic goals of Caltrans include reduction of vehicle-miles traveled (VMT) and steering people toward shifting from private cars to public transport. As a part of this effort, Caltrans should assist local governments and transit providers in establishing transit hubs. And, to assess the modal shift, its dynamics and conditions, it needs to measure public transit ridership. In the absence of quality APC data from transit providers, one should turn to alternative data sources. These include automatic fare

collection (AFC) companies, mobile app vendors (e.g., Transit App[5], Swiftly[6]), mobile operators. Caltrans could set up a project exploring these alternative data sources and their assessment against actual APC data. Competition would also motivate transit providers to publish their APC data.

7. Caltrans and regional planning organizations could make the availability of high-fidelity APC data a condition for transit provider's participation in projects they fund and/ or coordinate. These APC data should be available in GTFS-RT and GTFS-ride format.

8. Regional planning organizations can initiate multi-agency pilot projects to demonstrate coordinated, shared route systems for passengers with shared revenue. Costs would be assessed based on stop locations, and revenue would be assigned based on proportional distance between them. This model could increase transit agency margins while also providing a coordinated system to benefit passengers. The passenger information exchange can be done through GTFS-RT and/ or GTFS-ride feeds.

Pilot Design

There are three categories of incentives for transit agencies to start publishing their APC data:

1. Force the agencies – for instance, by making it a funding requirement for certain projects.
2. Create a competitive environment for ridership data providers.
3. Show a potential for saving or gaining money using accurate real-time APC data.

The last category requires marketing research to find out which companies are willing to pay for real-time APC data.

Possible pilot projects that can be developed around the first two categories are described next.

Multi-Agency Coordination Pilot

Problem

To attract more people, public transit should offer a competitive alternative to private vehicles in terms of accessibility (should be close by, easy to use and affordable) and reachability – that is, the desired destination should be reachable within reasonable time from the moment one wants to start their journey. Individually, transit agencies do not address this problem. It requires an approach on the level of a regional transit system.

Potential Solution

Reachability could be improved through coordination between transit agencies. New connection points can be established, and efficiency of existing connections can be increased by increasing the frequency of service or by creating connection protection – when buses wait for connecting passengers. Coordination of transit agencies implies the exchange of accurate passenger information.

[5] https://transitapp.com
[6] https://www.goswift.ly

Participation
This pilot could be initiated and funded by a regional planning agency – It is their responsibility to improve the performance of the regional transit system. Two or more transit agencies can implement the coordination.

Success Criterion
The metric of success would be an increase in ridership on the coordinated transit routes and financial gains – revenue increase or saving because of certain cost sharing.

Alternative Ridership Data Sources Pilot

Problem
To ensure the sustainability of the transportation system in terms of congestion, environmental impact and equity, Caltrans' goals include: 1) encourage travel mode shift – from private cars to public transit; hence, 2) reduction of VMT; and, as a result, 3) reduction of congestion, more efficient energy consumption and cleaner air. The question is: how to quantify the mode shift and continuously measure the progress? For that, transit ridership data should be available.

Possible Solution
To analyze the mode shift, a continuous monitoring of transit ridership must be maintained. Trends should be analyzed, and their causes inferred. Transit agencies should be the best sources of accurate ridership data, but, unfortunately, they rarely share it in sufficient detail, let alone in real time. Thus, it makes sense to use indirect sources of such data. For example, information about transit ridership may come from fare collection, trip planning applications, cell phone tracking and, possibly, other sources. This information may be not as accurate as the one coming directly from APC systems, but it may be sufficient to infer ridership trends. This approach is scalable: one does not need to negotiate with individual transit providers about data sharing. Moreover, it creates a competitive ecosystem for ridership data exchange, in which transit providers may feel compelled to ensure accuracy of their passenger counts and to publish them.

Participation
This pilot could be initiated and funded by Caltrans and regional planning agencies. It could be made a part of mobility hub projects, where the effectiveness of mobility hubs needs to be measured. Participants can include AFC companies, mobile app vendors, mobile operators and anybody else capable of estimating transit ridership in real time.

Success Criterion
This project should demonstrate a viable business model for real-time transit ridership data providers. Data quality must be validated using ground truth observations obtained from transit agencies.

Platform Concept
Most currently deployed APC systems is adequate for the real-time passenger count publishing. Systems that are not, are unsuitable because APC data are uploaded from buses only once a day, generally via WiFi, as opposed to real-time upload via cellular communication. Once the cellular data upload is available, it is up to the process organization within a transit agency to augment GTFS-RT (or GTFS-ride) feed with passenger data.

An APC platform should consist in (see Figure 5):

- **Sensors**. Infrared lights and 3D time-of-light cameras are presently the top two passenger counting sensor technologies – they are considered state of the art. Aside from passenger counts, current APC sensors can count wheelchairs and strollers, monitor bike rack occupancy and the driver seat.

- **CPU**. Even if APC is deployed as a part of an AVL system, it is recommended that it could also work as a standalone deployment, where data are collected and processed independently of the AVL processor. This is useful for real-time data validation, detector fault detection and error detection in the AVL software.

  Remark: the interface between sensors and the CPU does not need to be standardized, just needs to be well defined.

- **Communication links** should be cellular – it should be independent of local WiFi routers to be able to upload data from any place with cellular coverage. Buses with AVL have this capability.

- **Cloud data processing** – cloud part of the workflow in Figure 5 – must work in real time.

- **Validation** should be performed to ensure that data adheres to some quality standard, like VDV 457.

- **GTFS-RT** and/ or **GTFS-ride standards** should be used for publishing real-time APC data. It would be beneficial if not just passenger counts, but also wheelchair, stroller and bike counts could be published.

Conclusions

The findings of this project can be summarized as follows:

- Present APC sensing technology is as good as it gets: it has 98-99% accuracy.

- APC technology provides more information than just passenger counts: sensors can reliably distinguish between passengers, baggage, and objects like wheelchairs, bicycles, or strollers.

- Present APC workflow allows real time publishing of passenger counts using GTFS-RT. The decision about real-time ridership reporting lies with a transit provider – technology is not an obstacle.

- Transit agencies cite these causes for not making ridership public in real time:
    a. "Raw" (aggregated from sensors) APC data is of poor quality and needs extensive processing, not possible in real time, before it can be published.
    b. Not all buses are equipped with APC, and data extrapolation is needed.
    c. APC data are uploaded from buses not in real time, but at the end of the day – when buses return to the garage.

- Poor data quality is the main cause. Given that APC sensors are highly accurate, passenger counts get skewed due to:
    a. Malfunctioning on-bus equipment – sensors, GPS, CPU, communication channels.
    b. Bad integration into an AVL system.

- APC data quality can be ensured through:
    a. Monitoring the health of on-bus equipment.
    b. Collecting APC data independently from AVL – to allow comparison and validation.
    c. Periodic validation against manual counts obtained from on-bus cameras.

- Maintenance of APC data quality needs investment that transit providers are generally unwilling to provide. The APC problem is solved for them as soon as they can produce ridership data good enough for NTD reporting.

- Incentives are needed for transit agencies to improve their APC data for real-time publishing. This report provides a list of potential use cases of APC data, but roughly they fall into three categories:
    a. Forcing the agencies to make improvements through tightening of the FTA requirements for NTD reporting by establishing an APC quality standard similar to the VDV 457 used in Germany. And/ or, make funding of certain projects for transit agencies contingent on their commitment to provide real-time APC data.

b. Creating a competition for transit ridership data providers by using alternative data sources including AFC companies, mobile app vendors and mobile operators.
c. Indicating ways of money saving or a commercial value of APC data.

- Possible pilot projects can be developed around these incentive classes.

Appendix: APC Vendors

The table below contains companies that position themselves as providers of APC technologies. However, we distinguish those who focus on APC from those who treat APC as just a component of an AVL system. By APC hardware we mean APC sensors, and by APC software – on-bus CPU firmware and cloud software for processing, validation, analysis and reporting.

Vendor	APC hardware	APC software	AVL & integration
Avail Technologies, Inc.		✓	✓
BEA, Inc.	✓		
Clever Devices Ltd.	✓	✓	✓
Conduent			✓
Connexionz	✓	✓	✓
DILAX Systems, Inc.	✓	✓	✓
DoubleMap	✓	✓	
Hella Aglaia	✓		
INIT Innovations in Transportation, Inc.	✓		✓
Iris	✓		
NextBus	✓	✓	
Passio	✓		✓
Syncromatics	✓	✓	✓
TransLoc		✓	
Trapeze Group		✓	✓
TripSpark	✓	✓	
TSO Mobile	✓		✓
Urban Transportation Associates, Inc.	✓	✓	

Glossary

American Public Transportation Association (APTA) – a nonprofit group of approximately 1,500 public and private sector member organizations that promotes and advocates for the interests of the public transportation industry in the United States.

Automatic Passenger Counter (APC) – a system of sensors that count passengers boarding and alighting transit vehicles.

Automatic Vehicle Location (AVL) – technology to automatically determine and transmit the location of a vehicle.

Central Processing Unit (CPU) – the hub that processes and combines data from other ITS components to create meaningful correlated data.

Comma Separated Values (CSV) – a delimited text file that uses a comma to separate values. Each line of the file is a data record. Each record consists of one or more fields, separated by commas. The use of the comma as a field separator is the source of the name for this file format.

Federal Transit Administration (FTA) – an agency within the United States Department of Transportation (DOT) that provides financial and technical assistance to local public transportation systems. The FTA is one of ten modal administrations within the DOT. Headed by an Administrator who is appointed by the President of the United States, the FTA functions through Washington, D.C headquarters office and ten regional offices which assist transit agencies in all states, the District of Columbia, and the territories.

Global Positioning System (GPS) – a satellite-based radionavigation system owned by the United States government and operated by the United States Space Force.

General Transit Feed Specification (GTFS) – defines a common format for public transportation schedules and associated geographic information. GTFS "feeds" allow public transit agencies to publish their transit data and developers to use that data to write applications.

GTFS Real Time (GTFS-RT) – a GTFS extension that enables ending real time information about bus location and occupancy, trip updates and service alerts.

GTFS-RT as a Service (GRaaS) – software developed by Caltrans division Cal-ITP to promote GTFS among transit providers.

GTFS-ride – an open, fixed-route transit ridership data standard that allows for improved ridership data collection, storing, sharing, reporting, and analysis.

Light Detection and Ranging (LiDAR) – a method for determining ranges (variable distance) by targeting an object or a surface with a laser and measuring the time for the reflected light to return to the receiver. It can also be used to make digital 3-D representations of areas on the earth's surface and ocean bottom by varying the wavelength of light. It has terrestrial, airborne, and mobile applications.

National Transit Database (NTD) – formed in 1974, it is a federal reporting program for transit agencies receiving Federal Transit Administration (FTA) funding. It serves as a primary repository for all transit-related data and statistics in the United States. The performance data from the NTD is used to allocate FTA funding and to report on public transit performance to Congress and researchers.

Passenger Miles Traveled (PMT) – the cumulative sum of the distances ridden by each passenger.

Transportation Network Company (TNC) – a company that, via websites and mobile apps, matches passengers with drivers of vehicles for hire that, unlike taxicabs, cannot legally be hailed from the street.

Transit Signal Priority (TSP) – a general term for a set of operational improvements that use technology to reduce dwell time at traffic signals for transit vehicles by holding green lights longer or shortening red lights. TSP may be implemented at individual intersections or across corridors or entire street systems.

Unlinked Passenger Trips (UPT) – total boardings on an individual vehicle. "Linked trips" refers to the total number of riders and measures the actual number of complete trips from origin to destination, including transfers. Unlinked trips are viewed as a measure of transit utilization (at the system, route, or subroute level), while linked trips are used to measure revenue passengers. The ratio of unlinked to linked trips indicates the relative usage of transfers in the transit system.

Vehicle Miles Traveled (VMT) – a measure used extensively in transportation planning for a variety of purposes. It measures the amount of travel for all vehicles in a geographic region over a given period.