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# A study on the effects of urban shadow impingement on solar powered transportation systems

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## 1. Abstract

This paper deals with the impinging effects of urban environmental shadows on solar powered transportation systems in order to inform future engineers and city planners on how to construct such infrastructure to take into account the intrusion of shadows onto power generation systems. To study this phenomena, an ongoing solar powered automated transit system project was used as a case study, with a planned route being created within a real time interactive 3D modeling system. Qualitative analysis was performed on portions of the route covering university, residential, and athletic areas, focusing on high-rises, the contrast between single and double storing housing, and an athletic field respectively, all while analyzing the geometry of the shadows at different times of the day. Results were drawn from the study, and improvements were postulated.

Keywords: *Solar power, transportation, shadows, automation, urban*

## 2. Introduction

As a result of an ever increasing global population, temperature, and congestion, sustainable public transportation options are becoming a greater necessity in the modern age. This paper will describe a solar powered transportation system being developed in the Bay Area called the Spartan Superway. The Spartan Superway is an Automated Transit Network that uses elevated and automated podcars to move around passengers within an urban environment while being primarily powered by solar. However, urban planners and engineers must recognize that there are facets of a highly developed urban environment that can reduce the usable energy of a solar PV system, namely shadows cast by objects such as buildings (Levinson, 2009).

## 3. Setup

### *3.1 Description of Case study*

The transportation model chosen to study was the ongoing Spartan Superway project at San Jose State University. The Spartan Superway is a personal rapid transportation system designed to run off of renewable resources, specifically solar energy. The Superway works as follows: an elevated guideway encapsulates a city. On this elevated guideway are individual pod cars. Each of these pod cars is completely automated (requiring no driver) and can hold up to four to six people. Passengers can walk up to a station, hail over a ride on their smartphones, and then select their destination. The ride will then continue without any stops. Furthermore, the system is simultaneously powered by a series of solar panels on top of the the track, with a wayside power system to take any


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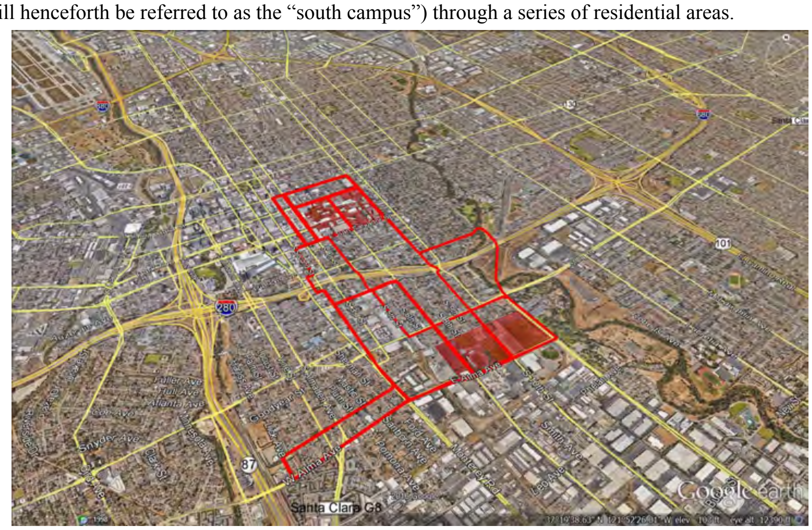
necessary energy from the grid. Since each of the solar panels is in series with one another on a flat plane, the shadows of one solar panel will not affect the power generation of another one . Fig 1. shows a model of the Superway at intersolar 2014.


**Figure 1: A real-world model of the Superway was exhibited at Intersolar 2014**

### *3.2 The route*

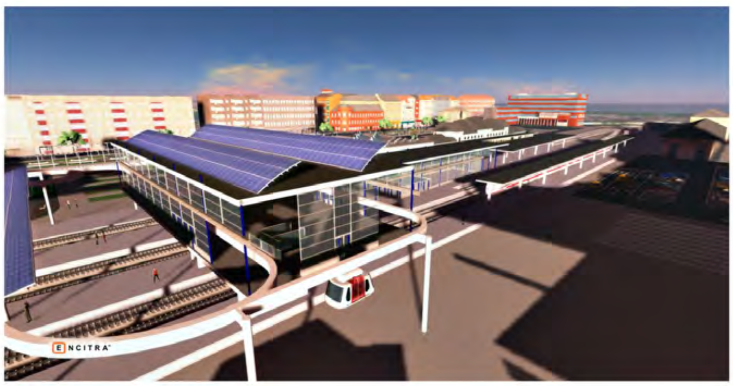
In order to study how shadows can impinge on solar power generation, a route developed by the summer 2016 Spartan Superway Civil Engineering team was chosen for our model. In essence, the route connects the main campus of San Jose State University (located none-other but in the city of San Jose) to the southern athletic center (which will henceforth be referred to as the "south campus") through a series of residential areas.




(**Figure 2 ) A map of the south campus route, courtesy of the civil team**

### *3.3 Software system*

For the purposes of this paper, the south campus route will be analyzed as the case study for shadow effects on solar powered transportation. To perform the analysis, the aforementioned path and a section of Downtown San Jose will be recreated in a three-dimensional modeling software system known as **Encitra** (www.encitra.com). Encitra is a 4D (three spatial dimensions + time) immersive modeling software that allows users to construct almost any object in real time. Most importantly, Encitra generates shadow effects that can be controlled with the time of day. Since the goal of this paper is to construct a general model for the effects of shadow impingement on solar transportation, it was decided to detach the shadow effects from a geographic location to broaden the scope of its applications. A visual example of an Encitra solar network system can be seen in Fig. 3.



**(Fig. 3) An example of the modeling and shadowing capabilities of the *encitra* software**

### *3.4 Modeling*

To model the terrain for San Jose, data from the USGS Earth explorer website was downloaded, and with the use of a proprietary process, the terrain map was generated. Once all of the presets were completed, the "south campus" route was modeled in San Jose. The entire trackway was recreated in the software, and (thanks to the generous assistance of the Swedish Encitra team and American Superway modeling team) visualizations of buildings surrounding the guideway were created. a picture of the model can be seen in Fig. 4. Notice how the system blends in nicely with the surrounding environment.

**(Fig. 4) The Superway model in Encitra**

### *3.5 Shadow analysis preliminaries*

To analyze the shadows, a few procedures were taken. First, the shadows were decoupled from geographic location in order to study a more general solution for global urban environments. To make the analysis process smoother, the morning and afternoon were chosen as the time periods for shadow generation since the peak volume of traffic occurs during these hours (as most commuters are driving to work, and home respectively). Noon was not studied as all of the shadows in the software were directly perpendicular to the ground during that time (proof seen in fig. 5). The Encitra software has been developed to set the default parameters of the shadows based on a latitude of 0 degrees and the time of year to be the solar equinox.


**Fig. 5: Shadows at noon, note how the geometry is directly perpendicular to the ground**

### *3.6 Object of study*

For our objective, it is necessary to study how shading from an urban environment harms the power generation of solar powered-transport. In order to accomplish this, It was decided to divide the study into three sets; shadows by a university, shadows by a residential area, and shadows by an athletic field. These areas were specifically chosen to focus on high-rises, the contrast between single and double storing housing, and an athletic field respectively Each set was done at 6:00 AM, 3:00 PM, and 6:00 PM. The Teal circle is the University, the dark blue circle is the residential area, and the yellow is the athletic field (fig. 6).

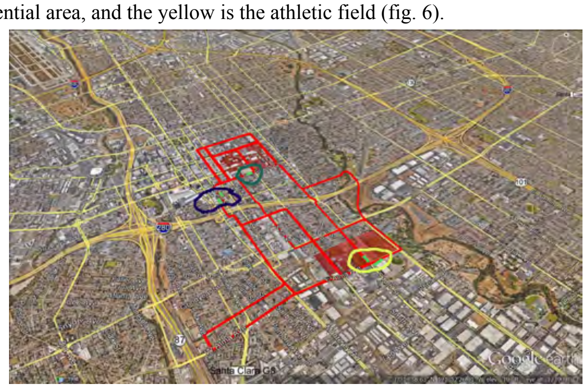


**Fig 6: The locations being studied**

## 4. Method

To analyze shadows, the following procedure was developed. First, a high-interest location was scouted. After finding one, the area would be focused in on with a vertical view. Pictures would be taken on the area would then be taken at 6:00 am, 3:00 PM, and 6:00 PM. The shadows were outlined in green, to make them more apparent.

## 5. Analysis

### *5.1 The University*

For the university area, it was decided to focus in on a high-rise building, as doing so could serve as a future model for similar transportation systems.

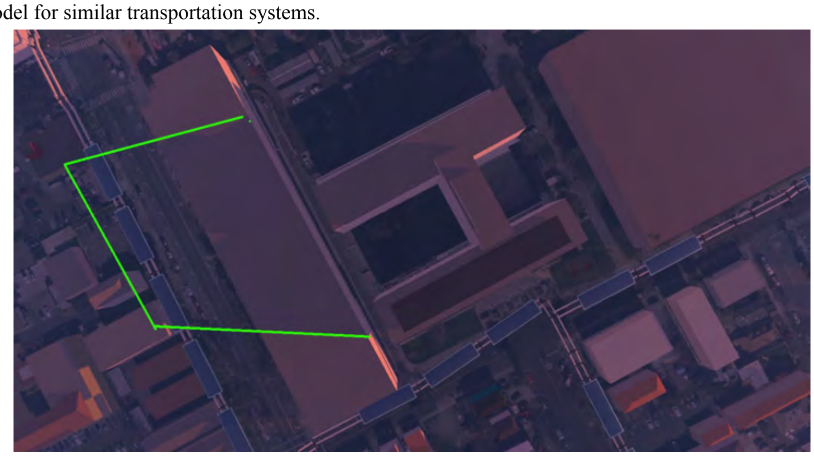


**Figure 7: University high-rise at 6:00 AM**

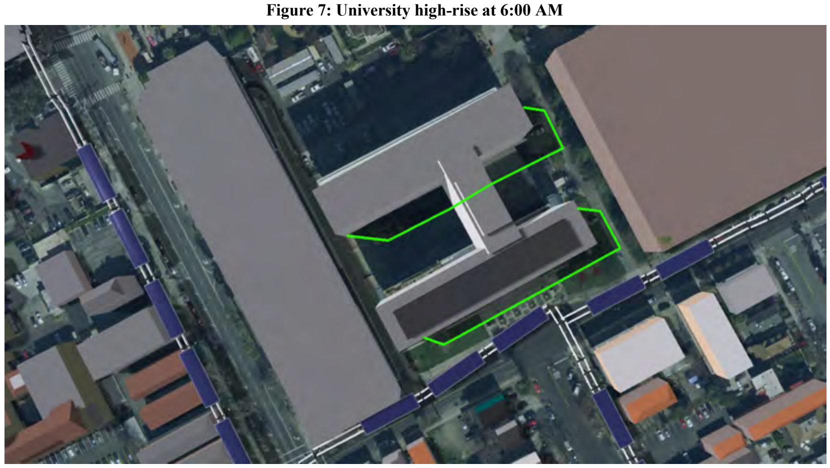


**Figure 8: University high-rise at 3:00 PM**

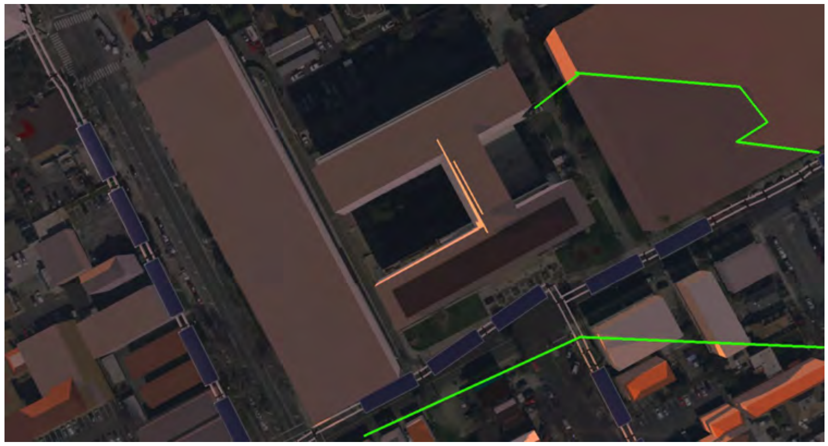


**Figure 9: University high-rise at 6:00 PM**

As one can extrapolate from Figures 7,8, and 9, the high rise building causes a long-shadow to be cast over the track-way, resulting in major power losses.

*5.2 The residential area*

The second part to be analyzed by the residential area, precisely the vertical block above the intersection of second street and Pierce avenue. This specific location was chosen since it contains a double-story house flanked by two single story ones, providing a superb model that could simultaneously illustrate the contrasts between mono- and multi-story unit and show how a system could be integrated into a residential area. The double story house is shown in the middle of figures 10.11. And 12 (the dark brown building)

**Figure 10: The residential area at 6:00 AM**

**Figure 11: The residential area at 3:00 PM**

**Figure 12: The residential area at 6:00 PM**

As one can observe in fig. 12, during the late 6:00 PM evening, the shadows from the single story houses miss the guideways, while the double story house envelops the solar panels (even when they are on the other side of the block). Future transportation experts must take this data in to account when planning routes near such areas

*5.3 The athletics area*

Finally, the "south campus" athletic field was analyzed for shadow impingement. (figs. 13-15)

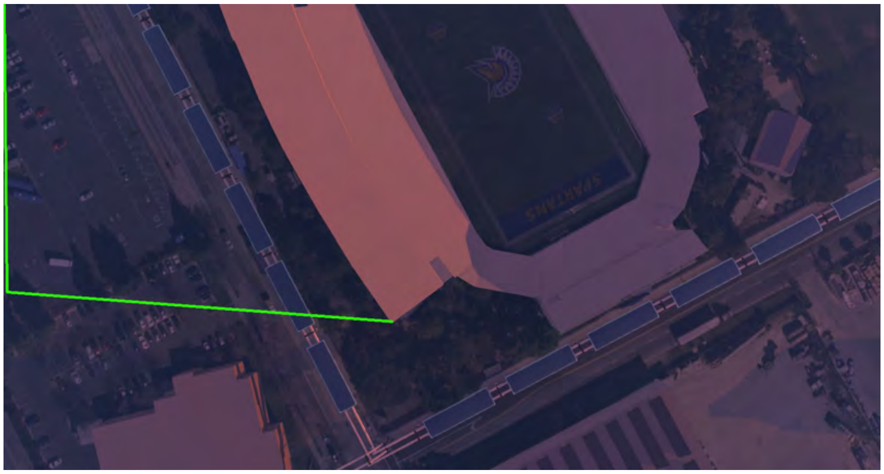



**Figure 13: The athletic stadium at 6:00 AM**

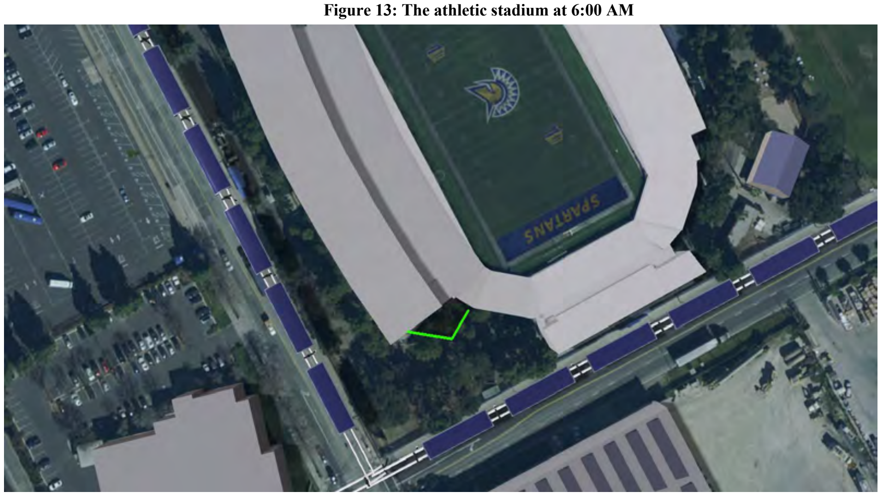



**Figure 14: The athletic stadium at 3:00 PM**

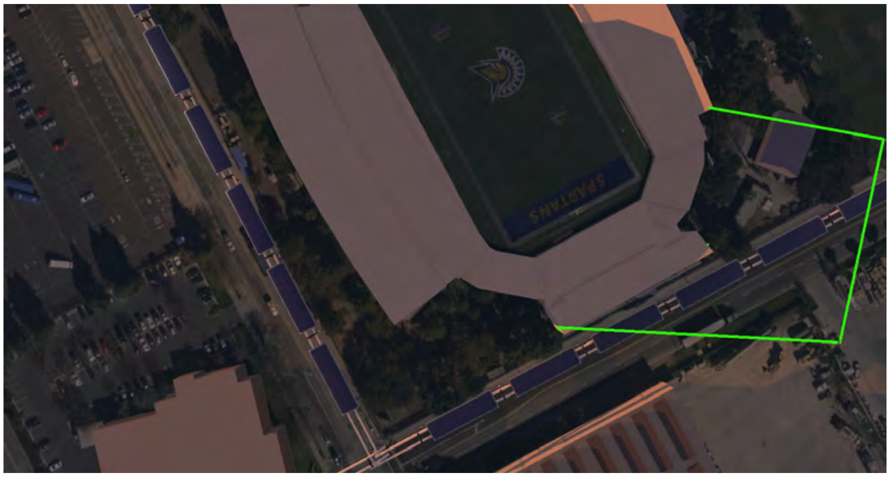


**Figure 15: The athletic stadium at 6:00 PM**

As one can observe, the athletic stadium creates long shadows that envelops everything in its direction. However, streets near athletic fields are usually surrounded by wide streets, it would logical if the guideways were put on the opposing sides of the streets, to ensure that the solar panels do not get harmed.

## 6. Conclusion

After analysis, the following can be concluded. The shadows from single story units are not too damaging, multi-story-units can be incredibly damaging, and putting a solar powered track on the same side of an athletic field would result in a shadow-impinged solar PV-system. Also, at a later stage, this model must be analyzed for pedestrians crossing the street and the effects of foliage.

The results from these studies could be applied to planning future solar powered transportation systems. When taking shadows into construction, it would be rational if solar panels could be mounted at a greater height (so they could dodge shading from two story units), put solar panels on the other side of the street from high rises (to escape the large shadows cast), and install a power storage station (to hold all excess energy from midday, where there is little shading), position the track to be routed to go through single story neighborhoods instead of multi-story areas, connect solar panels onto the roofs of high rises, as such buildings receive larges amounts of solar irradiance (Redweik et. al, 2013). In addition, the use of partial shade resistant solar panels could prove to be useful (S. Dongaonkar, & M. A. Alam. (2012)), and omitting solar panels for large stretches of shaded area near skyscrapers would be very pragmatic. Finally, adding solar trackers may not be practical for solar panels in densely urban areas, as such devices would move the solar panels into the direction of the shadows, causing an immediate power loss.

## 7.. Background literature

References

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