SJSU SAN JOSÉ STATE UNIVERSITY

INIST

SPARTAN SUPERWAY

Spartan Superway Development
a white paper
2017-03-14

The SPARTAN Superway is a long-term research initiative at San José State University to establish solar powered automated rapid transit ascendant network ("SPARTAN") systems for urban environments. Founded in 2012 by Professor Burford "Buff" Furman with Ron Swenson of The International Institute of Sustainable Transportation (INIST), since its inception more than 200 students, mentors, and faculty have done extensive research, published a major study, written numerous publications, produced functional prototypes of key subsystems, and established an international alliance of universities and industry collaborators on the pathway to commercialization.

The Superway consists of car-sized or minivan-sized vehicles ("podcars") suspended from a network of elevated guideways, which in turn have photovoltaic (PV) solar panels mounted above them (Figure 1). The solar arrays provide sufficient energy ("net zero") for the entire transportation network. The Superway and other Automated Transportation Networks ("ATN") enable people to travel between any pair of stations in their network without waiting, line transfers, or intermediate stops. ATN thus offers a ride experience on par with the personal automobile but with significant advantages – eliminating parking, accidents, and congestion, while liberating urban space for pedestrians, bicyclists, sidewalk cafés, and farmers' markets.

Figure 1. Solar Powered Automated Transit. Relatively small vehicles traverse a network of exclusive guideways and utilize off-line stations to provide on-demand, non-stop, origin-to-destination mobility. Suspending the ATN vehicle below the guideway makes the upper surface available for PV panels that can power the system. (JPods system, from (Wilmott, 2015))

ATN as a concept dates back to the 1950s, and five transit systems that have ATN-like features exist around the world[1]. The disruptive novel combination of solar PV with vehicles suspended on the elevated guideway distinguishes the Spartan Superway from all currently operating ATN systems.

Over the course of five years, the SPARTAN Superway research teams have been collaborating with universities and commercial parties who share this common vision of solar powered, suspended ATNs. One primary collaboration has been developing drive-train technology patented by Beamways AB, Sweden (Gustafsson, 2014). The patent holder is heavily involved in the development process, which ensures that results can be readily applied in real systems, and that the Intellectual Property ("IP") generated during development is properly protected. The patent has issued in the USA, China, Japan, Korea, and Russia, and is pending in Europe, India, and Brazil.

In addition, the Superway team has begun developing and testing the Solomon Knot Crossbeam (SKC) – a novel high strength structural element for the Superway elevated infrastructure, in collaboration with Futran Podcars RSA, South Africa[2].

The Superway is being developed substantially by students at San José State University (SJSU) with the guidance of SJSU faculty and industry mentors. Students and interns from other universities have also participated, including Delft University (Netherlands), Uppsala University (Sweden), Presidio Graduate School (San Francisco), Southern Illinois University, Linköping University (Sweden), Pusan National University (South Korea), INRA (Lyon, France), inGHenia (Lille, France), and Brazil's Scientific Mobility Program (BSMP) sponsored by the Ministry of Education and the Ministry of Science and Technology. Many of these university affiliations are ongoing, and new ones are being developed.

Why is the Spartan Superway important?

Superway is important, because:

1. **Most mechanized transit modes** (even electric vehicles, indirectly) depend on finite and polluting fossil fuel sources. The SPARTAN Superway is truly sustainable in the sense of exclusively using renewable energy sources, and doing so within its own footprint.
2. **Most mechanized transit modes** compete for the same space at grade, imposing congestion and safety hazards upon the traveling public, endangering pedestrians, bicyclists, pets, and wildlife[3]. The SPARTAN Superway will ***Rise Above*** and liberate the streets for humans to live and thrive.
3. **Public transit** is inefficient and costly, and does not provide adequate mobility for the economically disadvantaged or handicapped. The SPARTAN Superway is clean, convenient, accessible, on demand, fast and efficient and provides mobility equitably for the entire community.
4. **Pollution** from internal combustion engines disproportionately impacts communities of lower socioeconomic status. The SPARTAN Superway operates with clean energy, has high capacity, and with small, low impact, low cost stations, it can reach all parts of the community.

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[1] More information about existing ATN systems and the state of the ATN industry in 2014 can be found in Furman, et.al., 2014 (http://transweb.sjsu.edu/project/1227.html) .

[2] PCT International Application, Andries Louw, 2017.

[3] Kirsten Korosec. "2016 Was the Deadliest Year on American Roads in Nearly a Decade, Fortune, 2017-02-15

In summary, SPARTAN solar powered automated rapid transit is poised to take off as *the* solution to remedy the myriad deficiencies that have accrued as transportation systems evolved over the past century. A new approach is needed to establish ***resilient*,** sustainable urban mobility.

The SPARTAN Superway is a game-changer

The SPARTAN Superway is presented here as a game-changing opportunity to mitigate and possibly eliminate the impacts of fossil fuels that propel land-based transportation, while at the same time enabling society to eliminate many other adverse impacts of modern mobility.

Environmental impacts of automobile-centric transportation systems are extensive. Most urgently, greenhouse gas emissions (GHGE) from all forms of vehicles[4] are among the leading causes of climate change. Furthermore, systems based on finite, rapidly depleting natural resources cannot endure. Unchecked exploitation of coal, oil, and gas, especially in countries with limited environmental oversight, has produced long term pollution and damage to the natural landscape. For all these reasons it is essential to eliminate dependence on fossil fuels and instead focus on renewable energy to combat climate change and preserve hydrocarbons as minerals for chemical feedstock. The Spartan Superway provides such a solution, as it is completely solar powered, therefore eliminating emissions, while also supporting the renewable energy industry.

Safety is a crucial issue for transportation. Currently, automobiles, trolleys, trucks, buses, pedestrians, and bicyclists all compete on the same plane, resulting in more than a million fatalities and several million severe injuries around the world every year. The Spartan Superway is designed on an elevated guideway to eliminate collisions and traffic, and thereby provides room for bike paths and pedestrian walkways. Overland, conflicts with wild animals and agricultural activities are eliminated.

Livability in cities remains a challenge greatly impacted by transportation. Whether gas-powered or electric, cars are noisy, they impose hazards that discourage strolling, shopping, sidewalk cafés or street markets, and they waste enormous amounts of space. The Spartan Superway will allow more relaxing, green environments for social spaces, as well as the health benefits of clean air. Because Superway vehicles operate 24/7 like a city-wide fleet of automated taxis, the need for parking lots and structures is reduced, creating space for affordable, transit-oriented housing development. Additionally, automated transit provides passengers with more time to relax and socialize rather than adding the stress of driving and fighting congested traffic.

Convenient public transit is rare due to infrequent, slow scheduled service, and necessarily wide separation between origin points and stations. Such first and last mile gaps in service hinder many from taking public transit. With small economical stations positioned relatively close together, the Spartan Superway is even faster – passengers can go directly from origin to destination, with no in-between stops. ATN vehicles are on demand and available 24/7, and a user can schedule a vehicle at any time by a mobile app or kiosk terminal available at a station. The Spartan Superway network will connect to other transit systems and extend to communities lacking frequent public transit, thus reducing the need for cars to bridge the last mile gap between homes and stations.

Economical transit is an issue due to expensive fares that compete with cheap gas prices and parking fees. Also, there is a growing need to replace aging transit infrastructure, which requires investment

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[4] This includes electric vehicles, which largely rely on grid power, which for the most part is generated from fossil fuels.

and support. The Spartan Superway will have fair, dynamic pricing, which would incentivize ridership. This will also provide access for those in lower socioeconomic communities, many of whom cannot afford the increasing costs of both transit and owning a car. There must be fare integration with other transit agencies to make transferring easy and affordable.

Educational programs in science and technology provide students with skills and experience, sparking their passions to create a better future. The SPARTAN Superway engages students from San José State University and around the world to design and implement SPARTAN technology. It is important to note that the Superway project requires more than just engineers. Integrating other fields such as environmental studies, urban planning, art, and socioeconomics is key to the project's success. Sustainable transportation is an important emerging field, so it makes sense to expose students to it and engage them in it during their formal education, so that they will be prepared to enter the field when they graduate.

Summary of work to date

2012-2013 (Year 1)

The Spartan Superway project began as an interdisciplinary senior engineering project that also included students from the College of Business, Urban Planning, and interested volunteers. The team designed and submitted an entry for the Solar Skyways Challenge design competition. In addition to an extensive report, the team fabricated a 1/12 scale functional model of a solar-powered automated transit system (Figure 2). The team's work earned the first place award that was presented at the Podcar City Conference in Washington D.C. in October, 2013 (Figure 3).

Figure 2. 2013 Scale model. 1/12th scale model of a solar powered automated transit system

Figure 3. 2013 Solar Skyways. SJSU student Brian Burlingame receiving Solar Skyways first place award

2013-2014 (Year 2)

In year two, engineers designed a straight section of guideway at full-scale (16 ft long) with a movable bogie (Figure 4), and improvements were made to the 1/12th scale functional model. Both were exhibited at Maker Faire 2014 and Intersolar 2014. Additionally, SJSU Industrial Design students explored use cases, what transit vehicles and stations might look like, and how users might interact with an ATN system via smartphone user interface (Figure 5). The work included a station mockup and three full-scale vehicle cabin mockups and the design of a low-cost functional scale model alternative for control system development[5].

Figure 4. 2014 Full Scale. Guideway and movable bogie at Intersolar 2014 (front and back views)

[5] Krueger, A., 2014. Design of a Simplified Test Track for Automated Transit Network Development. SJSU MS Thesis (available at: http://tinyurl.com/zqqwaat).

 

Figure 5. 2013 Industrial Design. Station design concept (left) and smart phone user interface (right)

2014-2015 (Year 3)

In year three, a major accomplishment was the design and fabrication of a full-scale section of guideway that demonstrated autonomous motorized operation of a bogie and the switching concept patented by Beamways[6] (Figures 6 and 7). The 1/12 scale model was completely revised to more closely resemble the Beamways switching concept and its control software was improved (Figure 7). Summer interns from Brazil, Sweden, South Korea, France, and the U.S. contributed significantly by refining various aspects of the solar power subsystem and designing a system for life-testing the switching wheels; designing and fabricating a full-scale exterior model of an ATN vehicle; improving the control system for the 1/12th scale model (Figure 8); designing a suspension for the exterior cabin model; designing and fabricating a lifting gantry for the cabin model; improving the mechanical design of the scale model vehicles (Figure 9); upgrading the full scale bogie control system; and designing a test specimen for torsion testing of the full scale guideway cross section. Also in this year an investigation of linear motors and their sensitivity to misalignment and variation in gap geometry was conducted[7].

 

Figure 6. 2015 Full Scale Prototype. Motorized bogie and guideway section demonstrating switching ability at Maker Faire

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[6] U.S. Patent No. 8,807,043 (available at: https://www.google.com/patents/US8807043)

[7] Aylen, E., 2015. Performance of Linear Induction Motors within an Automated Transit Network. SJSU Mechanical Engineering MS Project report.

Figure 7. 2015 Full Scale Prototype. Prototype demonstration of autonomous operation and switching ability at Maker Faire

Figure 8. 2015 Scale Model. Revised 1/12 scale model at Maker Faire

Figure 9. 2015 Summer. Exterior cabin model and gantry crane (left); demonstration of further improvements to the 1/12th scale model (right)

<u>2015-2016 (Year 4)</u>

In year four, substantial progress was made in demonstrating the ability of a suspended ATN vehicle to traverse guideways with slopes of up to 30 percent, which would provide the means for a station to be located at ground level or for operation in a hilly city. A guideway 65 ft long at half scale with switching sections, upsloping and downsloping sections was designed and fabricated (Figure 10) along with a half-scale bogie, cabin, and active suspension (Figure 11). The guideway was outfitted with solar panels, 4th-rail wayside power distribution, and electrical power management allowing grid tie and battery energy storage. Graduate students investigated the design of automated doors[8] and the dynamics and full-state control design for a suspended vehicle moving on a guideway[9]. Software engineers did initial architecture and prototyping for a smart phone user interface that would enable a prospective rider to interact with the 1/12th scale model as if it were a real system in operation.

Summer interns made significant progress in: planning station locations and guideway locations for an ATN network connecting the SJSU North and South campuses; sizing the solar PV needed for 24/7 net zero metered operation of the proposed SJSU ATN network; initial siting and conceptual design for a full-scale test track near the SJSU south campus (Figure 13); upgrading electronics and control of the 1/12 scale model; improvements to the active suspension system and half-scale bogie; integrating sensors and controls for the half-scale model; and organization of the Spartan Superway Design Center at 128 East St. John Street in San José.

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[8] Wang, H., 2015. Design of an Automatic Door System for an Automated Transit Network Vehicle. SJSU Mechanical Engineering MS Project report.

[9] Brown, W., 2016. Full State Control of an Automated Transit Network Vehicle. SJSU Mechanical Engineering MS Thesis.

Figure 10. 2016 Half Scale Guideway. Guideway with sloped sections and solar panels at Maker Faire

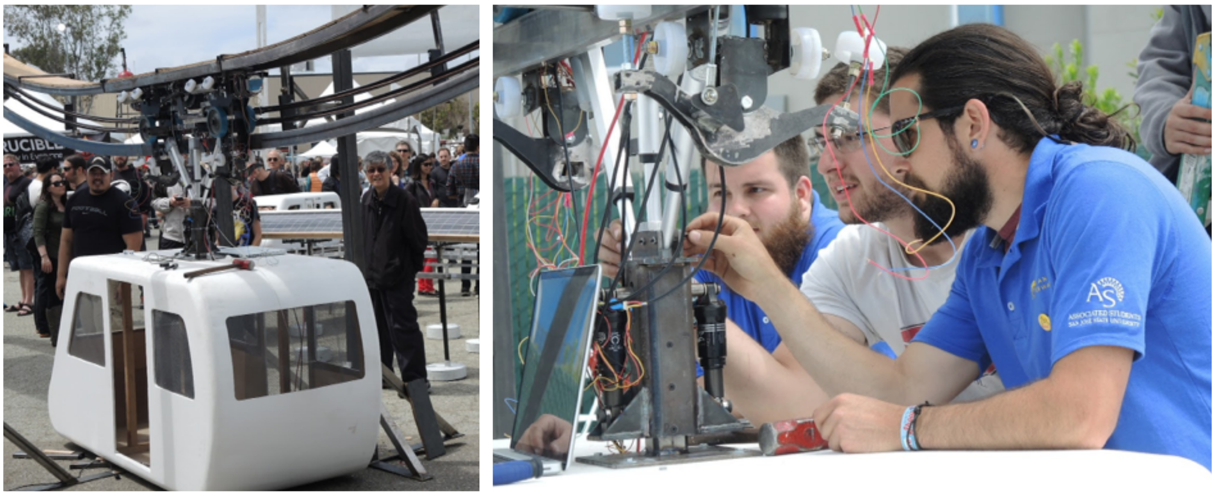

Figure 11. 2016 Half Scale. Half scale vehicle (left) and active suspension (right) at Maker Faire

<u>2016-2017 (Year 5)</u>

The current senior project teams are: revising the half-scale model to reliably demonstrate autonomous operation and the ability to traverse sloped guideways (Figure 12); revising and improving the 4th-rail wayside power system; revising and improving the active suspension system for the half-scale model; improving the functional reliability of vehicles and precision in position sensing in the 1/12th scale model; implementing a smart phone User Interface app to control the 1/12th scale model; improving the solar charging system for the 1/12 scale model; exploring and comparing standard tubular steel structural elements with concrete filled steel tubular (CFST) elements; exploring the design of expansion joints between guideway sections; planning the supply chain and comparing costs for conventional steel vs. CFST structural elements; and developing solar PV racking concepts for the full-scale test track.

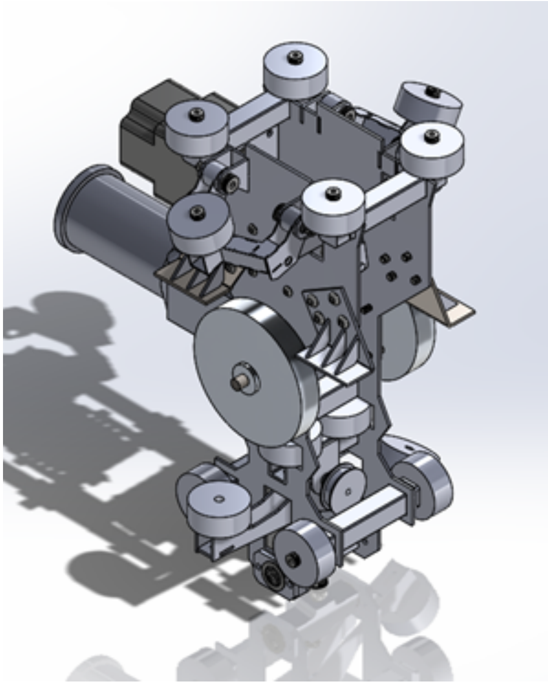

Figure 12. 2017 Half Scale Bogie. Revised model of half-scale bogie.

During this period, the SPARTAN leadership has been developing university-industry partnerships in cooperation with San José State University Research Foundation and the College of Engineering. Several industry groups have expressed interest and negotiations are in process to create definitive agreements for ongoing research and development within the SPARTAN framework.

Work ahead

2017-2018

The plan starting in the summer of 2017 is to expand upon the work done in 2016 for a full-scale test track. A plot of land near the corner of 7th and Alma Street currently owned by the City of San José is in the process of being vacated to the owners of the adjoining property at 1555 South 7th Street. Figure 12 shows the proposed layout of the test track. The track is a 'squeezed loop' approximately 400 m in circumference that has two stations, one at grade and one elevated (about 8 m high).

Figure 13. Plan and elevation section of proposed test track layout.

2018-2019

Prototype testing and safety certification will be conducted during 2018. Design will begin for a pilot ATN network that will connect the North and South SJSU campuses (Figure 14). Design will begin for extending the pilot network and connecting it to other parts of San José and other cities.

Figure 14. Proposed pilot ATN network connecting the North and South campuses of SJSU.

2020 and beyond

The North-South SJSU campus network opens for passenger service. Proceed on projects in California, the USA, and internationally that are currently being developed. Continuing focus on testing, research and development for the benefit of industrial partners and the broader community.

Rationale for Technologies Selected

The Spartan Superway is progressing toward the goal of commercialization with the integration of advanced structural systems, mechanical components, electronics, software, art and architecture, urban planning, and legal/regulatory guidance. A few of these are highlighted in more detail here.

Guideway and Bogie

The Superway's integrated guideway, bogie, and switch design was determined to be the first key requirement for successful commercialization, and as noted above, has been developed according to the patented design of Bengt Gustafsson, the founder of Beamways. Gustafsson patented a unique approach to the bogie and guideway for a suspended vehicle[10] which is a fundamental departure from the supported vehicles utilized in all of the ATN systems in current operation[11]. While it is substantially more challenging to engineer, suspending the passenger cabin from the guideway achieves significant advantages over a guideway that supports a vehicle cabin from below:

1. **Enclosed:** The bogie and guideway can be enclosed, and thereby protected from snow, ice, accumulation of debris, wildlife, or humans intent on interference;
2. **Solar:** The surface above the guideway is available and unobstructed, so sufficient solar panels can be installed to provide 100% of the energy requirements;
3. **Aesthetics:** The guideway can be relatively slim, which is important in minimizing visual intrusion;
4. **Comfort:** Riders are pushed around by side forces when a supported vehicle takes a corner, whereas the motion of a suspended vehicle on a curve pushes riders downward into their seats with centrifugal force (not side forces), resulting in much more relaxing ride comfort;
5. **Switch:** Merging or diverging on the Superway guideway network eliminates the condition in which the support wheels would have to cross a relatively wide gap. The Beamways approach also eliminates having a long unsupported 'sliver' of cantilevered guideway that would occur in more simplistic designs at a merge or diverge section of guideway, such that the bogie and vehicle would need to pass through a clear space while traversing the switch.

Structural System

The Superway test track will integrate the unique patented Solomon's Knot CrossBeam system for superstructure construction, leading to what is projected to become the lowest cost automated transit superstructure. This system, developed in South Africa by Andries Louw, uses high strength Swedish steel, enabling the Superway to achieve elegant, slim, strong, aesthetically appealing structures in the urban landscape.

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[10] U.S. Patent No. 8,807,043 (available at: https://www.google.com/patents/US8807043)

[11] The Cabintaxi (Cabinentaxi) ATN system used both supported and suspended vehicles and successfully demonstrated operation on its test track from 1973-1979. Plans to implement the system in Hamburg fell through after funding from the German government was terminated, and the technology was never implemented in revenue service.

Control System for High Capacity

The Superway test track will incorporate the patented control system developed by Transit Control Solutions, a Silicon Valley company headed by Eugene Nishinaga, former Director of Research and Development at BART (Bay Area Rapid Transit) and helped build the world's first Automated Transit Network system at West Virginia University in Morgantown in the 1970s.

Research and Development Ahead

The Superway project has made impressive strides on a very modest budget to demonstrate innovative approaches to achieve solar powered automated transit. Core development work, field testing and emerging challenges will require more extensive research and development. The SPARTAN development team has prepared a comprehensive 'living' document to organize and prioritize the research that remains to be completed to deliver a system for commercialization.

Meeting the Challenge For Commercialization

The 20th century opened with the introduction of incredible technologies that forever transformed personal mobility and the form of human settlements. Now as the 21st century unfolds, those sophisticated 20th century tools for expanding human capabilities have intensely amplified the impacts of humans upon the earth's life support systems, even threatening the very survival of civilization according to some respected members of the scientific community[12]. Technologies based on fossil fuels and nuclear power made possible a great migration from farm to city, leading to stunning advances inadvertently accompanied by pollution, species extinction, climate change, congestion, even warfare. In turn, "smart" and "green" technologies (smart phones, smart cities, smart buildings, automated cars, renewable energy) have been justifiably invoked to remedy those maladies[13]. At this juncture, the enduring success of the human experiment depends upon combining and integrating such "smart" new technological breakthroughs coherently to achieve sustainable outcomes. The SPARTAN Superway is a breakthrough which was designed from the outset to mitigate the burdensome impacts of modern transportation technologies upon society.

Tough problems require collaboration. We are collaborating with Industry, academia, and government (national, state, and local). We issue the challenge: Join us in creating a zero carbon emission transportation system beyond oil.

Research Questions Link: https://tinyurl.com/hseupdo

[12] Veerabhadran Ramanathan, Center for Atmospheric Sciences, Scripps Institution of Oceanography, UC San Diego: "The effect of greenhouse gases on global warming is, in my opinion, the most important environmental issue facing the world today."

[13] https://en.wikipedia.org/wiki/Technological_utopianism

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Publications

2016

Alvarez, R., et. al., 2016. Spartan Superway: A Solar Powered Automated Public Transportation System (available at: http://tinyurl.com/jbla3hz)

Branco, L., Rosenfeld, E., Neto, D., and Furman, B., 2016. Case Study of a Solar Power Installation on an Automated Transit Network in San José. ASES National Solar Conference 2016, San Francisco, CA, USA July 10-13, 2016 (available at: http://proceedings.ises.org/paper/solar2016/solar2016-0020-Branco.pdf).

Furman, B., 2016. The Spartan Superway: A Solar-Powered Automated Transportation Network. ASES National Solar Conference 2016 Proceedings, San Francisco, CA July 10-13, 2016 (available at: http://proceedings.ises.org/paper/solar2016/solar2016-0019-Furman.pdf).

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2015

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2014

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2013

Kipping, G., et. al., 2013. SuperWay: A Solar Powered Automated Transportation System. Available from: http://tinyurl.com/pvx9pnk and video of scale model operation: http://tinyurl.com/zlkfsbk

Presentations and Exhibits

2012 IEEE Vehicular Technology Society meeting, August 29, 2012

2013 IEEE Vehicular Technology Society meeting, April 25, 2013

2013-2016 Podcar City 7 (Washington DC), 8 (Arlanda, Sweden), 9 (Mountain View, CA), 10 (Antwerp)

2013 International Solar Energy Society, Cancún, Mexico November 5, 2013.

2014-2016 Maker Faire Spartan Superway exhibits

2014 ASME Santa Clara Valley Section Technical Presentation, June 26, 2014

2014 Intersolar, Spartan Superway exhibit, San Francisco, July 2014

2015 Stanford University Mobility Seminar, February 16, 2015

2015 Silicon Valley S.T.E.A.M. Festival, San José Reed-Hillview Airport, July 2015

2015 Electric Automobile Ass'n 43rd Annual Electric Vehicle Show, De Anza College, Sept 19, 2015

2016 American Solar Energy Society Conference, San Francisco, July 10-13, 2016

2016 US DOT T3e Webinar, November 17, 2016

2016 American Geophysical Union, December 12, 2016

2017 Paseo Prototyping Festival [planned, April 8, 2017]

2017 Maker Faire [planned, May 19-21, 2017]

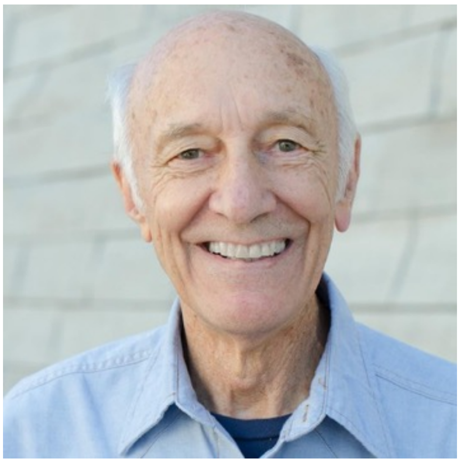
Resumés

Burford (Buff) Furman (SJSU)

Burford (Buff) Furman is a professor of Mechanical Engineering at San José State University, where he has been since 1994. Prior to SJSU, he worked in disk drive development at IBM in San José from 1982 to 1993. He is also a registered professional mechanical engineer in the state of California since 1984. His areas of teaching and research are focused primarily in mechatronics, Automated Transit Networks (ATN), precision machine design, and dynamics.

Buff is a Research Associate with the Mineta Transportation Institute (MTI) and was the Principal Investigator for a major study on the state of the ATN industry published by MTI in 2014. Since 2012, he has been working intensely with interdisciplinary groups of students to develop solar powered ATN.

Ron Swenson (INIST)



Ron Swenson is President of the International Institute of Sustainable Transportation (non-profit) which has been a lead sponsor and advisor for the Spartan Superway and related student solar initiatives. The Institute organizes the annual international Podcar City Conference which has hosted the leaders in automated public transit for 10 years in Europe and the USA.

Ron has done extensive research and development in solar powered transportation, building a prototype solar-powered electric tricycle (1981), a solar race car in Mexico (1992-1996), several electric bicycles and a solar powered utility vehicle (1998-2004), all which served to seed the development of solar powered automated public transit in conjunction with San José State University (2012-present).

Ron is also President of Swenson Solar, developer of commercial solar systems and an ecovillage of approximately 100 solar powered homes and apartments in Santa Cruz, California. He is a Fellow, Life member, and former Board member of the American Solar Energy Society.

Eric Hagstrom (SJSU)

Eric Hagstrom received his Bachelors of Science in Mechanical Engineering from San José State University in 2016, and is currently instructing senior mechanical engineering students working on the Spartan Superway project. In the summer, he manages the Spartan Superway Research Internship Program (SSRIP) that engages both international and domestic engineering students in interdisciplinary research and development for the Spartan Superway project.

When Eric is not spending time as an instructor, he is the General Manager for the Spartan Superway Project.

Spartan Superway Student and Summer Internship Teams

2012-2013 (Year 1)

2013-2014 (Year 2)

2014 Summer

2014-2015 (Year 3)

2015 Summer

2015-2016 (Year 4)

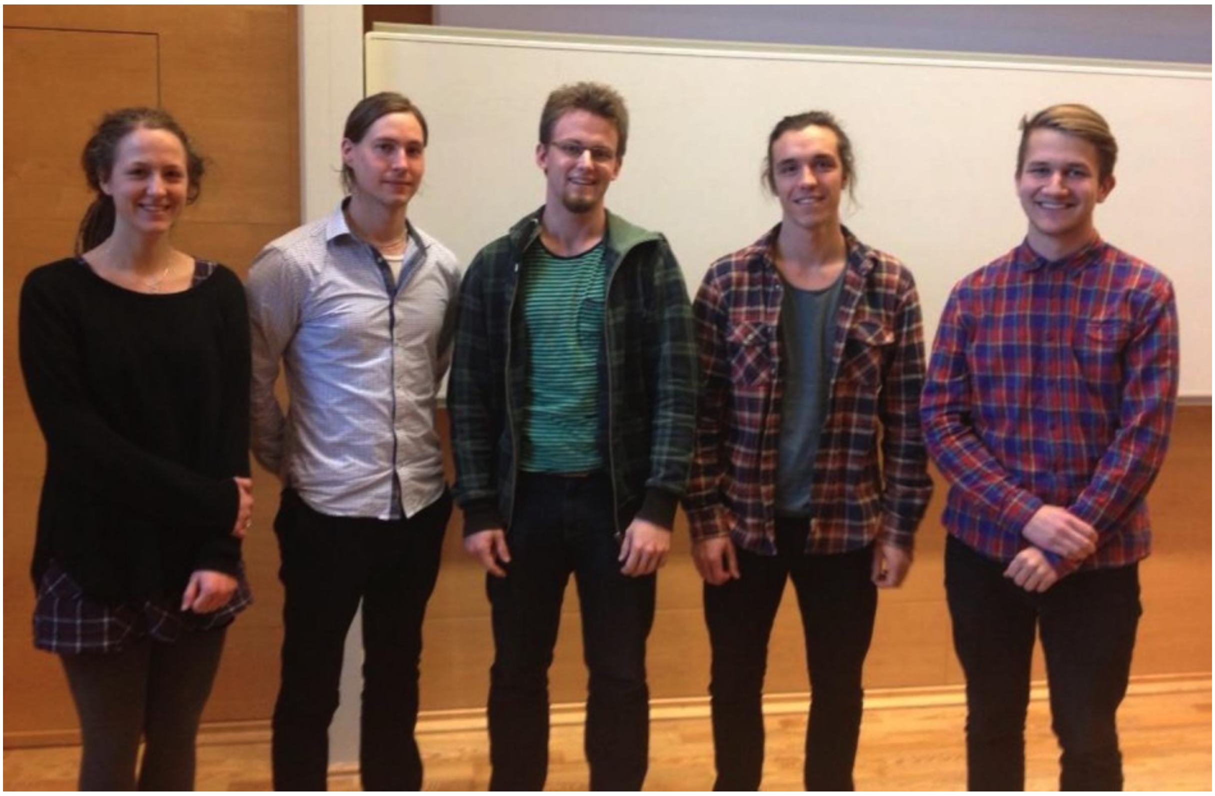
2016 Summer

2016-2017 (Year 5)

Cooperating University Teams

2012 Nerds 'n Squares, Delft University, Netherlands

2013 Ångström Engineering Team, Uppsala University, Sweden



2014 Presidio Graduate School, USA

2015 Architecture Department, Southern Illinois University, USA

2015 Pusan University, South Korea