

[Additional & Expanded Doors](#) . [Open-Layout Buses](#) . [Articulated Buses](#) . [Other Notes](#)

## **Bus Layout**

Amplify gains from boarding improvements by facilitating movement of riders at stops while maintaining comfort while traveling

# Additional & Expanded Doors

Purchase articulated buses with four or five wide-door sets only.

Purchase 40 foot buses with three wide-door sets as old buses are replaced.

## EXISTING CONDITIONS

Although articulated buses could ease capacity problems, they would maintain or exacerbate speed and reliability concerns without concurrent door design changes.

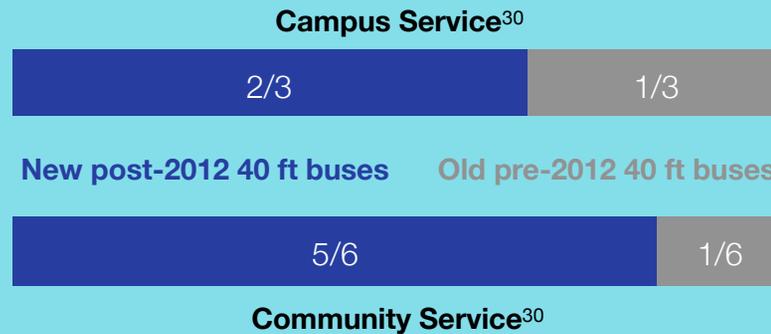
## NEW ADVANTAGES

Articulated buses will replace two existing buses with two doors each on the VE and RC routes, so an articulated bus with three doors will mean a reduction in doors overall. Four of five door set articulated buses would allow for equivalent or better than existing boarding times. All-door boarding [ [see](#)



Three door 40 foot bus in Helsingborg, Sweden; common across Europe

Narrow rear doors and seats blocking the rear exit [ [see Open-Layout Buses](#) ] on old 40 foot buses slow alighting, especially on Loop routes which disproportionately get old buses, presumably because passengers are not paying a fare. **In a study of 329 CATA stop dwell times, post-2012 New Flyer and Gillig 40 foot buses had 7.6% lower dwell times than their older 40 foot bus counterparts, and those buses on Loop and Link routes had 8.4% lower dwell times.**<sup>29</sup>



<sup>29</sup> With the caveat that type of bus was not randomized for each trip. See [appendix](#) for raw data.

<sup>30</sup> With the caveat that route and time of day were not randomized for each trip. From 90 campus service trips and 24 community service trips on 40 foot buses. See [appendix](#) for raw data.

## 40' 2 Door

Common in N America

## 40' 3 Door

Common in Europe<sup>31</sup>

Current Worldwide Use

Capacity (New Flyer Xcelsior model)

83

more than 83

Approx max distance between doors

20 ft

20 ft

Approx distance to last door from back of bus

13 ft

NA

Passengers per alighting door

41.5

27.67

New Flyer Xcelsior Specifications

Standard

Not Offered

### All-Door Boarding



minimum proposed



proposed

Suggested CATA Use

Passengers per boarding door

41.5

27.67

### Front-Door Boarding



existing



discouraged

Suggested CATA Use

Passengers per boarding door

83

83

Proof-of-Payment & All-Door Boarding ] is also required for the number of boarding doors to be equivalent between two 40 foot buses and one articulated bus. Where articulated buses will replace one 40 foot bus, four or five doors are still important to allow for increased ridership due to higher capacity without increased dwell times.

Three door 40 foot buses can be used on Loop routes, to increase internal passenger movement and capacity without articulated buses, which would increase capacity but might come with reduced frequency.

Doors create more standing room and less room for seating which increases capacity, and adding doors is not passenger-hostile whereas removing seats with nothing to replace them could be seen as passenger-hostile.



Three door 60 foot bus in New York City with unfortunately narrow middle and rear doors

## 60' 2 Door

## 60' 3 Door

## 60' 4 Door

## 60' 5 Door

Current Worldwide Use

Outdated in N America<sup>31</sup>

Common in N America

Common in Europe<sup>31</sup>

Common in BRT systems

Capacity (New Flyer Xcelsior model)

123

more than 123

more than 123

more than 123

Approx max distance between doors

40 ft

20 ft

20 ft

17 ft

Approx distance to last door from back of bus

13 ft

13 ft

NA

NA

Passengers per alighting door<sup>32</sup>

61.5

41

30.75

24.6

New Flyer Xcelsior Specifications<sup>33</sup>

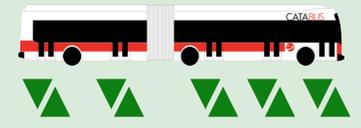
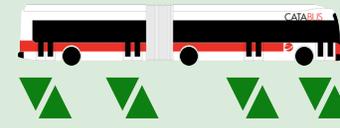
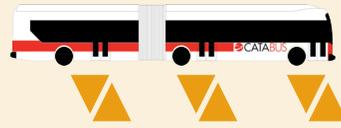
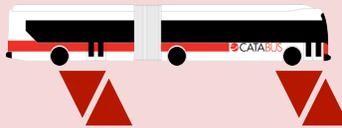
Standard

Standard

Option

Option

### All-Door Boarding



Suggested CATA Use

**discouraged**

**minimum proposed**

**proposed**

**future potential BRT**

Passengers per boarding door<sup>34</sup>

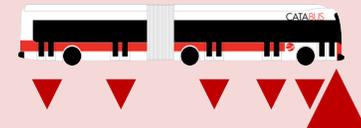
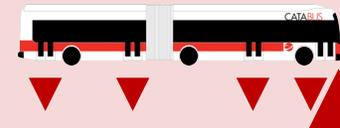
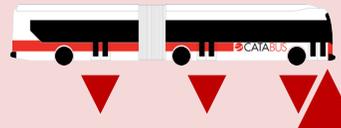
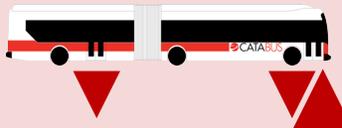
61.5

41

30.75

24.6

### Front-Door Boarding



Suggested CATA Use

**strongly discouraged**

**strongly discouraged**

**strongly discouraged**

**strongly discouraged**

Passengers per boarding door<sup>34</sup>

123

123

123

123

## STRATEGY OPTIMIZATION

Ensure doors are as wide as possible to reduce friction of passenger movement and allow multiple people to board and alight simultaneously, like the rear doors of existing CATA New Flyer and Gillig buses.

Work with international or national manufacturers to produce three-door 40 foot buses for sale to all United States transit agencies to reduce unit cost.

## OPPORTUNITIES & POSSIBILITIES

Explore adding buttons for opening doors and wheelchair ramps inside and outside the bus so doors do not have to open when there are no passengers using the door, and bus operators do not have to control opening and closing all doors.

Electric powered buses could more easily accommodate a third door at the back of the bus [ [see electric powered buses](#) ].<sup>35</sup>



*Four door 60 foot buses in Oslo, Norway with buttons for opening doors and wheelchair ramps outside the bus*

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<sup>31</sup> [Alon Levy, "The Dynamics of Bus Bunching," Pedestrian Observations, August 18, 2018;](#) ["Exqui.city," Van Hool, March 30, 2018.](#)

<sup>32</sup> ["Xcelsior: Choose Your Way Forward," New Flyer Industries, September 2017.](#)

<sup>33</sup> Passenger volume per door calculated by dividing average capacity by number of doors. Articulated buses would be less crowded as a percentage of their maximum capacity than 40 ft buses at the same ridership, but reduction in number of buses on routes (specifically VE and RC tripper buses) and induced demand from faster buses with higher capacity (specifically on Loops) will mean trips at capacity will increase ridership and stay at or near capacity with articulated buses. However, boarding and alighting times grow exponentially with crowding, so less crowded articulated buses would have significantly less dwell time.

<sup>34</sup> Actual passenger volume per door will vary between doors. For example, more passengers will exit at doors in the middle of buses rather than at the ends because the middle doors are closer to more space inside the bus. Additionally, more passengers will board via front and middle doors than rear doors because when unprompted, passengers generally wait at the front of stop platforms. This effect is more pronounced on buses with fewer doors and on larger buses operating routes which are also served by smaller buses because the front doors are the only ones which predictably stop at the same place.

<sup>35</sup> ["The Mercedes-Benz Citaro Goes Electric," Mercedes-Benz, March 30, 2018.](#)

# Open-Layout Buses

*Increase capacity and space for internal passenger movement in new buses by changing seating and removing chokepoints.*

## EXISTING CONDITIONS

Chokepoints on post-2012 New Flyer and Gillig buses create uneven crowding and limit internal passenger movement.

Express buses can not stop on Atherton St because riders take too long to alight from crowded buses.

## NEW ADVANTAGES

More open spaces and fewer chokepoints, in addition to more doors [ see [Additional & Expanded Doors](#) ], allow for more efficient internal passenger movement at stops, decreasing stop dwell time. Passengers can more easily alight crowded buses, allowing express buses to stop on Atherton St. Easier alighting also makes a hub on Atherton

## SEAT LAYOUT

There are four typical seating arrangements which can be used together to balance comfort and capacity.

[ A ] **Double/double forward-facing seats** provide the most seated capacity but provide the lowest overall capacity when standees are counted. The narrow aisle significantly slows movement, even when the bus is not crowded. This arrangement should be used away from doors for passengers going long distances.

[ B ] **Aisle-facing seats** are undesirable because of middle seats, which force some riders to sit between two strangers.<sup>36</sup>

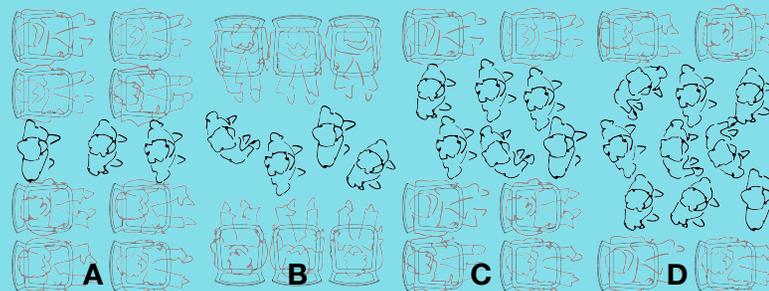
**Additionally, only one staggered row of riders is able to stand because sitting riders must have space for their legs and expect**

**slightly more personal space in front of them than they would from someone standing to their side.**<sup>37</sup>

These seats work well as folding seats over spaces for wheelchairs and in spaces without the length necessary for front-facing seats.

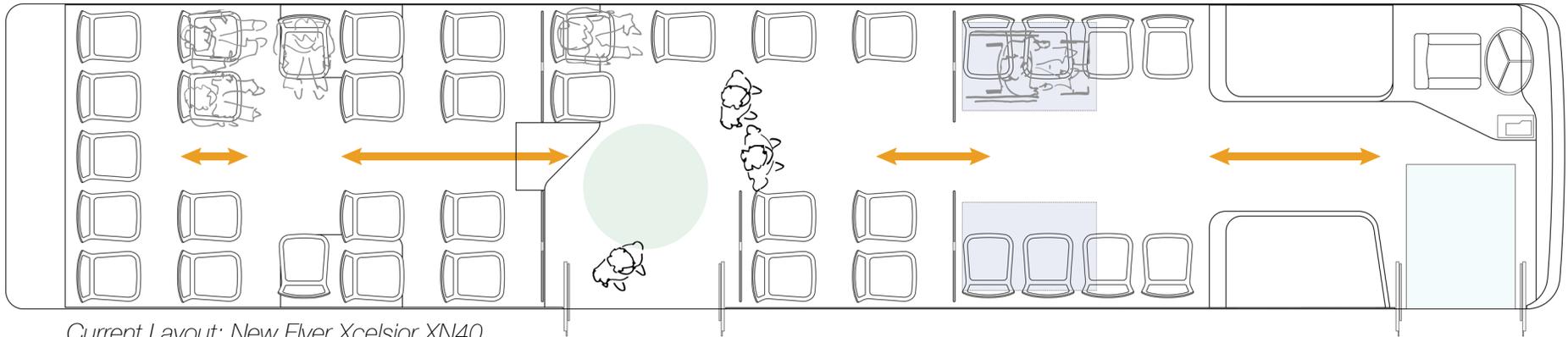
[ C ] **Double/single forward-facing seats** allow two people to stand next to each other. This arrangement balances seating and standing capacity, but the same balance can be achieved with different seating in two separate sections of the bus.

[ D ] **Single/single forward-facing seats** provide the most capacity of any arrangement: three standees can stand next to each other, slightly staggered. Single forward-facing seats are preferred by most single riders.<sup>37</sup> This arrangement allows for passenger movement and is especially useful near doors.



<sup>36</sup> Keith Barry, "The Ideal Subway Seating Arrangement? No Middle Seats," Wired, Condé Nast, April 16, 2013.

<sup>37</sup> Bjorn Swenson, "The Space Fallacy of Aisle-Facing Seating," Seattle Transit Blog, September 23, 2014.



Current Layout: New Flyer Xcelsior XN40

at Blue Course [ see Atherton Hub ] more efficient.

### TWO DOOR MODIFICATIONS

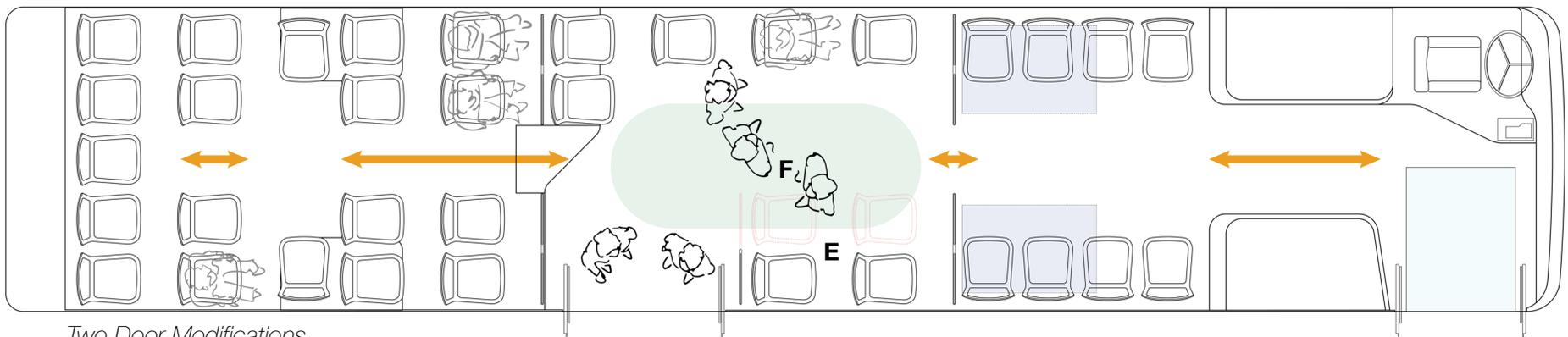
Two seats and a partition [ E ] can be removed from existing buses to create a large open area in the middle of the

bus, allowing for increased capacity and easier passenger movement at stops.

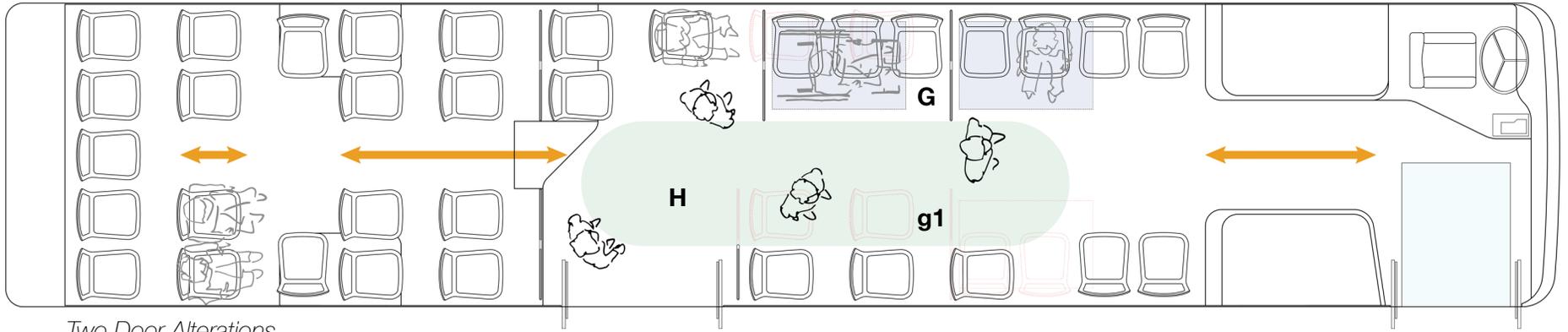
Single seats are more valuable than each of their two seat equivalents because there is no possibility of sitting next to a stranger. Many double seats are used by only one rider until the bus

is relatively crowded, when standing capacity and movement are more important than seating capacity.

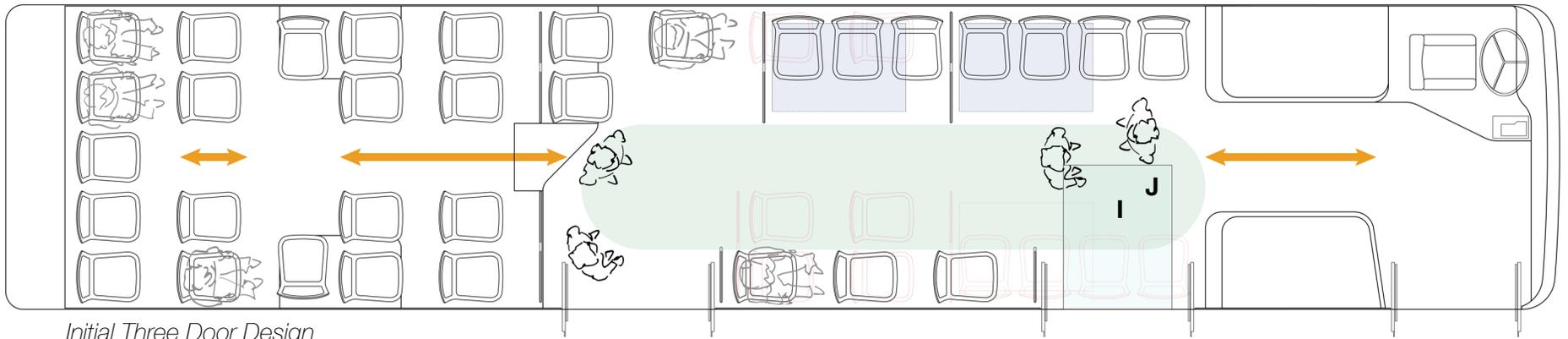
Open space for movement [ F ] will help especially with the implementation of all-door boarding [ see Proof-of-Payment & All-Door Boarding ], when riders will be boarding and alighting



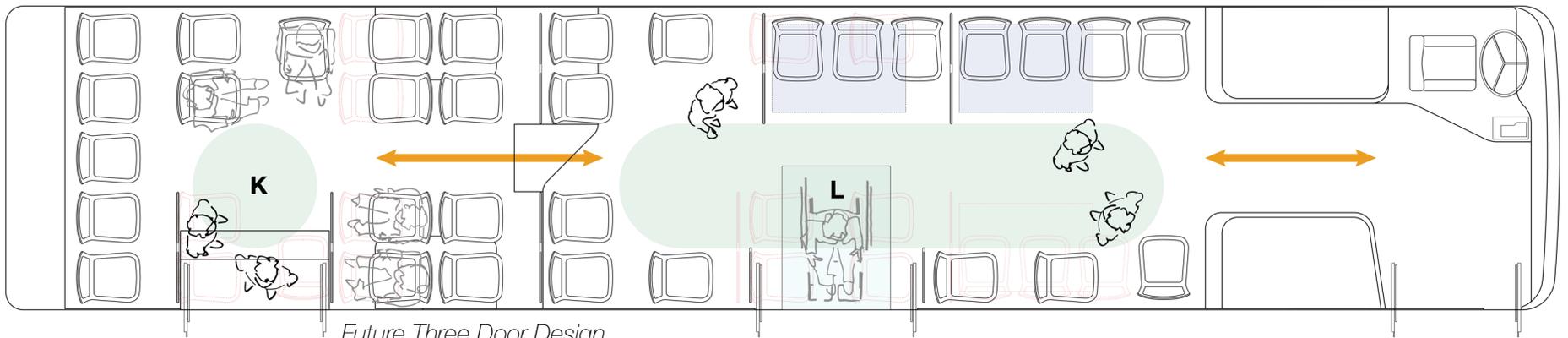
Two Door Modifications



Two Door Alterations



Initial Three Door Design



Future Three Door Design

from the middle door.

## TWO DOOR ALTERATIONS

New 40 foot buses should host an expanded open space with fewer chokepoints, to facilitate movement.

Both wheelchair spaces and aisle-facing seats should be moved to the left side of the bus [ **G** ],<sup>38</sup> clearing the right side of seats and partitions more than one seat-width wide [ **g1** ], and removing one chokepoint.

The wide middle door is able to continue and expand the open space [ **H** ] because there is little else in the way on the right side of the bus.

## INITIAL THREE DOOR DESIGN

To accelerate the introduction of three-door 40 foot buses in the US, the third door can be added between the existing doors [ **I** ], so no changes to the engine compartment below the high-floor area are necessary.

The third door is perfectly positioned for wheelchair ramp access [ **I** ] to the wheelchair spaces—which would

necessitate buttons for deploying those ramps [ [see buttons for door opening](#) ]—and expands the open space on the middle right side of the bus [ **J** ].

## FUTURE THREE DOOR DESIGN

The ultimate three door 40 foot bus design should include a third door at the back of the bus, as is used all over Europe.<sup>39</sup>

**A rear door allows passengers to continue moving back in the bus to increase capacity, without worrying that they will not be able to alight at their stop**, removes a chokepoint, and creates a small new open space for internal passenger movement [ **K** ].

The middle door, with wheelchair ramp, should be placed directly in the middle of the bus [ **L** ], to minimize the distance passengers are from the nearest door.

Electric powered buses could more easily accommodate a third door at the back of the bus [ [see Additional & Expanded Doors](#) ].<sup>40</sup>

## STRATEGY OPTIMIZATION

Stop request buttons should be added to poles for easier access by standing riders, especially near doors where passengers with upcoming stops are more likely to stand.



*Crowded middle area and empty back aisle because riders fear being far from a door at their stop; solved with all-door boarding and a third rear door*

<sup>38</sup> [DKS Associates, "Transit Operations Analysis," Alameda County Congestion Management Agency, September 4, 2006, 7.](#)

<sup>39</sup> [Alon Levy, "Bus Bunching."](#)

<sup>40</sup> [Mercedes-Benz, "Citaro."](#)

	<b>Current Layout</b>	<b>Two Door Modifications</b>	<b>Two Door Alterations</b>	<b>Initial Three Door Design</b>	<b>Future Three Door Design</b>
Bus Layout	New Flyer Xcelsior XN40	Middle 2 Seats Removed	Middle Open Space Created	Middle Door Added	Back Door Added
Number of Seats	36	34	34	32	32
Seat Orientation	10 aisle-facing	10 aisle-facing	11 aisle-facing	9 aisle-facing	9 aisle-facing 4 backward
Number of Middle Seats	4	4	3	3	3
Number of Standees <sup>41</sup>	27	30	31	34	36
Number of Movement Chokepoints	4	4	3	3	2
Areas with Door Access only via Chokepoints	2	2	1	1	0
Open Spaces for Movement	1 small space	1 medium space	1 large space	1 large space	1 large, 1 small
Number of Doors	2	2	2	3	3

### OPPORTUNITIES & POSSIBILITIES

Explore wheelchair securement devices which allow mobility-impaired riders to secure themselves, lowering dwell times.<sup>42</sup>

## Articulated Buses

*Articulated buses will allow for higher capacity on crowded routes and will free revenue hours for increased frequency.*

### EXISTING CONDITIONS

Existing 40 foot buses see capacity problems on many routes, leading routes including the Blue and White Loops to leave passengers behind and making two buses per trip standard on the VE route and routinely necessary on other routes.

<sup>41</sup> Typical, non-crush level of crowding on CATA buses. Clive D'Souza, Victor Paquet, James Lenker, Edward Steinfeld, "Effects of transit bus interior configuration on performance of wheeled mobility users during simulated boarding and disembarking," Applied Economics 62: 94-106, DOI: 10.1016/j.apergo.2017.02.008, February 13, 2017.

<sup>42</sup> "Quantum," Q'Straint, 2019.

A completed Articulated Bus Study,<sup>43</sup> a renovated bus depot, and allocations in the Transportation Improvement Program<sup>44</sup> mean CATA can purchase and operate articulated buses.

## NEW ADVANTAGES

VE and RC services should be first to receive articulated buses, as the Articulated Bus Study recommends, and weekend V, N, and R routes could use articulated buses to reduce crowding.<sup>45</sup>

Doubled and tripper VE, RC, etc. revenue hours could be used to increase Loop service or improve V, N and R service to 30 minute headways [ see [Increased Trunk Frequency](#) ], especially on weekends.

Addition of articulated buses on some routes will free more post-2012 40 foot buses to serve Loop routes. These buses will allow for faster boarding and alighting as compared to the older 40 foot buses, which have narrower rear doors, and which operate

disproportionately on Loop routes [ see [Loops getting older buses](#) ].

## STRATEGY OPTIMIZATION

Extremely crowded White Loop buses on Friday and Saturday night<sup>46</sup> could be exchanged for articulated buses with all-door boarding [ see [Proof-of-Payment & All-Door Boarding](#) ], since they would not be in use for morning and evening peak-time crowding, but high frequencies should be retained to attract riders who might otherwise use ride-hailing apps or walk. Higher capacity would encourage more ridership because buses would be less crowded.

## OPPORTUNITIES & POSSIBILITIES

Explore the possibility of spaces or vertical racks for bikes inside articulated buses—potentially only off-peak travel, to be used as standing room at peaks—to reduce dwell time

variability due to bike loading and unloading on the front rack.

## Other Notes

Consider policies to increase capacity on existing buses:

- **Use recorded announcements and posters to encourage students to put backpacks at their feet to increase standing room on crowded buses**<sup>47</sup>
- Create recorded announcements to encourage riders to stand two people-across in wide aisles and to move to the back of the bus on crowded buses. All-door boarding [ see [Proof-of-Payment & All-Door Boarding](#) ] will help distribute riders more evenly as well
- Explore always folding up front aisle-facing seats on Loop buses and potentially other crowded routes to increase standing capacity

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<sup>43</sup> [Centre Area Transportation Authority, "Assessment of Articulated Bus Utilization."](#)

<sup>44</sup> ["Transit Projects - Bus: Revenue Rolling Stock: Purchase - Replacement project CATA," Pennsylvania Department of Transportation, 2015.](#)

<sup>45</sup> [Centre Area Transportation Authority, "Assessment of Articulated Bus Utilization," 116.](#)

<sup>46</sup> [ibid.](#)

<sup>47</sup> [Metropolitan Transportation Authority, "Take Your Pack Off Your Back," Courtesy Counts, accessed July 21, 2019.](#)



*White Loop with aisle-facing seats folded up, leaving significantly more standing capacity*

- Establish a goal to eliminate the time Loop buses spend as discharge-only, both from capacity increases and from less bus bunching,<sup>48</sup> especially from bus lanes [ [see Bus Lanes](#) ] and lower dwell times [ [see Proof-of-Payment & All-Door Boarding](#) ]

Explore electric powered buses, especially because articulated buses accelerate more slowly and use more fuel than 40 foot buses.<sup>49</sup> In-motion charging<sup>50</sup> or overhead wires—with a nearby depot, potentially near OPP [ [see second CATA depot](#) ]—might be justified on Loop routes, with potential expansion to other high-frequency routes. Battery powered buses should be considered in future bus purchases.<sup>51</sup>

Ensure future bus purchases include low windows which seated riders can look through without straining, unlike newly purchased Gillig buses. Ensure future bus purchases include middle and rear doors which slide out and to the side, like newly purchased Gillig buses and unlike New Flyer buses.



*Newly purchased Gillig bus with unfortunately high windows, necessitating riders to strain their necks to see outside, but optimal middle and rear door mechanics*

<sup>48</sup> Alon Levy, "Bus Bunching."

<sup>49</sup> Centre Area Transportation Authority, "Assessment of Articulated Bus Utilization," 2.

<sup>50</sup> Alon Levy, "In-Motion Charging," Pedestrian Observations, December 9, 2018; "Xcelsior CHARGE On-Route Charging," New Flyer, January 2019.

<sup>51</sup> Alon Levy, "Battery-Electric Buses: New Flyer," Pedestrian Observations, March 30, 2019; Alon Levy, "The Verdict's Still Out on Battery-Electric Buses," Citylab, The Atlantic Monthly Group, January 17, 2019.