FTA RESEARCH

FEDERAL TRANSIT ADMINISTRATION

TriMet Streetcar Prototype
Final Report

JANUARY 2015

FTA Report No. 0085
Federal Transit Administration

PREPARED BY

TriMet
City of Portland
Portland Streetcar, Inc.

U.S. Department of Transportation
Federal Transit Administration

COVER PHOTO

Courtesy of Casey Ailes.

TriMet Streetcar Prototype

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liter	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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EXECUTIVE SUMMARY

This report documents the effort led by TriMet, the City of Portland (City), and Portland Streetcar, Inc. (PSI) to domestically manufacture a streetcar for operation in the Portland Streetcar system.

TriMet is the regional transit provider for the Portland Metropolitan Region and the eligible Federal Transit Administration (FTA) grant recipient. The City owns the Portland Streetcar system. PSI is a non-profit entity designated as the Operating Entity by TriMet and the City of Portland. TriMet received a grant from FTA to domestically manufacture streetcars. Oregon Iron Works (OIW) was selected through a competitive process to develop a prototype vehicle produced by a domestic manufacturer. OIW entered into an agreement with Skoda for the production of the prototype vehicle. The purpose of the grant was to increase the capability of domestic manufacturers in the business of supplying streetcars.

The report documents the initial process of producing the streetcar, the extension of the grant to support domestic manufacture of the propulsion system by Rockwell Automation, and operation in revenue service. Also included are a discussion of the market for streetcars in the U.S. and a history of streetcar manufacturing in the U.S.

Portland began looking for a streetcar that was smaller than the typical light rail vehicle and capable of operating in mixed traffic. No streetcars were readily available in the U.S. at that time. Portland issued a Request for Proposals (RFP) in 1998 for streetcar vehicles and received two responses. A Czech Republic manufacturer, Inekon-Skoda, was selected to provide the vehicles for Portland. Tacoma (Washington) obtained options from Portland and placed an order for three cars. The Portland system opened in 2001.

By 2005, two modern low-floor streetcar systems had been implemented in Portland and Tacoma. Many other cities expressed interest in developing a streetcar system for their communities. Portland was developing a major extension that would call for seven additional vehicles to support its system. The market for streetcars was growing, and no domestic or Buy America-compliant vehicle was easily identified as available.

Federal transportation legislation that passed in 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), included an appropriation of $1 million per year for four years to TriMet to support the domestic manufacture of a streetcar. FTA awarded the grant to TriMet in 2006. In subsequent appropriations, FTA amended the grant and added $490,000 to the grant. In 2010, FTA added another $2.4 million to support the domestic manufacture of a propulsion system for the streetcar and to support the engineering necessary to allow increased energy storage capability to support off-wire operations. The total federal investment was $6.9 million.

OIW was selected through a competitive process to manufacture the streetcar for Portland. OIW formed United Streetcar, LLC and entered into a joint venture with Skoda to produce the prototype vehicle. The vehicle was completed in 2009. At that time, TriMet, the City, and PSI, with United Streetcar, proposed that the prototype be used to develop a domestic manufacturer for a propulsion system. Rockwell Automation was selected, and FTA approved this additional project for the prototype. The vehicle was completed in 2012 and operated in revenue service for nine months. United Streetcar and Rockwell Automation then, at their own expense, provided an upgrade for the propulsion system that is now in revenue service in the Portland Streetcar system.

As of 2014, a domestic market for streetcars has been established, in the range of 20–30 vehicles per year. In total, 5 modern systems are operating today, with 10 more under construction. There is estimated to be a demand over the next 5 years for as many as 148 additional vehicles.

Support for the domestic manufacture of streetcars has been partially responsible for the following results:

- United Streetcar has produced 18 streetcar vehicles for Portland (7), Tucson (8), and Washington, DC (3).
- The federal government has increased its support for streetcars, partially funding 12 systems in the U.S. In addition, 6 proposals are qualified for project development under the FTA Small Starts program.
- A total of 12 manufacturers are offering streetcars in the U.S., with all of them offering Buy America-compliant manufacturing.
- Rockwell Automation has produced a domestic propulsion system that is in operation.
- Two other propulsion manufacturers have developed Buy America-compliant systems since 2009.
- The number of domestic suppliers for streetcar components has grown significantly.

The partnership exhibited among the federal government, TriMet, the City of Portland, PSI, OIW, United Streetcar, and Rockwell Automation has had a significant impact on the availability of streetcars for the growing U.S. market. This effort has extended the opportunities for Buy America-compliant and domestic suppliers.

SECTION

1

Background

The City of Portland, Oregon, was interested in establishing a streetcar system and began looking for a streetcar that was smaller than the typical light rail vehicle and capable of operating in mixed traffic. No streetcars were readily available in the U.S. at that time. Portland issued a Request for Proposals (RFP) in 1998 for streetcar vehicles and received two responses. A Czech Republic manufacturer, Inekon-Skoda, was selected to provide the vehicles for Portland. Tacoma, Washington, obtained options from Portland and placed an order for three cars. The Portland system opened in 2001.

By 2005, two modern low-floor streetcar systems had been implemented in Portland and Tacoma. Many other cities expressed interest in developing a streetcar system for their communities. Portland was developing a major extension that would call for seven additional vehicles to support its system. The market for streetcars was growing, and no domestic or Buy America-compliant vehicle was easily identified as available.

Passed in 2005, Federal legislation named the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) contained language that allocated $1 million per year for four years to TriMet, the regional transit provider for the Portland Metropolitan Region and the eligible Federal Transit Administration (FTA) grant recipient, for the purpose of domestically manufacturing a streetcar. This action by Congress was followed by a letter from the ranking members of the House Transportation and Infrastructure Committee defining a "domestic manufacturer" as a U.S. company with 50% or more shares owned by U.S. citizens and with an operating plant in operation for the last 3 years.

In July 2006, FTA issued a Notice of Grant Award to TriMet. TriMet entered into an intergovernmental agreement with the City of Portland to procure, oversee, own, and operate the prototype streetcar. The City of Portland operated seven streetcars on its system and was prepared to incorporate the prototype into its fleet and conduct evaluations of its performance. The City of Portland contracted with Portland Streetcar, Inc. (PSI), the operating entity for Portland Streetcar, to oversee the manufacturing.

In September 2006, the City of Portland issued an RFP for a domestic manufacturer to produce a modern streetcar. The RFP required that the manufacturer be a company for which at least 50% of the company is owned by U.S. citizens and that the company owned a manufacturing facility in the U.S. that had been operating for the past 3 years.

Figure 1-1 is a timeline of the TriMet streetcar prototype project.

Figure 1-1

Timeline of TriMet streetcar prototype project

2005:
August – SAFETEA-LU passed by Congress with $4 million designated to domestically manufacture a streetcar.

2006:
May – FTA approves a grant to TriMet for the prototype.
September – City of Portland issues RFP for prototype.

2007:
January – Oregon Iron Works selected as manufacturer.
March – Contract approved for prototype with Skoda Design.

2009:
May – Prototype delivered to Portland Streetcar.
July – Prototype inaugurated in revenue service with U.S. DOT Secretary.
September – FTA requested to consider domestic manufacture of propulsion using Rockwell Automation.

2010:
April – FTA approves grant to TriMet for $2.4 million to support domestic propulsion and off-wire capability study.

2011:
June – Off-Wire Capability Study completed by United Streetcar.

2012:
September – Car 15-Prototype conditionally accepted by City of Portland.
September 22 – Prototype begins operating in revenue service.

2013:
September 2012 to March 2013 – Prototype operates in revenue service.
March – United Streetcar and Rockwell begin upgrades of propulsion system.

2014:
July – City of Portland accepts upgraded Car 015 with fully-compliant safety certification

SECTION 2

Streetcar Manufacture and System Performance

Two proposals to manufacture the streetcar were received, from Oregon Iron Works (OIW) and from Inekon. Inekon filed a request to be exempted from the domestic manufacture requirement. The request was denied.

OIW and Skoda proposed a partnership to develop the domestic streetcar. OIW formed a wholly-owned subsidiary, United Streetcar, LLC for the development. United Streetcar entered into a licensing agreement with Skoda for the purpose of licensing the Skoda design. Skoda agreed to provide trucks, motors, and propulsion systems as part of the manufacturing agreement.

Oregon Iron Works gets contract for streetcar

Oregon Iron Works, Inc. was awarded a $4 million contract to produce the nation's first domestically-manufactured modern streetcar. The announcement was made Friday at the company's headquarters in Clackamas by U.S. Representative Peter DeFazio, D-Ore., Chairman of the House Subcommittee on Transportation. "I'm proud that Oregon will get to show that we can produce a quality product as good or better than they make in Europe and restore good, family-wage manufacturing jobs here at home," DeFazio said. DeFazio, with the assistance of the Oregon and Washington congressional delegations, secured a special authorization of $4 million to foster the domestic production of a streetcar vehicle similar to the Portland Streetcar.

Oregon Iron Works will build a prototype streetcar under the aegis of its newly-formed subsidiary, United Streetcar, LLC. The prototype will be based on the model currently manufactured in the Czech Republic by Skoda, provider of cars for Portland's five-year-old streetcar system. The design is for a four-axle, double-ended, low-floor streetcar, fully compatible with the existing Portland Streetcar. The award of this contract will make Oregon Iron Works the sole U.S. manufacturer of the modern low-floor streetcar.

Oregon Iron Works will add 20 new employees to produce the streetcar. The company employs more than 400 and has additional manufacturing facilities in Vancouver.

Portland Business Journal, January 26, 2007

United Streetcar and Skoda went to work manufacturing the streetcar. Construction of the Prototype vehicle was completed at OIW by United Streetcar in Clackamas, Oregon, in June 2009. It was introduced to the public at a ceremony on July 1, 2009. The vehicle operated on a temporary use permit.

Figure 1-2
Prototype production

Figure 1-3
Prototype vehicle

Figure 1-4

U.S. DOT Secretary LaHood (left) at the prototype introduction ceremony

Domestic Propulsion System

Following the demonstration of the prototype vehicle in July 2009, the manufacturer, OIW/United Streetcar, experienced some challenges with the contractual relationship and services supplied by Skoda. OIW contacted Rockwell Automation, a prominent industrial control system manufacturer with facilities throughout the world and a large presence throughout the U.S., regarding its interest in developing a domestically-produced propulsion system. Rockwell expressed a strong interest in exploring the principle of establishing domestically-produced products for the transit industry. OIW had previous work experience with Rockwell on several occasions for the supply of important components to support specialty production contracts.

As a result of this potential manufacturing interest, the final testing of the prototype was suspended in September 2009, pending discussions with FTA regarding its potential interest in participating in an effort to support development of a domestically-manufactured propulsion system.

In September 2009, the City of Portland, OIW, and Rockwell Automation met with FTA officials to discuss the potential of supporting the development of the propulsion system using Rockwell Automation. TriMet and the City of Portland submitted a funding request to FTA for $2.4 million for replacing the Skoda propulsion system with the Rockwell Automation propulsion system in the prototype vehicle. A total of $400,000 of the $2.4 million request was proposed to be used to determine the engineering changes needed to add more extensive batteries in the system to enable operation off-wire.

In April 2010, FTA approved the grant request, and work began on producing the domestically-manufactured propulsion system. Rockwell Automation worked with OIW to develop a design for installation on the prototype, and the City of Portland contracted with PSI to oversee the manufacture and certification of the prototype. The City conducted the selection process for engineering and project management and selected LTK Engineering, which was retained by PSI. Shiels Obletz Johnsen was retained to oversee the design, testing, and installation of the system.

In June 2012, OIW and Rockwell Automation moved the prototype from the test track at their facility to the Portland Streetcar tracks for testing and certification. In September 2012, the City completed the safety certification of the prototype with the new propulsion system, and the vehicle was put into revenue service.

The primary specification requirement was the maximum operating speed for the vehicle. A Conditional Acceptance specified that the vehicle speed was limited to 25 miles per hour. The braking tests for the system indicated that additional adjustments were needed to ensure the full utilization of the dynamic braking system. The prototype successfully met safety specifications for 25 mph or less.

The prototype also experienced some difficulty with the low-voltage power supply system that supplies AC current for lights, cabs, air conditioning, and battery recharging. These difficulties resulted in problems in preparing the vehicle for revenue service each day. The Conditional Acceptance required that OIW provide an individual on the vehicle while it was operating in revenue service.

Revenue Service Performance

On September 22, 2012, the prototype was put into revenue service for the Portland Streetcar system. The Portland Streetcar Loop opened with 11 streetcars scheduled to operate on 2 lines in the system. The streetcar fleet consisted of 10 streetcar vehicles plus the prototype (the City had not yet received the 5 vehicles ordered from OIW). The new line operated without a spare until June 2013.

The prototype operated through June 29, 2013. It was put on a schedule for operating approximately 12 hours per day for 6 days per week (with fewer vehicles needed on Sunday, the prototype was not scheduled for service on that day).

A detailed log of the operations was kept for the operation of the prototype. Initial operations were disappointing, with numerous faults occurring and much difficulty encountered in assuring a reliable operating vehicle. The logs show that the vehicle experienced numerous interruptions of service and required assistance and towing on several occasions, as well as several periods of failure from October through March 2013. The logs showed that while some weeks provided 100% operational reliability, there were weeks where the vehicle was available less than 30% of the time scheduled.

OIW and Rockwell Automation continued working on the vehicle, and the service reliability improved significantly from March to June 2013, with 97.22% reliability in that period. The overall reliability during the nine months of operation was 82.06%.

The faults that were being experienced often were a result of control devices that stopped the system if it was not operating normally. For example, a system monitors the temperature of the motors; if the temperature is exceeded, the system stops. It was determined that the initial setting in the control system was too low and was reset. There are other examples of the control system interface and protections that needed adjustment to accommodate the transit operation. Many of the corrections were made in the system to accommodate these faults and enable a more reliable operation. The prototype continued in revenue service through June 2013.

OIW and Rockwell Automation both recognized that additional work was necessary to upgrade the propulsion system to fully meet the technical specifications required for the reliable performance of the prototype. They proposed to modify the existing drives with an upgraded IGBT transistor that would improve the braking performance of the vehicle. In addition, Rockwell upgraded the low voltage power supply system (LVPS) and proposed a replacement to improve the electrical interface with the AC electrical requirements and to provide access to additional technical operating parameters. This plan was presented and accepted by the City of Portland. OIW and Rockwell Automation proposed these upgrades at no additional cost to the grant and the City of Portland.

In July 2013, the prototype was removed from revenue service so Rockwell Automation could begin the installation of the upgrades, which were installed in 2013. The LVPS was delayed until 2014; the system was subcontracted to Bonitron who manufactured the LVPS in Tennessee. The system was installed in 2014, and testing began on the upgraded vehicle.

The testing was completed in July 2014, and a full certification without conditions was issued. The prototype vehicle was certified at that time for revenue service, meeting the specifications required to authorize operation at 30 miles per hour, as is the case for the 10 vehicles in the Portland Streetcar fleet.

The City Portland, OIW, and Rockwell Automation committed to operate the prototype in revenue service as part of the Portland Streetcar system.

Off-Wire Feasibility

In 2009, when the City of Portland proposed to FTA consideration of developing a domestically-manufactured propulsion system, FTA expressed an interest in investigating the feasibility of developing a vehicle that could operate off-wire.

As a result of this interest, the City of Portland, with TriMet, submitted a grant request to FTA that included $400,000 to evaluate potential off-wire options for providing power to the streetcar and to investigate the extent of the design and structural changes needed to accommodate off-wire operation. The grant was approved by FTA in 2010.

OIW was retained to conduct the evaluation through its wholly-owned subsidiary United Streetcar, LLC. United Streetcar was tasked with preparing an estimate of the power requirements for operating streetcars, an evaluation of on-board energy storage systems, and preparation of a preliminary design for a vehicle that would include sufficient storage capability. A study showed that using onboard energy storage systems to power a streetcar over a specified distance without using overhead wires is feasible. The preferred design was a combination of ultracapacitors and lithium ion batteries.

Kinkisharyo has developed a streetcar vehicle that relies on a battery storage system. Seattle has ordered seven vehicles from Inekon Group in the Czech Republic that will operate off-wire for 2.4 miles of the First Hill Streetcar line. Dallas has ordered two vehicles from Brookville that will operate from Oak Cliff to Union Station completely off-wire on the historic bridge connecting the two locations, with operation scheduled to begin in 2015.

The United Streetcar analysis showed that the design modifications needed to accommodate the storage systems were minimal. The added weight of the storage systems could be accommodated with the structural designs already developed for the standard vehicle. Modern energy technologies, including batteries and ultracapacitors, achieve levels of performance that meet the power demands of United Streetcar's vehicles. These designs can provide safe and reliable operation in the transportation environment.

Final Vehicle Acceptance

The prototype vehicle was approved for use in 2009 with Skoda propulsion as a demonstration, in 2012 with the Rockwell Automation propulsion under conditional acceptance, and in 2014 with upgraded Rockwell Automation propulsion and full certification. In 2012, Rockwell Automation completed the installation of the domestically-manufactured propulsion system, which was fully tested and conditionally certified to operate in revenue service on the Portland system. In 2014, the upgraded system was provided to the City of Portland for testing, which was completed; final acceptance by the City of Portland was concluded in July 2014.

SECTION 3

Domestic Streetcar Production and Use

OIW entered into a contract with the City of Portland to build a prototype vehicle with the intent to enter into the business of supplying streetcars to other cities. Since 2006, when the prototype contract was signed, OIW has been successful in obtaining orders from Portland for five vehicles (2010), Tucson (Arizona) for eight vehicles (2011), and Washington, DC for three vehicles (2012). OIW anticipates that another vehicle will be supplied to Portland in 2014.

OIW learned an important lesson in developing the prototype. The Skoda design that was used was inefficient with regard to the required labor to assemble the car. As a result of the prototype experience, OIW redesigned the steel structure to substantially reduce the labor hours required for assembly. Subsequently, the United Streetcar design was used for all the vehicle orders for Portland, Tucson, and Washington, DC.

OIW also learned the critical importance of a propulsion system and effective system integration for the reliable operation of the vehicle. The prototype taught OIW that the Skoda propulsion, while acceptable, needed stronger support in the U.S. market to be reliable and effective. OIW explored options and successfully encouraged Rockwell Automation to develop a domestic propulsion system. This was done on the prototype while OIW was contracting for production vehicles.

OIW proposed to include the Rockwell Automation propulsion system in the production vehicles proposed for Portland and Tucson. Although the initial proposals to both cities included the Skoda propulsion system, it was agreed by all parties that Skoda would not be included. Portland and Tucson reviewed the options and agreed to use the Elin propulsion system to support the production vehicles. OIW secured an agreement with Elin, an Austria-based company at that time owned by Siemens that now offers a Buy America-compliant propulsion system, to supply the propulsion system (the Elin name has since been changed to Siemens). The Elin system was used in the 10 Inekon vehicles used in Portland, 3 vehicles in Seattle, 3 in Tacoma, and 3 in Washington, DC. Use of a proven propulsion system was the primary reason for this decision.

OIW/United Streetcar successfully supplied vehicles to Portland (currently operating), Tucson (opened July 2014) and Washington, DC (scheduled to open November 2014). Although the vehicles have been delayed from their original scheduled delivery, they have been delivered to each community and certified for revenue service. Sun Link is Tucson's 3.9-mile streetcar line that connects the region's two largest activity centers (Downtown and the University of Arizona) to commercial districts and a redevelopment area. It was designed to improve transit service in the corridor, support population and employment growth, and create economic development. The DC Streetcar is a modern, environmentally-friendly transportation option designed to connect District neighborhoods, support economic development, and reduce short inner-city auto trips. The streetcar will accommodate population and employment growth, offer enhanced transportation options to new activity centers, and provide coverage and core capacity relief to the existing transit network.

Figure 3-1
Sun Link streetcar in Tucson

Figure 3-2
DC Streetcar

Streetcar Suppliers in the U.S.

The domestic manufacturing of streetcars has stimulated more extensive work to contract with domestic producers of technical components and equipment. OIW was able to identify more than 200 domestic suppliers of components. This research effort resulted in strong growth of available parts and components for streetcars throughout the U.S. OIW developed a list of local producers that were used in the manufacture of the prototype. Figure 3-3 and Table 3-1 shows the locations of the companies included.

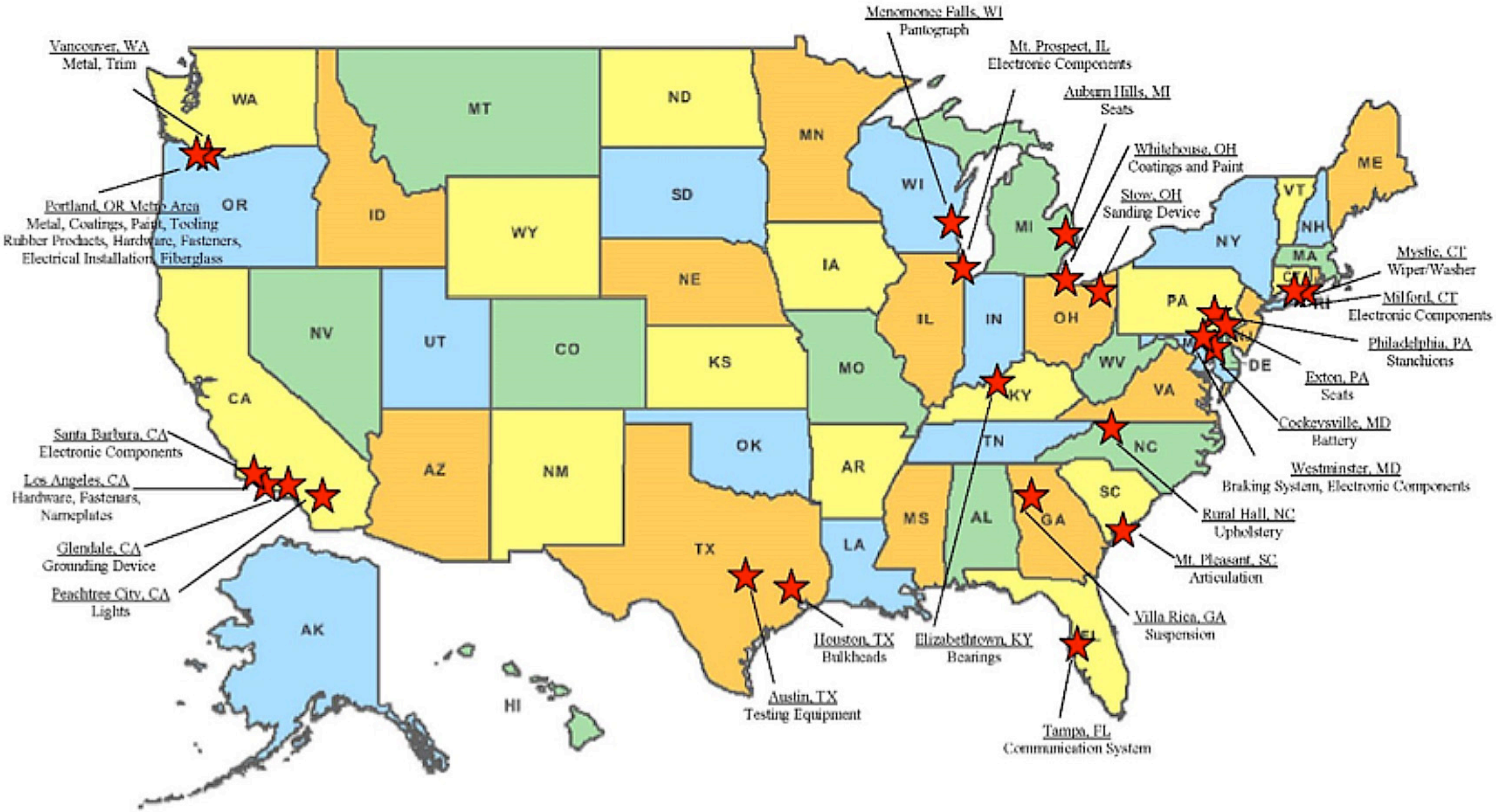


Figure 3-3

Major streetcar vendor locations in the U.S.

Table 3-1

Major Streetcar Vendors in the U.S

State	City	Company
CA	Alameda	Next Bus Inc.
	Belmont	Jameco
	El Cajon	Mouser Electronics
	Englewood	I.H.S. Global
	Glendale	Glenair Inc.
	Huntington Beach	MesaBearing
	Long Beach	Control Switches
	Los Angeles	Nelson Nameplate, McMaster
	Pleasanton	TECO Pneumatic Inc.
	Santa Barbara	Hi-Tec Enterprises
	Santa Fe Springs	Compass Concepts, Inc.
CT	Valencia	Solid Concepts
	Milford	EAO Switch, Trans-Lite
	Mystic	B-Hepworth
	Stafford Springs	American Sleeve Bearing
	Windsor	Scapa
	Woodstock	Linemaster
FL	Tampa	Vecom
GA	Peachtree City	HELLA USA
	Villa Rica	GMT
IL	Bensenville	S&W Manufacturing
	Chicago	Central Steel & Wire Co.
	Mt. Prospect	ETA Circuit Breakers
IN	Michigan City	M.S. Foster
KY	Elizabethtown	SKF USA Inc.
	Wilder	W. B. Jones
MA	Franklin	Pierce Aluminum
	Shrewsbury	Tristar Plastics Corp.
	West Hanover	Triangle Engineering
MD	Cockeysville	SAFT
	Westminster	IFE North America, KNORR
MI	Auburn Hills	RECARO
	Madison Heights	Sika Corp.
MO	Lee's Summit	Austin Hardware
	St. Louis	Tubular Steel
NC	Rural Hall	Lantal
NJ	Farmingdale	Dialight Corp.
	Florham Park	LAPP
	Piscataway	IEEE
	West Deptford	Bumper Specialties

Table 3-1 (cont.)

Major Streetcar Vendors in the U.S

State	City	Company
NY	Depew	PCB Piezotronics
	Farmingdale	Tapeswitch Corp.
	Huntington	American Transit Assoc., Scaltbau NA
	Ronkonkoma	H.A. Guden Co.
OH	Brookpark	Buckeye Fasteners
	Chagrin Falls	Safeguard Technology
	Eastlake	Major Electronix
	Maple Heights	Clifton Steel Co.
	Stow	PROIBEG
	Toledo	Parker Steel
	Whitehouse	BASF Corp.
OR	Aloha	Seals Unlimited
	Beaverton	Chinook O-Rings, TTI Inc.
	Canby	American Steel - Portland
	Clackamas	CRB Mfg., Grainger Inc., Independent Welding, Fastenal, Clackamas Autobody, Pesznecker Bros., Lumbermens, Maranatha Electrical, Marks Metal, PLATT, Applied Industrial Tech, All Source Packaging
	Estacada	Northwest Technologies
	Milwaukie	Western Cutting Tool, Acuren Inspection
	Monroe	Don Rowe
	Portland	Industrial Finishes, NW Rail Electric, East Side Plating Inc., Portland Container, La Grand Industrial, Alaskan Copper, Idex Solutions, Sherwin Williams, Chapel Steel, Pacific Machinery, Quimby Welding Supply, Fluid Connector Products, General Tool, Griffith Rubber Mill, Industrial Craters & Packers, Dunn Electronics, Unisource Mfg., Palm Abrasive, Stacy & Witbeck Inc., Ferguson Enterprises, Ryerson, Service Steel, Stack Metallurgical, Paragon Pacific Insulation, Newark Electronics, Bodycote Material Test, North Coast Electric, West Coast Wire, EJ Bartells Co., Team Tube, United Pipe Bending, C&M Products Engraving, Miler Fiberglass, Rexel Taylor Electric, RS Hughes Co. Inc.
	Tigard	Encore Metals, Oregon Bolt
	Troutdale	Safeway Services
	Tualatin	Albina Pipe Bending, Suburban Grind, Ecklund, KY-RO Inc.
	West Linn	Lisin Metallurgical
	Wilsonville	Ellison Tech.
	Woodburn	Universal Forest
PA	Exton	4 One LLC
	Johnstown	Penn Machine
	Middletown	TYCO Electronics
	Philadelphia	Bentech
	Trumbauersville	NASG
	Yardly	Secheron

Table 3-1 (cont.)

Major Streetcar Vendors in the U.S

State	City	Company
SC	Mt. Pleasant	Hubner
	Ridgeway	Lang Mekra
TX	Austin	National Instruments
	Houston	Maxbar Inc., American Alloy
	Stafford	Pro Dec Products
VA	Arlington	TRG Components
WA	Auburn	McNichols
	Longview	Brown Strauss Steel, Woods Logging Supply
	Seattle	International Paint, G.E. Totten & Assoc.
	Tukwila	EIS
	Tumwater	Temtco
	Vancouver	Vancouver Iron & Steel, Alliance Steel, Farwest Steel, State Pipe Supply, Stud Welding Supply, R&D Machine, Elixir, Interconnect Sales, Vancouver Oil
WI	Elkhart Lake	Kees Inc.
	Germantown	Ellsworth Adhesives
	Menomonee Falls	Schunk Graphite
	Oak Creek	Milwaukee Composites

SECTION 4

Lessons Learned

FTA granted funds to TriMet to domestically manufacture a streetcar. It was determined in 2006 there were no "domestic" manufacturers in existence willing to develop an American-built streetcar, meaning that a new company would need to enter the business. Oregon Iron Works (OIW) submitted a proposal to enter the business of building streetcars and established a wholly-owned subsidiary, United Streetcar, LLC, to manufacture streetcars. It has been successful in obtaining orders from Portland, Tucson, and Washington, DC, and, to date, it has completed 18 streetcars for use in the United States.

The opportunity to build a prototype starting in 2007 with FTA provided important support to a company agreeing to enter an entirely new business. Following are lessons learned throughout the process of building the initial vehicle, developing a domestic propulsion system, and producing vehicles for three different cities.

Manufacturing streetcars requires numerous disciplines.

Streetcars include propulsion systems, three brake systems, doors, pantographs, high-voltage and low-voltage controls, interiors, body frames, wheels, axles, trucks or bogies, insulation, fiberglass components, large glass windows and windshields, and air conditioning. Manufacturing a streetcar must bring together all of these aspects and coordinate them to assure maximum safety for the rider. More time is needed than is anticipated at the beginning to accomplish all of the required connections.

The process of manufacturing a streetcar involves integrating mechanical, structural, and electrical engineering. OIW provided mechanical engineering capability and contracted with Skoda to provide the electrical engineering responsibilities. The vehicle was then assembled. In testing the vehicle, difficulties were experienced in operating the vehicle due to faults that arose in conflicts with system protections, which is not unusual for an electrical system integrated with three braking systems. The knowledge and experience of the manufacturer (OIW) was limited, and it was highly dependent on Skoda to provide support.

OIW determined it needed a different approach to address electrical propulsion. It contacted Rockwell Automation to investigate the potential of developing a domestic manufacturer for the propulsion system, which constitutes about 20% of the vehicle cost. Rockwell Automation expressed strong interest in developing the propulsion system, and FTA supported this effort with a supplemental grant. This approach was based upon OIW relying substantially on suppliers for electrical engineering and support for the development of the streetcar.

Rockwell Automation developed a design for the system that was adequate for the streetcar. When the new system was installed and testing began, Rockwell's involvement was far greater than it had anticipated, requiring significant programming and technical adjustments in the vehicle during testing. Also, documentation and immediate response were more difficult, as OIW had to rely almost entirely on its sub-suppliers to address the electrical issues with the vehicle.

Going forward, OIW used a third contractor, Elin (Siemens), to supply the propulsion system for the Portland, Tucson, and DC production vehicles. Initial negotiations involved a request for more extensive electrical engineering from Elin than it typically was not accustomed to provide. Agreement was reached with Elin to supply the system. Testing and certification were more effective than the previous two cases but still reflected the lack of knowledge and experience of the manufacturer.

The lesson learned is that the primary manufacturer must have in-house electrical engineering capability to effectively manage the sub-suppliers and to efficiently respond to issues that arise during the testing, certification, and warranty periods.

Design quality is essential for proper development.

The ability to build a streetcar is dependent on the quality of initial design. OIW used the Skoda design for the prototype in 2006 but found that it was based on a much lower labor cost. The design provided for 60 different steel fabricated components and required 2,400 man-hours of labor to assemble. OIW has excellent mechanical and structural engineering capabilities but determined that any future vehicle should have a design that is able to reduce the labor required for assembly. The goal is to create a design that requires only 600 man-hours of labor.

The prototype vehicle was assembled with the Skoda design. The propulsion system was changed to the Rockwell Automation system. The lesson learned was applied to future manufacturing.

OIW developed a new design for the Portland, Tucson, and DC production vehicles. OIW had to develop an entire design team to prepare the full engineering drawings for the streetcar.

The new design provided during the production vehicle manufacturing process proved to be a challenging component. The design of a streetcar benefits greatly from experience with the final product already having been operational. The first vehicles produced under the OIW design were for Portland. These vehicles experienced specific design issues that required additional work by OIW and modifications in the design:

- The vehicle springs were specified to handle the weight of the vehicle but not the additional pressure associated with curves and slopes. The springs failed. OIW had to replace the springs at considerable expense and revise the design.
- The Portland specifications required that when springs fail, the vehicle must remain operational so it can return to the maintenance facility under its own power. The test for OIW showed that a hydraulic line was cut off and that several support elements prevented compliance. OIW had to redesign and retrofit the first two vehicles and adjust the others under production.
- The cab cover and windshield are built and installed separately. The design of the cab did not match the dimensions so that the cabs could be properly secured. This is an example of quality control needed during design that can be substantially resolved with experience.

OIW did not have experienced professionals to lead and develop the design. It has subsequently developed that capability and has made significant progress in creating a quality design that can assure reliable operation.

The lesson learned is that design quality has a large impact on the cost of production of vehicles. This reinforces the principle that experience and proven operable vehicles are the most effective to produce. Any new design for a streetcar, light rail, or automobile typically has had the same experience.

System integration is fundamental to success.

The integration of the propulsion, brake, electrical, and safety systems is essential for safety certification requirements. OIW relied upon Skoda to provide that integration in the initial design and development of the prototype, which proved to be challenging for OIW. Rockwell Automation agreed to participate in the development of an alternative propulsion system and to integrate the system. System integration was most likely the greatest cause of delay in completing the vehicle.

System integration is reflected primarily in the programming of the control systems (the “brains”) in the vehicle. Rockwell Automation assumed lead responsibility for the programming and assigned fully-qualified engineers who had experience with the various systems being installed. What they lacked was the experience with transit vehicles and their operating requirements. Following are examples of difficulties:

- Braking is the single most important function of a streetcar vehicle. Streetcars are equipped with three braking systems: dynamic, track, and disc. These brakes need to be programmed for use to meet safety standards. In the case of the prototype, the safety standards for braking at 42 mph could not be achieved, and the lower standard of 30 mph could not be achieved initially. The safety certification issued in 2012 limited the vehicle operation to 25 mph, as those speeds met the specifications for braking performance. Rockwell Automation had to develop an upgrade to the drives to enhance the dynamic braking to enable full certification of the vehicle for 30 mph in 2014.

- Programming the controls on the streetcar is important. The 750-volt direct current is subject to considerable variation. As a result, the systems on the vehicle are protected from spikes in electricity. Rockwell Automation had not had experience with this situation on a transit vehicle. The programming of the control systems on many occasions was too conservative, resulting in interruptions of operation of the vehicle because of major faults. These interruptions were experienced in the first three months of the operation in revenue service. As a result, the City of Portland required the manufacturer to have someone on the vehicle at all times when operating and Rockwell Automation available to correct the programming when the fault identifications were found. OIW and Rockwell Automation corrected most of the programming issues, and the vehicle operated far more reliably in revenue service.

The lesson learned is that the system integration of the propulsion, braking, and auxiliary systems requires an ability to manage the combination of components. Corrections after manufacturing are very expensive.

Prior experience is invaluable.

A new company starting the manufacture of streetcars faces a significant challenge in finding and retaining individuals who have experience with streetcars. While there is experience available for specialized skills, only a few individuals have a broader understanding of system integration and its role in streetcars. Time and patience are needed.

Streetcar manufacture relies upon sub-suppliers.

There are very capable sub-suppliers for major components of streetcars, including brakes, doors, pantographs, propulsion, and pantographs. This is very helpful to a new company entering into the manufacture of streetcars. System integration remains the prominent unmet need for new manufacturers.

Buy America and domestic manufacturing policies of FTA are effective.

FTA's emphasis on Buy America and domestic manufacturing has made a difference. OIW identified U.S.-based suppliers in excess of 200 companies that are able to supply streetcar vehicles. Whereas the prototype used trucks prepared by Skoda, OIW identified Penn Machine in Pennsylvania to supply trucks and wheels for streetcar vehicles used by OIW in manufacturing streetcars. Since the announcement of the funding of the domestic propulsion system by FTA, two major suppliers have established Buy America propulsion systems now available in the U.S.

The cost of supporting infrastructure for manufacturing is higher than estimated.

The propulsion system appeared to be a series of key components including drives, resistors, computers, connectors, auxiliary power, and low voltage. The specialized requirements for the equipment due to the variation in the electrical supply led to specific issues for Rockwell Automation:

- A propulsion system design typically is tested before being installed in the vehicle. Rockwell Automation has extensive testing equipment at its facilities but did not have the specific equipment needed for bench-testing its design. The cost of acquiring the equipment for this test was several million dollars. Such an investment made by propulsion manufacturers represented a huge barrier for Rockwell Automation, given the modifications that were needed. Rockwell Automation made the modifications.
- The low-voltage power supply system was required to have a rating of 28 volts. Rockwell produces a component with only a 24-volt rating. As a result, a subcontract with Bonitron in Tennessee was developed to produce the equipment. The first was not successful, and a second was produced at additional expense.

The lesson learned is that the expense for testing and production of the equipment specialized for electric transit vehicles is much greater than anticipated.

The barrier to entry in the electric transit vehicle market is greater than originally estimated.

The initial process of supporting the entry of a domestic manufacturer into the electric transit vehicle business was accurate, but the amount of funds required to successfully develop the manufacturing capability was seriously underestimated. FTA was appropriated $4 million to support domestic manufacturing. OIW bid on the project, recognizing that its own investment would be needed. To effectively enter manufacturing requires a successful design that has been demonstrated and sufficient integration of mechanical and electrical skills to enable a vehicle to reliably operate. The initial investment was followed by commitments from Portland, Tucson, and Washington, DC, to order streetcars from OIW without a proven vehicle. Even with these commitments, the financial commitment from OIW to enter the business was more significant than anticipated. OIW and Rockwell Automation had the capital to invest substantial funds in the research and development necessary to produce the vehicles and proposed that they make a full entry into the business by using the Rockwell Automation system for both the Portland and Tucson production vehicles. Such an entry would make Rockwell Automation and OIW full investors in the development of the domestically-manufactured vehicle; they were prepared to make such a commitment. However, Portland and Tucson decided not to accept such a proposal and opted to remain conservative, requiring that one operable system be produced before being installed in production cars. This effectively relegated Rockwell Automation to produce one system (which they did). The decision was logical for the cities, and experience showed that even with a proven Elin propulsion system, OIW had difficulty delivering certified vehicles in time.

Issues for Streetcars in the U.S.

The streetcar market is uneven. Five streetcar systems have opened, and 9 more are under construction for modern streetcars. To date, 39 streetcars have been ordered since 2009, with 148 more vehicles expected to be purchased in the next 5 years (25–30 per year).

Many more manufacturers are available. In 1998, there were few interested manufacturers of streetcars. In 2014, there were 12 manufacturers, including 3 U.S. domestic manufacturers that have expressed interest in building streetcars for the U.S. market, 5 of which have successfully won contracts, including 2 U.S. domestic manufacturers.

Specifications by local jurisdictions limit the market. The cities that have conducted procurement have issued varied specifications that often require additional engineering that either cause cost increases or preclude manufacturers from bidding on specific procurements.

Small orders are costly. Light rail vehicle orders typically have exceeded 20 vehicles and have been as high as 200 (Toronto). The largest number of streetcars purchased in one order to date has been 8 by Tucson. The next 5-year projection has the highest as 16 in San Antonio. Most orders are anticipated to be 10 or fewer vehicles.

Recommendations for Future Research

Strengthen Buy America. FTA has supported Buy America requirements, strengthening the development of domestic manufacturing.

Research domestic manufacturers of components. A report on the potential manufacturers or suppliers for components would be a valuable tool for manufacturers of streetcars. A list of suppliers is included in this report, but a more comprehensive report and investigation would be valuable as manufacturers put proposals together and would most likely encourage other companies to consider developing products that are valuable. The long-term market for replacement parts will be a more stable market.

Standardize procurement specifications. FTA could develop a standard set of procurement specifications that project sponsors could use to support their procurement. Such a standard document could be developed in partnership with the American Public Transportation Association (APTA) and the Community Streetcar Coalition. The concept would be to develop a procurement specification that would include ranges to enable existing manufacturers to offer in a competitive bid process for "off-the-shelf" proven designs for vehicles.

Conduct research on energy storage and off-wire capabilities. FTA could conduct research on the status of off-wire technology development and develop a list of potential suppliers for batteries, super-capacitors, and other technologies that would support the desire for increased off-wire operations. The industry is advancing rapidly, and new manufacturers are emerging. This is an opportunity to stimulate domestic manufacturers.

SECTION

5

The Modern Streetcar

Reintroduction in the U.S.

In 1987, newly-elected Portland City Commissioner Earl Blumenauer called for the development of a streetcar loop connecting the districts of the Central City. The City of Portland adopted the Central City Plan in 1988. In 1990, the City appointed a Streetcar Advisory Committee and commenced a feasibility study.

The Advisory Committee recommended that a modern streetcar be employed to support the proposed Loop in the Central City. A first phase of development was recommended that connected Portland State University with the Hoyt Street Yards in the north. The City of Portland issued an RFP for an organization to design, build, operate, and maintain the streetcar. A non-profit corporation, PSI, made up of local property owners and business leaders, was selected by the City of Portland for the contract.

The concept of the streetcar was to use the benefits of rail transportation in much higher-density parts of the city. The streetcar was intended to operate substantially in mixed traffic, sharing the right-of-way with the other users of the street.

Several cities were developing streetcar systems for their communities, including Tampa, Little Rock, Kenosha (Wisconsin), and Memphis. All of these systems were using historic trolleys or replica trolleys to operate on rails. Portland specifically sought a modern streetcar vehicle. PSI sponsored a trip to visit potential manufacturers of streetcars in 1998. PSI, the City of Portland, and TriMet visited Siemens, ABB Variotram, and Inekon. It was determined that the current light rail cars being acquired in the U.S. were too large and would have difficulty operating in mixed traffic. Each of the manufacturers was developing a smaller vehicle that could be used for streetcar operations in mixed traffic. An RFP was issued for vehicles in Portland, and Inekon-Skoda and Siemens submitted bids. The Czech Republic manufacturer, Inekon-Skoda, was selected. The first five vehicles were delivered to Portland in 2001.

Portland opened its system on July 21, 2001, with a 2.4-mile line and a 5-streetcar fleet. Portland expanded its system on three different occasions to achieve a 4-mile line. The streetcar was part of a redevelopment plan led by the City of Portland that resulted in $3.5 billion in new investment along the line and added 10,000+ new residential units in the corridor (as of 2008).

Numerous cities expressed interest in pursuing the concept of a streetcar for their communities. Sound Transit in Washington State developed Tacoma Link (light rail) and used options from Portland to acquire the Inekon-Skoda vehicles. Tacoma Link opened in 2004. Seattle adopted the streetcar concept for South Lake Union, acquired options from Portland, and opened its system in 2007. Washington, DC committed to build a streetcar in the district (scheduled to open in 2014). All three cities purchased options from the City of Portland to acquire the Inekon-designed streetcar. Inekon changed its design from the Skoda design (7 Portland vehicles, 3 Tacoma vehicles) to the Inekon TRIO design, which was supplied to Portland (3), Seattle (3), and Washington, DC (3).

In 2002, Mr. Blumenauer (as a U.S. Congressman) introduced the "Community Streetcar Development and Revitalization Act." The purpose of the legislation was to provide $200 million per year to support streetcar projects in the U.S. In 2005, SAFETEA-LU federal transportation legislation established the Small Starts program that was intended to encourage streetcar and bus circulator projects. The bill also included $1 million per year for four years to domestically manufacture a streetcar. The grant for the domestic manufacturer was directed to TriMet.

TriMet agreed to designate the City of Portland as a sub-recipient for conducting and overseeing the procurement and manufacture of the prototype streetcar. The City of Portland then contracted with PSI as the Operating Entity to oversee the manufacture and operation of the prototype. In September 2006, the City of Portland issued an RFP for the prototype vehicle. Two proposals were received, one from OIW and one from Inekon. Inekon was disqualified as it did not meet the definition of domestic manufacturer. OIW was selected as the manufacturer in January 2007.

In December 2005, OIW formed the wholly-owned subsidiary of United Streetcar, LLC with the mission of providing modern, efficient, safe, and reliable American-produced streetcars and being the pioneering force for increasing urban transit options throughout the U.S. In February 2006, it signed an exclusive agreement with Skoda to partner in the manufacture of the first American-made streetcar in more than 50 years. Skoda supplied the existing streetcar documentation including drawings, bills of material, and manufacturing documentation. It also supplied the propulsion system for the car; however, approximately 70% of the car was being sourced locally within the U.S. Companies around the country were getting involved in creating a new industry and expanding their market potential.

Once OIW and United Streetcar received the documentation, activities began with the formation of a streetcar group that reviewed the documentation and gained a better understanding of streetcars. Once they understood the process, the streetcar group began searching for U.S. manufacturers/ suppliers that could provide major components similar to those produced overseas. Companies were found in California, Connecticut, Florida, Georgia, Illinois, Indiana, Kentucky, Maryland, Massachusetts, Michigan, Missouri, North Carolina, New Jersey, New York, Ohio, Oregon, Pennsylvania, South Carolina, Texas, Virginia, Washington, and Wisconsin.

United Streetcar's prototype vehicle was delivered to PSI on May 15, 2009 for testing.

The Modern Streetcar Market

Modern streetcars are being planned all over the U.S. Figure 5-1 graphically depicts cities that have developed or are committed to developing a streetcar system in their community. Numerous cities have used vintage cars or replica vintage cars.

Figure 5-1

Committed streetcar cities

The modern streetcar has received attention by many of the cities that are planning streetcars. Table 5-2 lists the cities that have ordered or are anticipating ordering modern streetcars. Currently, there are five operational modern streetcar systems in the country—Portland, Seattle, Tacoma, Salt Lake City, and Tucson—and nine cities have fully-funded initial lines and are planning to open in the next five years—Atlanta, Cincinnati, Kansas City, Washington DC, Fort Lauderdale, Charlotte, Detroit, Dallas, and Oklahoma City. FTA has provided financial support to many systems through TIGER grants, Urban Circulator grants, and qualification for project development under Small Starts. Currently, six cities have been designated as qualified for project development—Fort Lauderdale, Tempe, Sacramento, San Antonio, Los Angeles, and Tacoma. The list in Table 5-2 includes cities that are fully funded as well as those awaiting formal commitment of funds. Cities that will use vintage cars are not included in the list.

Table 5-1

U.S. Streetcar Vehicle Market

City	#Off-Wire Vehicles Ordered	# Standard Vehicles Ordered	# Off-Wire Vehicles Anticipated	# Standard Vehicles Anticipated	Opening Year	Off-Wire	Manufacturer
Dallas, TX	2				2015	Yes	Brookville
Seattle, WA	7				2015	Yes	Inekon
Atlanta, GA		4			2014	No	Siemens
Cincinnati, OH (Phase 1)		5			2016	No	CAF
Kansas City, MO (Phase 1)		4			2016	No	CAF
Portland, OR		6			2012/15	No	United Streetcar
Tucson, AZ		8			2014	No	United Streetcar
Washington, DC		3			2014	No	United Streetcar
Seattle, WA – Broadway Extension			1		2016	Yes	
Fort Lauderdale, FL*			5		2017	Yes	RFP 2014
Seattle, WA – Center City Connector			10		2018	Yes	
Tempe, AZ*			6		2018	Yes	
Charlotte, NC			7		2019	Yes	
Anaheim, CA			10		2018/19	Yes	
Detroit, MI			6		2016	Yes	Final offer under review
Los Angeles, CA*			8		2018	Yes	
Oklahoma City, OK			5		2018	Yes	2014/Inekon selected
Sacramento/West Sacramento, CA*				8	2017	No	
Santa Ana, CA				7	2018/19	No	
Minneapolis, MN				12	2020	No	
Cincinnati, OH (Phase 2)				3		No	
Kansas City, MO (Phase 2)				3		No	
Kansas City, MO (Phase 3)				5		No	
Milwaukee, WI				4		No	
Salt Lake City, UT				6		No	
Tacoma, WA				5		No	
Total	*9*	*30*	*58*	*53*			

*Approved for FTA Project Development

Many cities have expressed interest in obtaining vehicles that can operate off-wire. Seattle and Dallas already have ordered vehicles that will have the ability to operate off-wire. The market analysis includes an estimate of the number of vehicles requiring off-wire capability desired by the cities.

Market estimates suggest that 111 vehicles are expected to be ordered in the next 5 years, averaging 20–30 vehicles per year.

The modern streetcar market has attracted many interested suppliers. Table 5-3 lists 12 manufacturers that are in various stages of offering or building streetcars for the U.S. market, with each offering a vehicle that would service the market. Several manufacturers have already secured contracts for production, including Brookville (2), CAF (9), Inekon (7), Siemens (4), and United Streetcar (17). Kinkisharyo has built a prototype of a modern streetcar with off-wire capability but has yet to receive an order.

Table 5-3 lists a country of origin for each manufacturer, and each of the interested suppliers listed has indicated its ability to meet all of the Buy America requirements for supplying vehicles in the U.S. For already-placed orders, all manufacturers are committed to meeting the Buy America requirements, except Seattle, where no federal funds were involved. Inekon, which is supplying Seattle, has established a working relationship with Pacifica Engineering for the assembly of Seattle's streetcars in the local region and has committed to meet Buy America requirements in other submittals.

Table 5-2

Modern Streetcar Potential Manufacturers, U.S. Streetcar Market

Manufacturer	Country of Origin	Vehicle	Partial Off-Wire	100% Possible	Vehicle Length	Vehicle Width	Low Floor	Technology	Infrastructure Required
Alstom	France	Citadis	Yes	Yes			100%	Induction	Imbedded Power
Ansaldo Breda	Italy	Sirio	Yes	Yes			100%	Induction	Imbedded Power
Bombardier	Germany							Induction	
Brookville	USA	Liberty	Yes	No	20m	2.45m	100%	Battery, SC	Charging
CAF	Spain	URBOS	Yes	No	24.7m	2.65m	Partial	SC	Charging Bars
Kinkisharyo	Japan	Ameritram	Yes	No	20m	2.45m	100%	Battery, SC	Charging
Pacifica/Inekon	Czech Republic	TRIO	Yes	Possible	20m	2.45m	Partial	Battery, SC	Charging
Siemens	Germany	S-70, S-100	Yes	Possible	26m	2.65m	100%	Battery, SC	Charging
Stadler	Switzerland	Tango	Yes	Possible	20-37m	2.1-2.8	100%	Battery, SC	Charging
TIG/m	USA	ViaTran	Yes	Yes	20m	2.7m	100%	Battery, Cell	None
United Streetcar	USA		Yes	Possible	20m	2.45m	Partial	Battery, SC	Wave Induction
Vossloh	Spain		Yes	Possible	Any	Any	100%	Battery, SC	Wave Induction

SECTION
6 History of Streetcar Manufacturing in the U.S.

Horsecars to Cable Cars

The history of streetcar manufacturing in the U.S. dates back to April 25, 1831, when America's first street railway began construction. The New York and Harlem Railroad Company laid rails along the Bowery from Prince Street to 14th Street, with service opening on November 14, 1832. The original streetcars were refitted omnibuses pulled by either a single horse or a team of horses. Within a year, a second line had been built and opened in New Orleans.

Figure 6-1
New York City horsecar

It was not until the early 1850s that the street railway industry boomed. It was this decade that saw French engineer Alphonse Loubat lay the first rails embedded in the pavement so they were flush with the surface in New York along 6th Avenue. By 1855, horsecar lines in New York transported more than 18 million passengers annually. That same year, John Stephenson invented and manufactured a new lighter horsecar that weighed half that of the original cars, thus easing the burden on the horses. A census taken in 1881 revealed that no fewer than 415 individual street railway companies were in existence in the U.S. Most owned and operated a single line, and several even built their own cars. That same census reported the use of 20,000 cars, 100,000 horses and mules, and more than 3,000 miles of track.

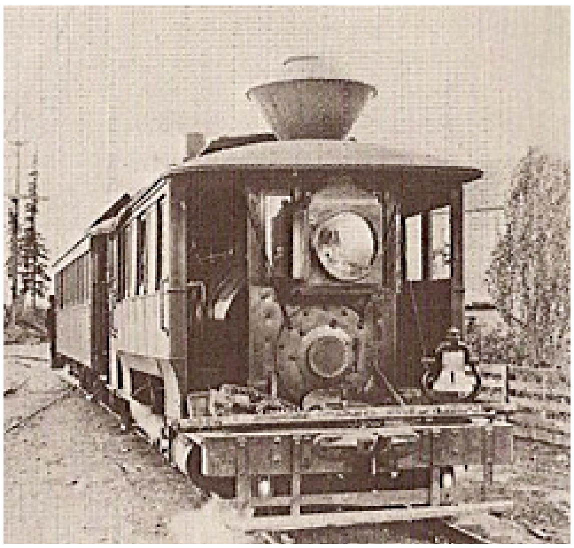
Manufacturers continued to improve upon the original horsecar design. In 1884, the Automatic Fare Collector was invented to make it easier for horsecars to be operated by a single employee. Horsecars were designed with two sets of doors; passengers would enter at the rear of the car, with the driver located at the front next to the exit. The Automatic Fare Collector allowed the passengers to deposit their fare upon entering into an inclined brass channel that led to the driver in the front of the car.

It was not uncommon to see overburdened horses and mules along a horsecar line, and often on the busier routes drivers would avoid a complete stop to lengthen the usefulness of the horses. Companies often owned a minimum of 10 horses for every car in service. In 1886, another improvement was added to help alleviate the strain on the horses when A. R. Witmer of Safe Harbor, Pennsylvania, invented the Car Starter, a series of springs that coiled as the horsecar came to a stop. The driver would then release the springs with a clutch to help the horses restart the car.

As successful as horsecars were, they had their downsides. In 1872, a rampant disease known as the "Great Epizootic" killed thousands of horses in the U.S. The loss was detrimental to many small street railway companies and fueled the search for alternatives to horsecars, the first of which was the utilization of steam power. However, as popular as steam engines were for the railways and cross country travel, they proved very unpopular for use on street railways due to the increased noise, smoke, and cinder pollution along the routes. Steam engines would also spook horses on the streets. Steam Dummies, which were smaller than the original steam engines, were manufactured to reduce the negative impacts on the city.

Figure 6-2

Steam Dummy



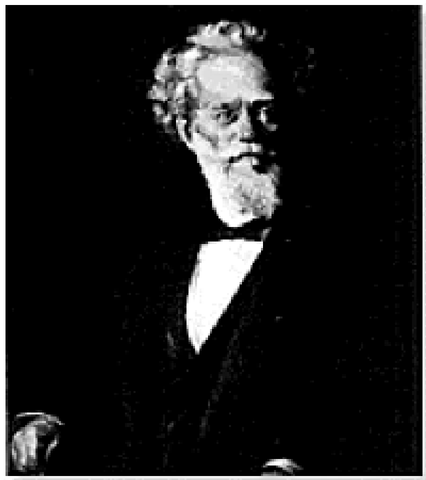
The Steam Dummies proved to be uneconomical for inner city use due to the higher costs of running a single car. Linking several cars for suburban service reduced the cost per rider significantly. The first Steam Dummy line was attempted in 1860 in San Francisco along Market Street, but the line was short lived and seven years later was replaced by horsecars. The biggest manufacturer of steam dummies was Baldwin Locomotive Works in Philadelphia.

Throughout the 1880s, several other attempts to replace horsecar technology were attempted. The first, in 1885, was the compressed-air car. George A. Clarke of Cincinnati invented a car that could refill its air tanks via an underground air supply at stops. Then, in 1886, the Standard Fireless Engine Company of New Orleans built an "Ammonia Car" to relieve the smoke and cinder problem they were experiencing with the Steam Dummies. However, the Ammonia Car consumed two gallons of liquid ammonia per car mile and proved to be uneconomical. Baldwin Locomotive Works manufactured a "Soda Car" based on the invention of Moritz Honigmann of Germany that ran on a strong solution of caustic soda that would increase in temperature when water was added, creating steam. Connelly Gas Motor manufactured a car for Brooklyn, New York, and

Elizabeth, New Jersey, that ran on a rudimentary internal combustion engine fueled by naphtha gas. None of these cars lasted past the testing phases.

The only invention between horsecars and the electric street railway that succeeded and showed staying power was the Cable Car. In 1867, Andrew Hallidie, a London-born San Franciscan, obtained a U.S. Patent for a "travelling ropeway or tramway" with stationary steam engines, a "Cable Car." A wire-rope manufacturer, Hallidie had witnessed a cruel horsecar accident that killed all four horses. He knew that wire-rope was already being used in elevators and long aerial tramways to bring gold and silver ore down from inaccessible heights, so he decided to apply that same technology to street railways. His plan, which is still used in some form today, was to have an endless loop of wire-rope powered by a steam engine generator at a central plant along the alignment. The engine would pull the rope through a trough between the rails below the surface of the street. The cars could then be attached to the rope via a "grip" that could be released to stop the car and reengaged to start the car. This would allow the cars to run independent of each other.

Figure 6-3
Andrew Hallidie



In 1872, Hallidie and three of his friends organized the first Cable Railway Company. They obtained a franchise to construct a line on Clay Street Hill, which was inaccessible by horsecar due to grades of more than 12% Construction was completed August 1, 1873, the final day of the franchise. At 5:00 AM, the first car made a successful run down the hill and back up again. Later that same day, after several test runs, Hallidie made the first revenue run to fulfill the franchise requirements. This first cable car line was a sensational success that gave a 30% return on their original investment. In 1877, Hallidie opened a second line on Sutter Street. By the late 1880s, as horsecars hit their peak and began their decline, San Francisco was served by extensive network of cable lines that incorporated 112 miles of track operated by 8 separate companies.

Cable Cars were expanding to other cities around the country as well. In 1882, the Post Office had begun using cable cars across the country to provide rapid mail distribution to branches. That same year, more than 1,000 patent applications existed for cable railways. As the popularity of cable cars grew, manufacturers improved on the design. Henry Root of the California Street Railroad improved on Hallidie's original grip design. The John Stephenson Car Company constructed an ornate grip car for Cincinnati's Walnut Hills Cable Road. The federal government even got involved. By 1887, cable cars were hauling more than 70,000 passengers

Figure 6-4

Cable car in San Francisco

a day. In 1888, Congressional legislation removed all horsecars from Washington, DC and replaced them with the new Cable Car technology. Capital Traction Company was created to operate all the DC lines. By the early 1890s, 28 cities were serviced by cable cars. In fact, in 1893 there were 305 double-track miles of cable cars in the U.S., at least one line in every major city except Boston, Detroit, and New Orleans. However, that number would decline, and by 1913 there were only 20 miles left, the majority of which are in San Francisco and remain operational today.

Early Electric Railways

The invention of electric railways was not an overnight success. It began in 1832 when Michael Faraday discovered that electricity could produce mechanical motion. This was the first discovery in a long series of inventors, tinkerers, and manufacturers to work on developing electric railways. In 1835, Thomas Davenport of Brandon, Vermont, exhibited a battery-powered rotary engine that ran on a small circular railway he built. In 1847, Moses G. Farmer of Dover, New Hampshire, operated an experimental electric locomotive on an 18-inch-wide track that pulled a car with two people in it powered by a 48-cell Grove Nitric Acid battery. In 1850, Farmer, along with Thomas Hall, exhibited an electric railway in Boston. This railway was the first to carry power to the car from a stationary source. In 1851, Professor Charles Page of the Smithsonian received a Congressional Appropriation for $30,000 to construct a battery-powered electromagnetic locomotive. The locomotive was powered by a 16- horsepower reciprocating electric motor and reached speeds up to 19 mph on a 39-minute, 5-mile trip between Washington, DC and Bladensburg, Maryland. The battery was fragile and cracked at the slightest jolt, destroying it by the end of the trip. In 1867, Moses Farmer was the first to attempt to run an electric car with generated power using a crude dynamo.

Figure 6-5

Leo Daft's Ampère Electric Engine

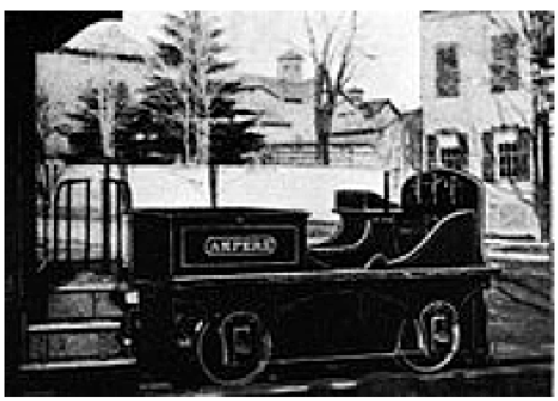


Figure 6-6
Ernst Werner von Siemens

It was not until the 1880s that viable progress was made in the electrification of street railways. Within three months of each other, Thomas Edison, Stephen Field, and Ernst Werner von Siemens of Germany all applied for similar patents on electric street railways. Field developed plans using a third rail to conduct the electricity and constructed an experimental electric locomotive in Stockbridge, Massachusetts. Edison originally used a lighting dynamo with friction pulleys for his loop at his Menlo Park, New Jersey, laboratories and in 1881 received financial backing from Henry Villard, President of Northern Pacific Railroad, to construct an improved locomotive. It was Von Siemens, however, who opened the world's first commercial electric railway, which carried 26 passengers at 30 mph on a 1.5-mile line. Von Siemens originally used 100 volts of power drawn from a third rail, but later changed to an overhead system after some "rude" experiences by horses and pedestrians crossing the tracks.

Figure 6-7
Troller system

In 1885, another battle over patents occurred between Professor John Henry and Leo Daft. Both men had invented a new way to electrify street railways—a two-wire overhead system attached to the car by a "troller" carriage that rode along the wires sending the current to the car via a flexible cable. The troller eliminated the problem of accidents when pedestrians and horses stepped on the third rail. The early troller had its own problems, however, as it would occasionally jump the wires and crash through the roof into the car. Both men successfully electrified track in 1885. Henry's was one mile long in Kansas City but was very noisy and, after a short while, he went bankrupt and the line closed. Daft's was a two-mile suburban line for Baltimore Union Passenger Railway to Hampden. Initially, Daft's line was successful and far cheaper to run than the original horsecars, although eventually the line reverted back to the horsecars. Henry did not give up after his first line. In 1887, he was hired by Electric Rapid Transit Street Railroad Company, which manufactured its own cars in San Diego, to electrify its line. Henry Electric Railway Company supplied the motors and electrical equipment for Electric Rapid Transit's cars.

The original two-wire design was replaced with a single-wire design in which the return current was sent through the rails. The line was initially highly successful, but by 1889 Henry was losing $20 per day and his company went out of business.

In 1882, Frank Sprague rode London's steam powered underground and was inspired to work on electrifying street railways. He retired from the Navy and worked for one year as an assistant to Thomas Edison before forming his own company, Sprague Electric Railway and Motor Company, in 1884. In 1885, he developed a motor mounting and gearing system that became almost universal in electric street railways. All prior mountings were inside the car attached via a belt or cable to the wheels. Sprague saw this as inefficient and mounted the motor so it was geared directly to the axle. Sprague's engine was often referred to as the "wheelbarrow" mounting, as one side hung from the truck frame on a spring and the other was supported directly by the axle with bearings allowing for rotation. This new mounting allowed for perfect alignment no matter how irregular the track surface became. In his first designs, Sprague used batteries to power his cars, but switched to the overhead trolley system eventually.

Figure 6-8

Frank Sprague

In 1887, the Richmond Union Passenger Railway Company was franchised to build a 12-mile system in Richmond, Virginia. The original franchise allowed for horse or mule power only, but it got permission to switch to electrification and then hired Sprague Electric Railway and Motor Company to do the work. The 12-mile line was to have 40 cars and a central station power plant, all to be designed and built by Sprague. This was the first line of its kind to be completed in the United States. Each car used two 500-volt motors originally made for factories, one for each axle. The central power plant was equipped with a 375-horsepower engine. Sprague completed the entire electrification process, including delivery of the cars in 90 days, receiving a payment of $110,000 only if the Richmond Union Passenger

Figure 6-9

Postcard of Sprague's Richmond line

Railway Company was satisfied with the work. In the middle of the job, Sprague was struck with typhoid fever, so most of the work on the line was completed by Sprague's assistants. They installed track on grades as high as 10% with extensive climbs. The truck mounting was retooled several times to adapt to the new conditions along the route.

As of January 1888, the company was able to run nine cars throughout the day. As the month continued, Sprague made continual modifications and improvements to the motors. On February 1, 1888, the service was increased to 10 cars daily. Slowly, Sprague increased service from 10 cars to 40 by May 1888. He ended up losing $75,000 on the job, but gained a priceless reputation for speed and reliability. By the end of 1889, there were no fewer than 154 electric street railway systems in the U.S., and only a year later there were more than 200. No less than half of the systems were equipped by Sprague's firm.

In 1890, Sprague Electric Railway and Motor Company merged with Edison General Electric. GE & Westinghouse continued to develop stronger engines, making electric lines more efficient. One such development was the GE-Type-K motorman's controller that regulated speed. It was so durable that the design was used on nearly all streetcars until the 1930s.

The Trolley Boom

In 1890, a census of the street railway industry documented 1,262 miles of electrified track. Twelve years later in the 1902 census, there were 22,000 miles of electrified track, more than 17 times that in 1890. The majority of the increase was due to the rapid conversion from horsecars to electric cars. It was not just track miles that increased. In 1902, more than $2 billion was invested in electric rail compared to less than $400 million in 1890. Ridership also was up on all street railways, from 2 billion riders per year in 1890 to more than 5 billion riders in 1902. During this time, the president of the American Street Railway Association (ASRA)was quoted as saying that he was "thoroughly convinced that electricity is the coming power," and soon after, ASRA was renamed the

Figure 6-10

U.S. Postal streetcar

American Electric Railway Association. Some of the greatest American turn-of-the-century fortunes were made in street railway securities.

The turn of the century also saw a change in the way railways were operated. In the early days of street railways, each line would be owned and operated by a separate company. At the turn of the century, companies began consolidating interests. The biggest example is the Pittsburgh Railway Company, which was an amalgamation of 114 underlying properties. Trolleys were used for every aspect of daily life from weddings, funerals, mail delivery (the mail could be sorted on route), firefighting, and milk delivery to street washing.

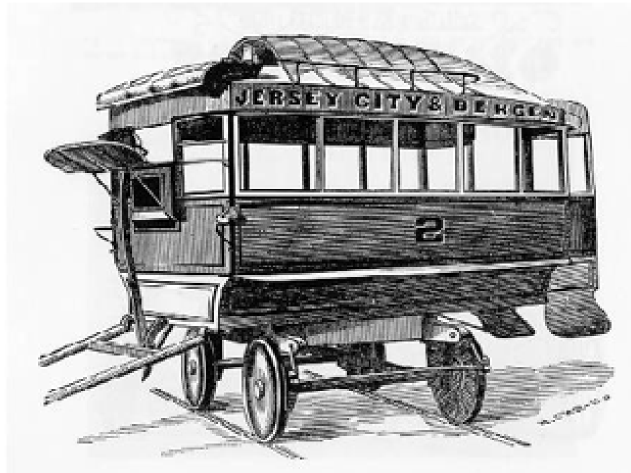
As the industry grew, hundreds of streetcar manufacturers opened their doors. Most were originally associated with a specific line, and each had its own distinct design. Most cars at the turn of the century had seats placed longitudinally that were finished in plain wood, rattan, leather, or carpeting. The finishing was often ornamental and could take a minimum of two weeks in the paint shop. Cars were originally single-truck and thus limited to 30 feet and 20,000 pounds. As ridership increased, so did the demand for larger-capacity vehicles, leading to the widespread adoption of double-truck equipment. The original double-truck cars were often double-ended with open platforms at each end where the motorman would operate the vehicle. This left the motorman out in the elements, and eventually an enclosed vestibule was added for his protection. Some trolleys also were left open for the entire length of the car for use in the warm summer months.

Manufacturers

Most streetcar historians have heard of the big cars and the big companies, but during the height of the trolley industry, hundreds of small companies were manufacturing streetcars and trolleys for their local lines. The first American-built passenger car was built in 1832 by the newly-formed John Stephenson Car Company in its six-story manufacturing plant in downtown New York City at 27th and Madison. Stephenson continued to be a prominent manufacturer and inventor. In 1859, he invented a reversible horsecar that allowed the car to be rotated on its axis without unhinging the horses. In 1860, he produced his first fare-box or "Bobtail" car, which was built for one-man operation. From 1876 to 1891, a reported 25,000 streetcars were manufactured at the Stephenson plant for both the U.S. and abroad. Stephenson Car Company was one of the most prominent builders until it was acquired by J. G. Brill Company in 1904.

Figure 6-11

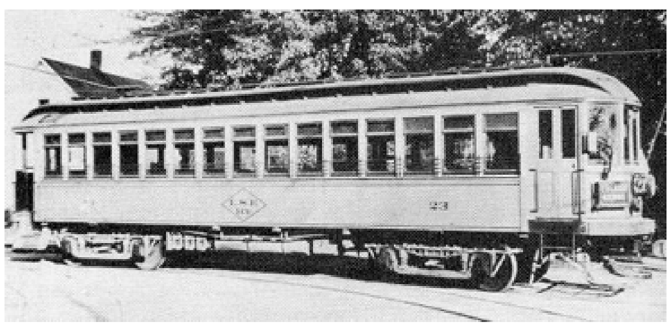
Stephenson's reversible horsecar in mid-rotation



Another prominent builder of the late 19th century was the Barney and Smith Car Company of Dayton, Ohio. Formed in 1849 by a former school teacher and Baptist minister, the Barney and Smith Car Company started with horsecar manufacturing. It first switched to railroads when the horsecars went out of style, but in 1894 it went into the electric streetcar business. The majority of its electric streetcar manufacturing was in interurbans, which were reminiscent of railroad cars.

Figure 6-12

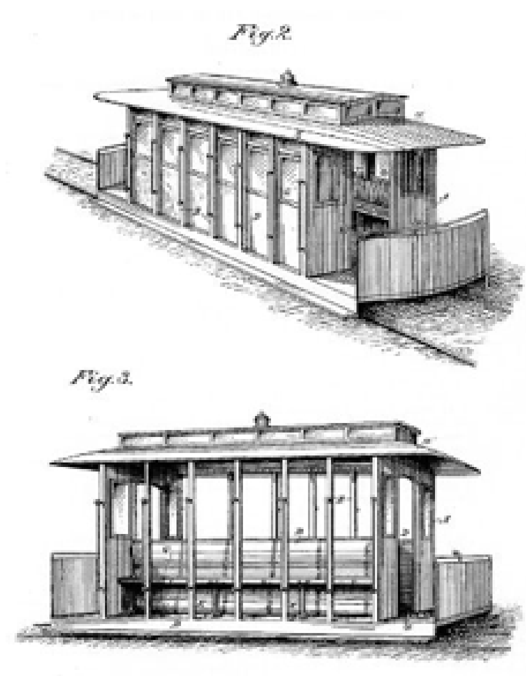
Barney and Smith Interurban



In 1875, the Brownell Car Company was started. This was one of the few companies that built all three major types of streetcars—horsecars, cable cars, and electric streetcars. The two most notable cars were Low's Adjustable Car, an early version of the popular "Convertible Car." In Low's car, the seats could be flipped so the seatbacks formed the outer wall of the car in the winter or formed a central wall with open seating in the summer. The conversion could be made by the operator in as little as three minutes. The second was the Brownell "Accelerator Car" which had seating and bulkhead door placements intended to accelerate the flow of traffic. The loading platforms were larger than any prior car with pocket doors on the side of passenger flow rather than central hinged doors. Brownell was eventually bought by Brill.

Figure 6-13

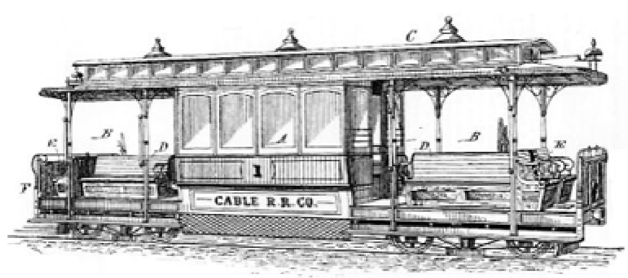
Patent drawings for Low's Adjustable Car



Another major development in streetcars was the adaptation of the "California Car," which was originally a cable car designed by John Hammond of the California Car Works. The California Car had an enclosed center section with open areas at both ends and was originally used on the California Street Line. Hammond patented both his design and the original car. There was only one grip in the cable car design with levers at both ends thus permitting the car to be operated in both directions without having to turn it around. Hammond added new features such as roof gutters and down spouts that also served as hand holds for passengers. The majority of Hammond's cars remained in California though other west coast cities purchased some for use in the summer months.

Figure 6-14

Hammond's California Car

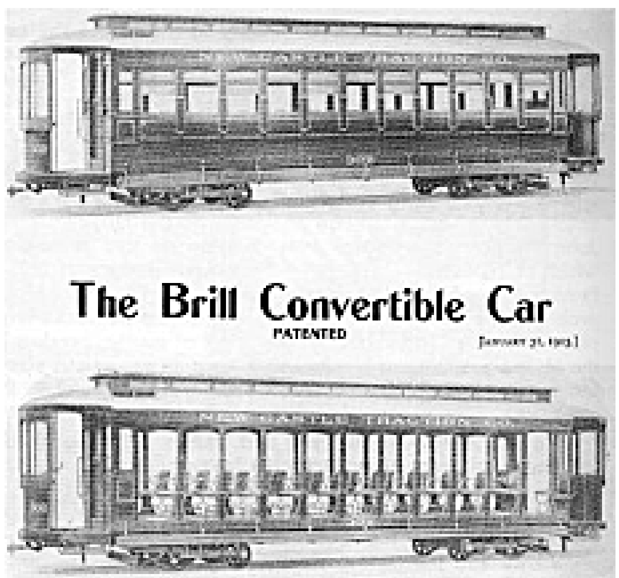


Though several advancements were made by smaller manufacturers, such as the earliest convertible streetcars built by the Heacock and Lovejoy Convertible Car Company in Portland, most of the major developments occurred at a handful of companies. J. G. Brill and Company, American Car Company, Cincinnati Car Company, Perley A. Thomas Car Works, and the St. Louis Car Company were the most prominent streetcar builders in the world.

The first of these five to be formed was J. G. Brill and Company. Initially, the company built all forms of rail transit, from horsecars to cable cars to steam railroad passenger cars, but eventually concentrated on the electric streetcar market. Some of the cars Sprague used in his original line in Richmond were manufactured by Brill. Brill absorbed a number of other streetcar manufacturers but was never able to create the monopoly it sought. It is most known for its convertible and semi-convertible cars; the "Narragansett" car with a patented two-step running board that facilitated boarding by women in the popular tight ankle-length skirts of the period; the Peter Witt or Pay-As-You-Pass car; and the "Brilliner," Brill's answer to the PCC car. Brill had patents for virtually every component of car construction, from trucks to trolley wheels and pioneered "package" selling where the buyer would get everything but the workers. J.G. Brill and Company was one of the last companies to close its doors to streetcars after producing more cars than any other manufacturer of the era (45,000 worldwide). Brill sold its last car in 1941, having sold only 30–40 of the new Brilliner cars.

Figure 6-15

Brill Convertible Car

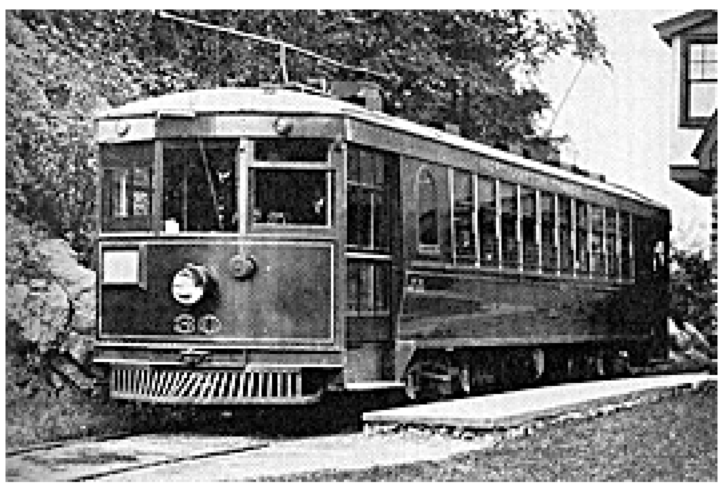


The American Car Company, founded in 1891 in St. Louis, was best known for two cars. In 1896, it built 350 single-truck cars for the Canal and Claibourne Railroad in New Orleans. Several of the original 350 cars ran until the 1930s, and one continues to run today as a rail grinder, track sander, and leaf vacuum. The second car that put them on the map was the experimental car built for Charles Birney in 1915. This was the first lightweight streetcar known as the "Birney Safety Car." This was a very popular design built for one-man operation with a "deadman" control, which stopped the car if the controller released the lever. Although it built the first Birney car, American Car Company was not the only producer. By 1930, it had produced 2,000 of the 6,000 Birney cars in operation worldwide. Less than a year later, it had closed their doors, having lost most of its business during the Depression.

Figure 6-16
Birney Safety Car

The Cincinnati Car Company was incorporated in 1902. Its most notable product was the curved-side lightweight cars built in the 1920s that had an s-curve in the side plates that gave it a greater strength-to-weight ratio. These cars became known as "Rubberstamp" cars since they were produced rapidly and in such high numbers. The Cincinnati Car Company became one of the largest manufacturers in the world based on this one design.

Figure 6-17
Rubberstamp" car



One of the last companies to throw its hat in the ring was the Perley A. Thomas Car Works, which was organized in 1916 in High Point, North Carolina. Perley Thomas originally formed the company to renovate and restore existing streetcars, but by 1924 it had become the fourth largest manufacturer in the U.S. behind J.G . Brill and Company, St. Louis Car Company, and Cincinnati Car Company. Perley A. Thomas Car Works is best known for the green streetcars along the St. Charles line in New Orleans. New Orleans Public Service, Inc. purchased more than 100 cars from Thomas Car Works. There are still 35 of the original 900 series cars delivered in 1922 and 1923 in operation.

Figure 6-18

Thomas's St. Charles Street streetcar post-Katrina

The St. Louis Car Company was founded in April 1887 and had shipped its first cars by October of that same year. By the end of 1887, it had developed a production capacity of 400 cars per year and within two years had exceeded that capacity. By 1892, reports indicated that it was producing 100 cars per month. Its success grew so quickly that by 1894 it was behind in production by approximately 500–700 cars. The St. Louis Car Company manufactured several different cars, such as the Pay-As-You-Enter (PAYE) car that was invented to catch missed fares. The PAYE cars were single-ended and required a loop to turn the cars at the end of the line. These cars proved to be highly popular due to the safer and more controlled boarding. Cities such as Chicago and Kansas City saw a 60% drop in platform accidents after converting to this design. As popular as its earlier cars were, the St. Louis Car Company is best known for its production of the PCC Streetcars during the 1930s and 1940s until its streetcar production ceased in 1952.

Figure 6-19

PCC Car

President's Conference Committee

In 1929, streetcar ridership was falling, so the American Electric Railway Association formed the Electric Railway President's Conference Committee (PCC). The committee was charged with underwriting and developing a standardized streetcar that transit firms could afford, would change popular perceptions, and would ultimately rejuvenate the industry. The principals on the committee represented 28 operating firms from nearly all of the largest cities, as well as 26 manufacturing firms, including J. G. Brill and Company, GE & Westinghouse, and the St. Louis Car Company. The committee was chaired by Dr. Thomas Conway, Jr., a scholar and visionary. Conway appointed Clarence Hirshfeld, the former head of research at Detroit Edison Company, as the Chief Engineer for the project. There was initial resentment of these choices among industry insiders since both Conway and Hirshfeld were outsiders. The committee was given a target sales price of $15,000 for the PCC car. The design was revolutionary. It was welded together seamlessly with no visible rivets. The corners were rounded instead of the traditional box look of older streetcars and the windshield was tilted back. Only three manufacturing companies ever built the PCC car: St. Louis Car Company, Canadian Car and Foundry (which took delivery of primered bodies from the St, Louis Car Company due to Canada's high import duties on completed products), and Pullman-Standard. J. G. Brill and Company had originally signed on to build the PCC car, but grew disenchanted with Conway and Hirshfeld's penchant for secrecy. Instead, they developed a competitive streetcar, the "Brilliner."

Figure 6-20

The Brilliner

The PCC cars embodied more than 100 patented components that were held by the Transit Research Corporation (TRC). TRC collected royalties on the patents that were then used to fine-tune the design during the 15 years PCCs were manufactured. Original brakes and doors were run with compressed air but were converted to electricity after World War II. A second development was the addition of "standee windows" along the top of the car so those passengers who were standing could see when their stop was approaching.

Figure 6-21

Interior of PCC car with "standee windows"

A typical PCC car is 46 feet long with two sets of door in a PAYE set up (similar to a bus), weighs 33,000 pounds and has a capacity of 55 seated passengers and 55 standing passengers. Frank Sprague saw Chicago's first PCC in operation on State Street. Between 1937 and 1946, Capital Transit of Washington, DC placed 9 orders and became the first city with a roster consisting exclusively of one-man PCCs, a total of 489 cars. Only four cities had a larger fleet than DC—Philadelphia with 540 cars, Pittsburgh with 666 cars, Chicago with 688 cars, and Toronto with 745 cars. However, by the late 1940s and early 1950s, most cities rushed to put their PCCs up for resale. By 1951, more than 4,900 PCCs were in operation in North America. The PCC was a success, but it did not revitalize the industry. In 1952 the last ever PCC car was delivered to the San Francisco Municipal Railway by the St Louis Car Company. This was the last new streetcar manufactured in the United States.

A Vintage Vision

In 1982, 30 years after the last PCC car left the line, Gomaco Trolley Company of Ida Grove, Iowa, began building vintage replicas with the aid of a contract from the U.S. Department of the Interior. The contract called for the construction of two 15-bench open-style cars that were to be replicas of the J. G. Brill car built in 1902. These first cars were delivered to Lowell Historical National Park in Lowell, Massachusetts, in 1984. In 1987, a third car was delivered to Lowell Historical National Park. This car was a semi-convertible replica of the 4100 series built in 1912 by the St. Louis Car Company and was equipped with cane seats that each had a heater underneath. That same year, two more open-style cars were produced, one each for the TECO Streetcar Line in Tampa and the Denver Rail Heritage Society in Denver. From the first project in 1982 to the most recent delivery in 2008 of two open-style trolleys for the "Americana at Brand" project in Glendale, California, Gomaco has provided cars to Portland, St. Louis, Philadelphia, Charlotte, Fresno, Little Rock, Mount Pleasant, and Memphis.

Figure 6-22

Fifteen-bench replica

Photo courtesy of Gamaco Trolley

Gomaco is not the only American manufacturer of vintage replicas. The City of New Orleans has manufactured more than 30 cars since the late 1990s, including 7 for its Riverfront line and 24 for the Canal Street line, which opened in 2004. They are currently in the process of rebuilding several cars after the flooding of Hurricane Katrina, but have plans to build more vintage cars in the future.

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