PROJECT UPDATE

January 2012

WHITE PAPER / GUIDELINE

NORTH AMERICAN APPLICATION OF MODERN STREETCAR VEHICLES
BACKGROUND

- No single comprehensive source of modern streetcar info
- Relatively small number of streetcars in service now in the US, but rapidly increasing demand
- Limited industry familiarity in North America; Light Rail and Streetcars have much in common, but there are also significant differences.
- If we can do an effective job of internal education and standards work, vehicles and systems will better match, and cost savings will follow
- **Project Goal:** To facilitate the successful introduction of modern streetcar vehicles into North American systems by promoting understanding of the core technical and operational issues.
PROJECT OVERVIEW

✓ Form working group
✓ Work with APTA to find the right place in the Standards Development Program for our effort
✓ Seek participation of North American agencies doing streetcar projects
✓ Develop initial document outline
✓ Document previous work in the topic areas
✓ Create project website
✓ Background research- comparison of North American and EU Operating Environments
✓ Carbuilder Survey

- Prepare initial drafts for each topic area, select appropriate format
- Circulate drafts internally for review and revision
  - Circulate drafts externally for comment
  - APTA balloting process
OPERATING ENVIRONMENT RESEARCH

- Are streetcar operating environments in North America different from other parts of the world? If so, how?
- Given that the majority of modern streetcar designs originate outside North America, are there prevailing vehicle design characteristics that might be incompatible with North American operating environments or standards?
- Which operating environment differences (including standards) have the highest potential to impact vehicle cost?
## APTA Streetcar Subcommittee Carbuilder Survey

### Vehicle Comparison Chart

(See individual vehicle pages for more detail)

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Widths</th>
<th>2.3</th>
<th>3.1</th>
<th>3.7</th>
<th>Radii (in-service)</th>
<th>Load Leveling Option?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alstom Citadis X04</td>
<td>34–43m</td>
<td>●</td>
<td>●</td>
<td>20m</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>AnsaldoBreda Sirio Tram–Train</td>
<td>33–44m</td>
<td>●</td>
<td>●</td>
<td>20m</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>Alstom Citadis X02</td>
<td>33–44m</td>
<td>●</td>
<td>●</td>
<td>25m</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>Bombardier Flexity North America</td>
<td>30–45m</td>
<td>●</td>
<td>25m</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siemens Avenue</td>
<td>28m</td>
<td>●</td>
<td>18m</td>
<td>NO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siemens S-70 Streetcar</td>
<td>24m</td>
<td>●</td>
<td>18–25m</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AnsaldoBreda Sirio</td>
<td>21–43m</td>
<td>●</td>
<td>●</td>
<td>18–20ft</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>United Streetcar USC 100</td>
<td>20m</td>
<td>●</td>
<td>18m</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinkisharyo Ameritram</td>
<td>20–45m</td>
<td>●</td>
<td>18m</td>
<td>YES</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**REV 4/8/11**

---

**North American Application of Modern Streetcar Vehicles 1-3-12**
FIVE TOPIC AREAS

1. Vehicle Configuration
2. Vehicle / Platform Interface
3. Vehicle / Track Interface
4. Power Supply
5. Standards
1. VEHICLE CONFIGURATION

Key Issues:

- The streetcar operating environment
- Off-vehicle fare collection
- Capacity
- Market direction
- Interior layout
- Partial versus 100% low floor designs
The Streetcar Operating Environment

- 100% in-street operation is very different than typical light rail alignment
- Forward / side visibility is a big issue in a street-running vehicle
- Full skirting with no protruding couplers
- Low floor streetcars are designed to work with off-vehicle fare collection (some cities use roving conductors or TVMs on vehicle), maximizing benefits of multiple doorways and stepless entry
• Worldwide 7,000+ low floor LRVs and trams in last 20 years, about half are 100% low-floor
• USA has 850 partial low floor LRVs and 20 partial low floor streetcars, no 100% low-floor vehicles (Only 12% of world production of low-floor vehicles)
• Market Trend: 100% low-floor vehicles dominate recent EU orders for tramways (70% still popular for LRV and Tram-Train)
### Capacity

- **Evolution of the streetcar “mix”: development / mobility**
- **How will capacity be expanded to accommodate growth in demand?**
  - Adding more vehicles
  - Buying modular vehicles whose length can be extended in the future (e.g. DART)
  - Buying longer vehicles initially
- **Important to make “apples-to-apples” comparisons on capacity (use 4 passengers per square meter)**

### North American Application of Modern Streetcar Vehicles 1-3-12
• Streetcar trips tend to be shorter- standing is more acceptable

• All low-floor configurations require some form of compromise for the floor; there will always be some restriction on floor space:
  o Steps inside the vehicle (partial low floor)
  o Narrowed aisles around the running gear (100% low-floor).

• In all configurations, only specific sections of the vehicle are typically arranged to accommodate wheelchairs.
Tradeoffs- Partial vs. 100% Low Floor

Partial Low Floor

PLUS

• Partial use of conventional running gear, (large body of local experience, lower maintenance costs)

MINUS

• Steps inside car
• Fewer low-floor doors

100% Low Floor

PLUS

• No interior steps
• Low-floor doors possible along entire length of vehicle
• Can minimize dwell time when combined with full length platforms

MINUS

• Special running gear required- more technologically complex (may impact maintenance costs, suspension may be stiffer)
• No steps, but interior layout is impacted by running gear “wheel wells” in many designs

North American Application of Modern Streetcar Vehicles  1-3-12
2. VEHICLE / PLATFORM INTERFACE

Key Issues:

• New Start versus Legacy System
• Accessibility- differences between ADA and EU approach
• “Nearly Level” versus “Fully Level” boarding
• Vehicle width
“Fully Level” Boarding
Vehicle Floor = 14” Platform = 14”

- Requires active suspension (load leveling) for ADA compliance
- Bridge plates not needed with platform at same level. Also no room to deploy- (located under car floor and require clearance for operation)

**PRO**
- Eliminates bridge plates (simplifies vehicle, reduces maintenance)
- Best dwell time- significant in high ridership applications.

**CON**
- More demanding on infrastructure- no room to play with on platform location
- 14 in. platform incompatible with buses unless special measures applied
- 14 in. platform more challenging to blend with sidewalks / roadway if side platforms are used
- Locating a level platform on a curve is difficult (easier to do with the “nearly-level” platform combined with bridge plates).
- Depending on carbuilder, active suspension may be higher cost or a custom feature. Active suspension also has its own maintenance issues.
“Nearly Level” Boarding
Vehicle Floor = 14” Platform = 0 - 10”

• Requires bridge plates for ADA compliance

**PRO**
• Much less demanding on infrastructure tolerances
• Compatible with busses sharing streetcar stops
• Lower platform height easier to blend into sidewalks
• With bridge plates, the nearly-level platform can be located on a curve

**CON**
• Use of bridge plates may increase dwell time, which may be a significant factor in high ridership applications or alignment where stopped streetcar blocks traffic.
• Bridge plates add further complexity to already complicated door systems
• Bridge plates are subject to maintenance issues, particularly in snow / ice conditions. (Load leveling is not without maintenance issues also).
Platform / Floor Height Survey

“Fully Level”, “Nearly Level”, or no platform at all.....

<table>
<thead>
<tr>
<th>City</th>
<th>Platform Height</th>
<th>Entrance Floor Height</th>
<th>Bridge Plates?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(in.)</td>
<td>(mm)</td>
<td>(in.)</td>
</tr>
<tr>
<td>Boston Green Line</td>
<td>0-4?</td>
<td>0-101?</td>
<td>14</td>
</tr>
<tr>
<td>San Diego LRV</td>
<td>8</td>
<td>203</td>
<td>14</td>
</tr>
<tr>
<td>Berlin, Germany</td>
<td>8.7</td>
<td>220</td>
<td>11.6</td>
</tr>
<tr>
<td>Milan, Italy</td>
<td>8.7</td>
<td>220</td>
<td>13.8</td>
</tr>
<tr>
<td>Nantes, France</td>
<td>9.8</td>
<td>250</td>
<td>14.6</td>
</tr>
<tr>
<td>Portland LRV</td>
<td>9.8</td>
<td>250</td>
<td>14</td>
</tr>
<tr>
<td>Portland Streetcar</td>
<td>9.8</td>
<td>250</td>
<td>13.8</td>
</tr>
<tr>
<td>Seattle Streetcar</td>
<td>9.8</td>
<td>250</td>
<td>13.8</td>
</tr>
<tr>
<td>Tacoma Streetcar</td>
<td>9.8</td>
<td>250</td>
<td>13.8</td>
</tr>
<tr>
<td>Melbourne tramway</td>
<td>11.4</td>
<td>290</td>
<td>11.8</td>
</tr>
<tr>
<td>Nottingham UK LRV</td>
<td>12.5</td>
<td>317</td>
<td>13.9</td>
</tr>
<tr>
<td>Charlotte NC LRV</td>
<td>14</td>
<td>355</td>
<td>14</td>
</tr>
<tr>
<td>DC Streetcar</td>
<td>14</td>
<td>355</td>
<td>14</td>
</tr>
<tr>
<td>Houston LRV</td>
<td>14</td>
<td>355</td>
<td>14</td>
</tr>
<tr>
<td>Phoenix LRV</td>
<td>14</td>
<td>355</td>
<td>14</td>
</tr>
<tr>
<td>San Jose LRV</td>
<td>14</td>
<td>355</td>
<td>14</td>
</tr>
<tr>
<td>Seattle LRV</td>
<td>14</td>
<td>355</td>
<td>14</td>
</tr>
<tr>
<td>Dallas LRV &quot;C&quot; car</td>
<td>15.5</td>
<td>394</td>
<td>16</td>
</tr>
</tbody>
</table>

North American Application of Modern Streetcar Vehicles  1-3-12
Platform Discussion

Low-floor car boarding from street level

“Dynamic Stop” alternative

Buses may not work with 14-inch platform

North American Application of Modern Streetcar Vehicles  1-3-12
• 3 well-established “standard” widths in world LRV / streetcar market; 2.3m, 2.4m and 2.65m (7 ft. 6.5 in. / 7 ft. 10.5 in. / 8 ft. 8 in.)

• US “Portland” type streetcar is 2.46m (8 ft. 0 in.)

• US Light Rail systems generally use “standard” 2.65m width, but consider “urban fit” when choosing streetcar width. Both 2.4 and 2.65 are common for streetcar.
Vehicle Width

Three Industry Standard Widths.
(Max width not including mirrors)
Car sides are typically tapered.
Critical issue is width at door thresholds

Comparison of 2400 and 2460mm
(3/4” difference per side is negligible, especially with nearly-level boarding).

North American Application of Modern Streetcar Vehicles 1-3-12
Urban Fit
Streetcars and Lane Widths

12 FT. LANE WIDTH

11 FT. LANE WIDTH

10 FT. LANE WIDTH (Very Narrow for Streetcar)

Notes: Tracks shown centered in lane, but may be offset. Vehicle dims are max width over static carbody, not including mirrors. For reference, standard US PCC streetcar width was 8 ft. 4 in. (2.54 m). Draft 9/28/11.
Why is the Vehicle Width Decision so Important?

- Initial vehicle purchase “locks in” location of platforms relative to track. Future needs should be considered, not just minimum needs for startup.
- Width impacts capacity, interior seating options
- Selecting a non-standard width will impact availability of competitive bids, especially in small order quantities
3. VEHICLE / TRACK INTERFACE

Key Issues:

• Implications of new vehicle configurations and running gear

• Track Design Criteria-unique aspects of streetcar track. TCRP Report 155; a significant new resource.

• Vehicle and Track are a SYSTEM
New Running Gear Types

- Fixed trucks, designs with and without conventional axles. How do new designs impact track design and maintenance criteria? Designs also continue to evolve, what’s ahead? The return of rotating trucks and conventional axles.

Examples: vehicles with fixed trucks and short modular body sections and the role of spiral transition curves and super-elevation. Do fixed trucks cause increased rail wear in curves? Vehicles with axle-less trucks and compatibility with single point turnouts.
Vehicle / Track Interface

• The urban nature of Streetcar / Tramway systems often require sharper curve radii and steeper gradients than Light Rail systems

• Legacy systems exist throughout the world that require sharper curves and steeper gradients than might otherwise be specified for a new start system

E.g.: horizontal curve radius; 40-50 foot (12.2-15.2 m) radius curves are common in many parts of the world, but US has most extreme curvature in its remaining heritage cities; Philadelphia at 35 feet (10.7m). Similar examples in Canada and the EU include Lisbon (old network) and Toronto, both at 36 feet (11 m).
Vehicle / Track Interface

What vehicle factors impact curving radius and gradeability?
- Running gear (axle and truck spacing, fixed or rotating)
- Articulation arrangement
- Number and lengths of carbody sections
- End overhang
- Motorization ratio (number of powered wheels)

What range of values have carbuilders structured their modular product lines to?
- 18-25m (59-82 ft) minimum curve radius, (with exceptions)
- Standard minimum values recommended for new Light Rail systems (embedded track); UITP: 20-25m (66-82 ft), TRB: 25m (82 ft). Are these values too conservative for urban streetcar systems?
Vehicle / Track Interface

- **Track Design Criteria** - Striking the right balance between unnecessarily restrictive design criteria (e.g.: curve radius requirements) and adherence to recommended limits as a means of limiting risk that features might be built into the infrastructure design which limit compatibility with standard vehicle designs.

- **Don’t design only to minimums and maximums!** The use of extreme design values, while sometimes necessary, is also a trade-off with long-term costs for track and wheel maintenance as well as noise, operating speed and passenger comfort, and compatibility with standard vehicle designs. Apply minimums and maximums thoughtfully, and in the context of a SYSTEM approach that considers the vehicles to be used and balances operational benefits with the related tradeoffs.
Vehicle / Track Interface

• Derailment Prevention and Ride Quality - Streetcar alignments must typically follow existing roadways through constrained urban areas. Track twist and wheel unloading are major factors for modern articulated vehicles. Additional considerations include super-elevation, compound horizontal and vertical curves, gradient and length of grades, transition curves (spirals), crossovers on grades.

• Different technologies for streetcar body configuration and running gear may have different strengths and weaknesses with regard to their suitability for local conditions. Some technologies may require an easier alignment to be successful. The important thing is to adopt a technology that fits the city – NOT attempt to rebuild the city to accept the chosen technology.

• Whether an existing system introducing new vehicles, or a new start, a SYSTEM approach is required- ensure that those parties responsible for vehicles and track design are working in concert to produce optimum compatibility.
Vehicle Maintenance

• Will maintenance / training practices which were previously acceptable be compatible with new vehicle types? Initial capital cost versus life cycle cost approach.

• What new technologies are available (e.g.: automated trouble reporting) to improve vehicle reliability?

• 100% LF cars require special running gear- what new maintenance and inspection issues does this bring? (example: access to parts for inspection without lifting car off trucks)

• For a small system without a drive-over wheel lathe, what’s involved with re-profiling (and changing) wheels on the various new truck designs?
4. POWER SUPPLY

Key Issues:
• Aesthetics matter! Good vs. bad practice for traditional overhead wire
• Challenges in comparing systems and technologies
• Rapidly advancing energy storage technologies
• Proprietary design issues
• Operational balance in design (understanding operational limitations)
Why Eliminate Overhead Wires?

- Aesthetic reasons in historic district
- Solution to a specific problem- e.g. impaired clearance, narrow right-of-way
- Simplifying a complicated crossing or junction
- Cost? (not a simple equation)
OCS Aesthetics

Poor (visually prominent)

Good (hardly noticeable)
# Speaking the Same Language

## Streetcar / LRT On-Board Energy Storage

<table>
<thead>
<tr>
<th>Types of Energy Storage (ES)</th>
<th>Battery</th>
<th>Super Cap</th>
<th>Flywheel</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Applications

1. **Conventional System**
   - OCS is primary power source.
   - Energy storage used for energy savings; can also be used as emergency backup power source.

2. **Ground-Level Power Supply**
   - Continuous: GLPS / OCS is primary power source. Battery used as backup power source for GLPS operation.
   - Non-continuous: energy storage and GLPS / OCS are co-equal power sources.

3. **Off-Wire Capable Vehicle**
   - Energy storage is primary power source. Recharging via intermittent OCS or GLPS.

4. **"Hybrid"**
   - (Add Generator)
   - Energy storage is primary power source. To date, prototype applications only.

---

North American Application of Modern Streetcar Vehicles 1-3-12
Off-Wire Capability

• Vehicle can use external power supply or on-board energy storage

• Recharge by capturing regenerative braking energy and while operating on powered alignment sections

• “Off-wire” range depends on alignment and operating conditions

• Batteries and Super Caps most common for energy storage (flywheels and other technologies also in development)

• Small number of vehicles in revenue service; Nice, France; Seville, Spain. Other lines under construction.

• Numerous prototype systems in extended testing

• Energy storage technology less proprietary than GLPS

• Consider life-cycle cost when comparing technologies

North American Application of Modern Streetcar Vehicles  1-3-12
Extended Range Off-Wire Operation

What would it take to build an entire line without overhead wire (or GLPS)?

- Vehicle range dependent on alignment and operating conditions
- External power source still needed for recharging
- How long does recharging take? Will this impact number of vehicles required?
- What happens when the line is blocked or a charging station goes out?
- What happens if initial line later becomes part of a larger system?
- “Hybrid” vehicle is another option
- The trade-off: infrastructure becomes less complicated, but vehicle becomes more complex
Ground Level Power Supply

- External to the vehicle - puts the power supply on the ground instead of in the air
- Specialized infrastructure and vehicle equipment
- Segmented power supply between rails - segments are turned on only when vehicle is over them
- “Contact” type system - embedded third rail
- “Contactless” type system - induction coils
- Significantly higher technical complexity
- Highly proprietary
- Complicates track design and installation
- To date, most installations cover only a portion of an otherwise conventionally-powered system
“Contact” Type System

- Embedded third rail
- In service in Bordeaux (13km 2007), Angers (1.5km 2011) and Reims (2km 2011)
- Under construction in Orleans, Tours, Brasilia and Dubai.
- Test installation in Naples
- Vehicles have battery backup in case a segment fails
- All installations to date in warmer climates, snow and ice issues are an unknown
“Contactless” Type System

- Inductive transfer of power- no physical contact
- Batteries provide vehicle energy storage, guideway power installed only on portions of alignment (at stops and where vehicle is accelerating)
- DC converted to AC for guideway power, converted back to DC inside vehicle
- Contactless power transfer expected to help with snow / ice issues
- Test installation in Augsburg 2011
5. STANDARDS

Crashworthiness-

• Differences between ASME RT-1 and EN 15227?
  • Carbuilders are still examining this issue
  • Further industry discussion needed

• What standards do the current lines of modular streetcar designs meet?
  • Primarily EN 15227

• APTA working with California PUC. CPUC is revising GO-143 and is considering substituting RT-1 Standard for the current fixed 2g buff strength approach.

• New APTA LRV procurement standard draft specifies RT-1
5. STANDARDS

Observed differences between US and EU approaches to rail transit ACCESSIBILITY

- EU has more surviving tramway systems, therefore dealing with more retrofits than new starts
- US had few surviving legacy systems, ADA thus provided almost a “clean start” in 1990
- Emerging EU regulations similar but ADA requires 5/8 in. max vertical step, EU tolerates 2 in. step
- Load leveling or bridge plates are thus a much bigger issue in the US market
- See Vehicle/Platform section for discussion of the options (and their inherent tradeoffs) for meeting the ADA vertical step requirement
5. STANDARDS

• **Braking rates** - What standards should North American agencies look to for streetcar braking rates / jerk rates? What factors (e.g., weight) could impact the use of these standards? How should the operating environment differences between the LRT and streetcar modes be addressed?

• **Fire Safety** - What standard should an agency include in their procurement documents, and what are the implications of doing so?
  - Does NFPA 130 take low-floor vehicles into account (almost all equipment on the roof instead of under the floor)?
  - Differences between NFPA 130 and EN 45545 - “one size fits all” versus operating environment categories. APTA to examine differences between the two standards
  - Pending new EU standard, current UK standard allows L-O-S operated tramways to meet same fire standards as buses.
  - What standards do the current modular streetcar platforms meet?
  - High potential to impact vehicle cost
NORTH AMERICAN APPLICATION OF MODERN STREETCAR VEHICLES

For more information, contact project manager John Smatlak: info@modernstreetcar.org, and check out the project website www.modernstreetcar.org

The main website for the APTA Streetcar Subcommittee is: www.heritagetrolley.org