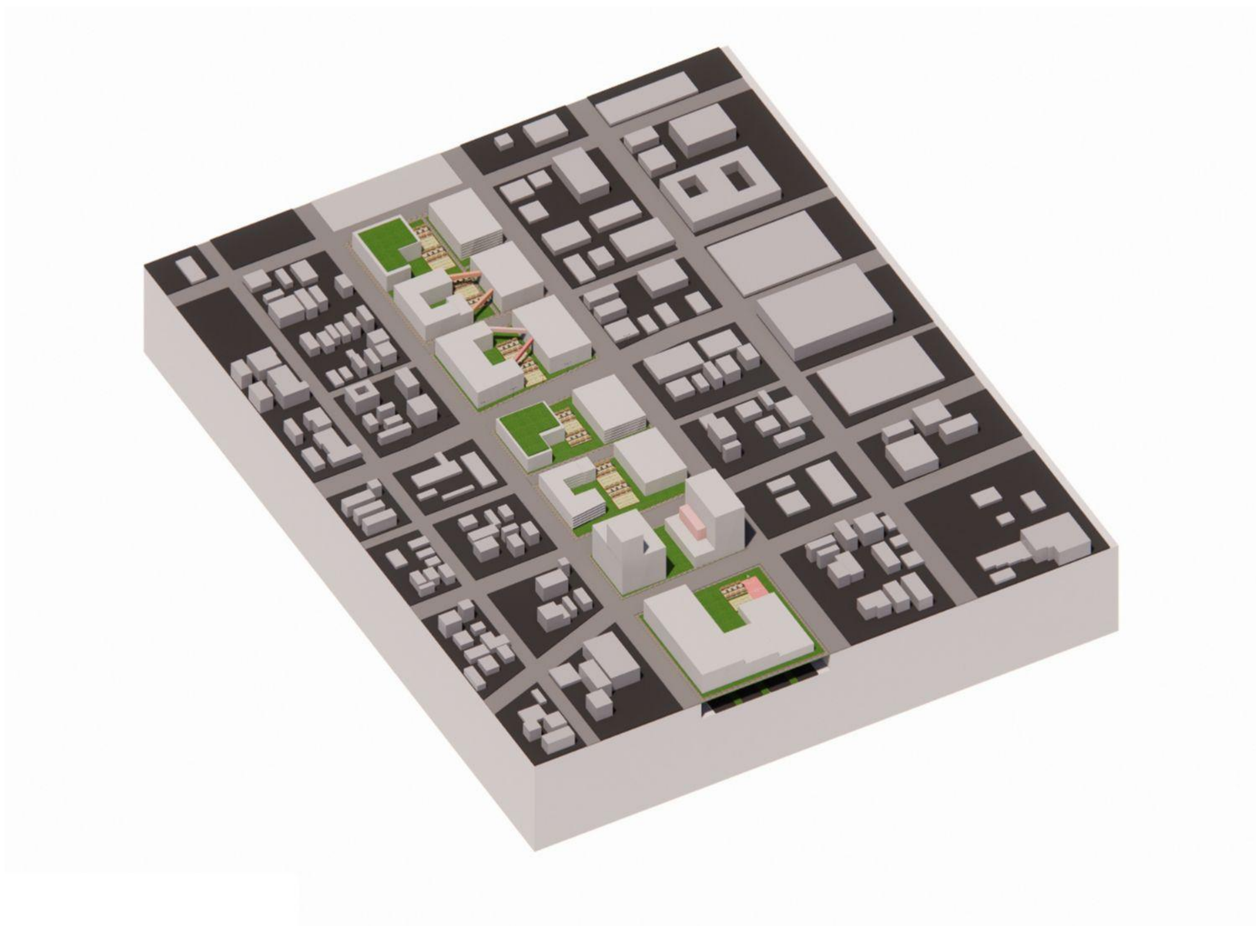
Raising The Project Proposal Bar With Digital Twin Models: Case Study of Oakland's, CA I-980 Highway



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Abstract

Oakland's I-980 is one of the most hated highways in the nation. Despite numerous well-developed proposals from local volunteer groups, the municipal government has not created any plan to respect its' constituents' wishes. We investigate a current proposal by ConnectOakland to remove the highway in favor of housing and a high-speed boulevard and contribute to the project by implementing a partial digital twin model of the area, including a 3-D model, an animation of cars and pedestrians moving in it, a computation of some quantitative changes this project would yield for the pedestrian population, and a project presentation website to bring our additions together into a comprehensive solution. We also offer our effort as a compass for future projects, whether volunteer or governmental, to evaluate a digital twin approach for their own projects. This work concludes: (1) that ConnectOakland's project is a long-overdue, necessary improvement to Oakland as the city grows to become both an economic center and a liveable environment; (2) using a Network Flow algorithm that this project yields an estimated 4.9% improvement in walking time from West Oakland to Downtown; (3) digital twin models are a convenient, easy, and future-proof tool to share a vision for a project with various stakeholders, most importantly the citizens.

Project Website QR Code:

Link to the website: https://oey.jgl.mybluehost.me/i980

Smart Cities Course (BDP 319)

May 10, 2022

Professor Junfeng Jiao

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Introduction

Digital Twin as a concept

A digital twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning, and quantitative reasoning to help decision-making.

A traffic digital twin represents a digital version of a physical object or process in traffic, such as a traffic signal controller, and is thus a two-way real-time data exchange between the physical and digital twins.

How does digital twin work?

A digital twin is a virtual model designed to accurately reflect a physical object. Objects under study - for example, wind turbines - are equipped with various sensors related to important functional areas. These sensors produce data on different aspects of the physical object's performance, such as energy output, temperature, weather conditions, and more. This data is then forwarded to a processing system and applied to a digital copy.

Once this data is known, the virtual model can be used to run simulations, investigate performance issues, and generate possible improvements, all in order to generate valuable insights that can then be applied back to the original physical object.

Digital Twin and Simulation

Although both analog and digital twins utilize digital models to replicate various processes of the system, the digital twin is actually a virtual environment, which makes its study richer. The difference between digital twins and simulations is primarily a matter of scale: while simulations typically study one specific process, digital twins themselves can run any number of useful simulations to study multiple processes.

The differences don't stop there. For example, simulations generally do not benefit from having real-time data. But digital twins are designed around a two-way flow of information, which happens first when object sensors feed the system processor with relevant data, and then again when the insights created by the processor are shared back with the original source object.

By having better and constantly updated data relevant to a wide range of domains, coupled with the additional computing power brought about by virtual environments, digital twins are able to study more questions from more vantage points than standard simulations—with greater ultimate Potential to improve products and processes.

Background

I-980 remains a testament to the intense disapproval of freeway construction at the end of the highway-building era. Initially proposed in 1947, public opposition to its construction grew so strong that the project was abandoned in 1971, leaving only a fraction of the highway completed at 18th Street in West Oakland.

Highway construction had already devastated central Oakland. Two preceding highways, the MacArthur and Cypress Freeways, cut off West Oakland's primarily African American residents from employment opportunities and razed homes and locally-owned businesses. After several years of construction calm, Oakland's business interests lobbied the Governor to restart the I-980, claiming it would bring people to Oakland's city center development. The highway was resurrected as part of the Interstate highway system and finally completed in 1985, over a decade after it was thought dead.

Now, the excessively wide highway cuts a 2-mile long trench that prevents West Oakland from enjoying the revival experienced by Uptown Oakland, the neighborhood on the opposite side of I-980 and its parallel frontage roads.

Moreover, the economic benefits promised as part of this highway's construction failed to materialize. Instead, the West Oakland neighborhoods adjacent to I-980 experience some of the highest asthma rates in the state of California (in the 99th and 100th percentile) and have notably poor access to healthy foods. Meanwhile, less than a quarter-mile away across I-980, Uptown Oakland is undergoing a renaissance. West Oakland residents should be able to walk to Uptown's services and amenities but are effectively cut off by a daunting route that consists not only of the Interstate highway but also a pair of frontage roads that serve fast-moving traffic. The right-of-way for all of this asphalt is an enormous 560 feet wide.

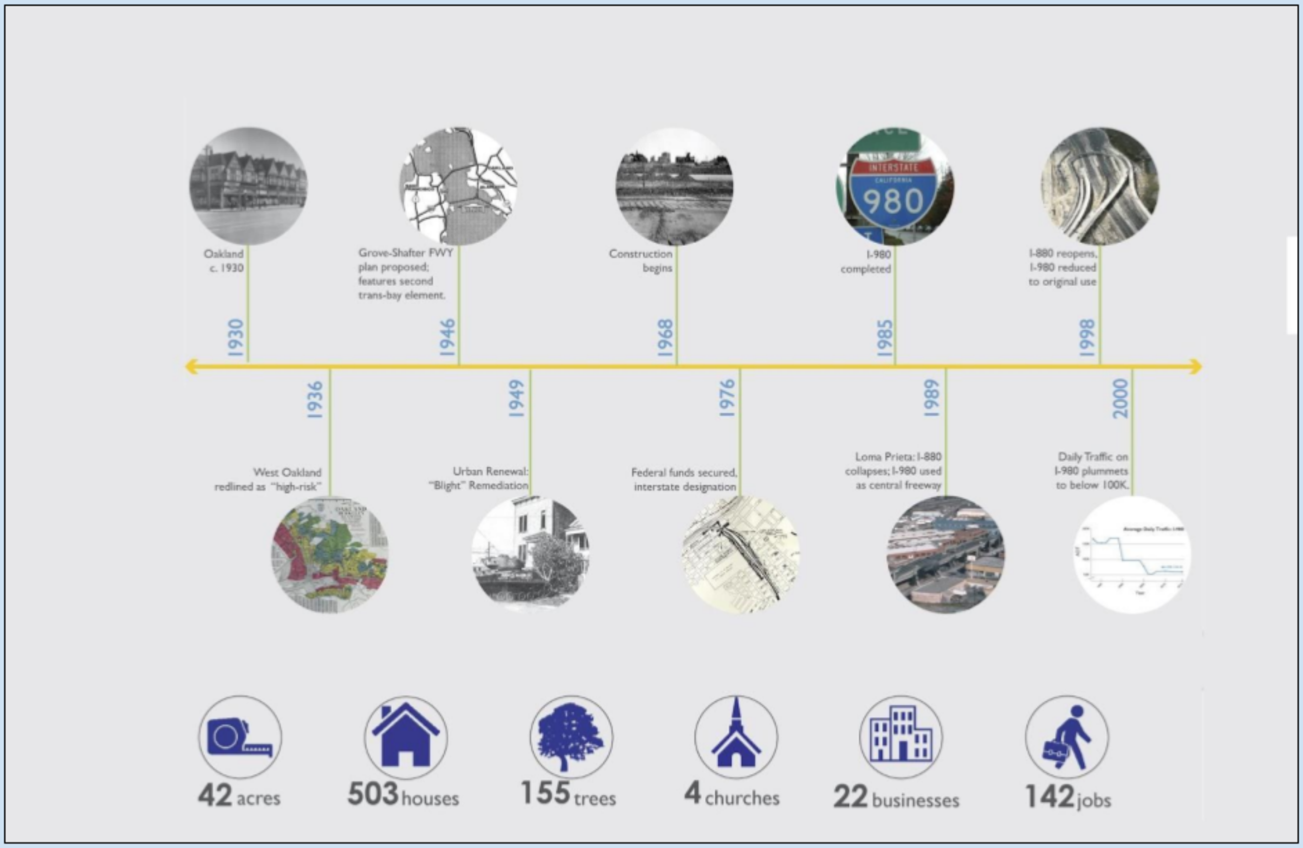
Caltrans acknowledges that the current number of lanes is excessive to accommodate the 92,000 cars per day that travel the road, a volume that accounts for only 53 percent of possible capacity. Most of these vehicles are local traffic, with both origins and destinations along the northern part of the corridor. Most trucks that prefer wide lanes to service Oakland's port already opt for I-880 over I-980. A surface boulevard integrated into a street grid along the route of I-980 would have the capacity to handle the traffic in a more suitable fashion.

Figure 1. ConnectOakland's vision

Issue and History

The tangled story known today as the I-980 highway spans six decades. Telling the story of I-980 is telling the story of Oakland's desire to become an integral transportation connection point for the Bay Area, as well as a destination for business and a growing economy.

Figure 2. Interstate 980 Construction Timeline



Motivation

Data from Traffic flow

Major pieces of transportation infrastructure, like freeways, airports, or rail lines, are costly and complicated, so most people rightly assume that they will get heavily used. This perception is so prevalent that "bridges to nowhere" make evening newscasts and the monologues of comedians. Most Bay Area freeways fit the former category with high traffic volumes and congestion. However, one freeway in Oakland is a clear exception to the rule.

While not a freeway to nowhere, the I-980 freeway in Oakland is a freeway with a questionable purpose since it was originally designed to access the unbuilt second Bay Bridge. As a result, the below-grade portion of the freeway is one of the least busy freeways in the Bay Area for daily traffic and may have the lowest peak hour traffic of any interconnected Bay Area freeway. I-980 is a six-lane highway that is only used at 25% capacity during peak periods. By comparison, neighboring freeways like the MacArthur Freeway (I-580), the Nimitz Freeway (I-880), Highway 24, and I-80, are operating between 36-43% of capacity during the same time periods. Can this piece of public land dedicated for transportation be used for a more efficient and higher use?

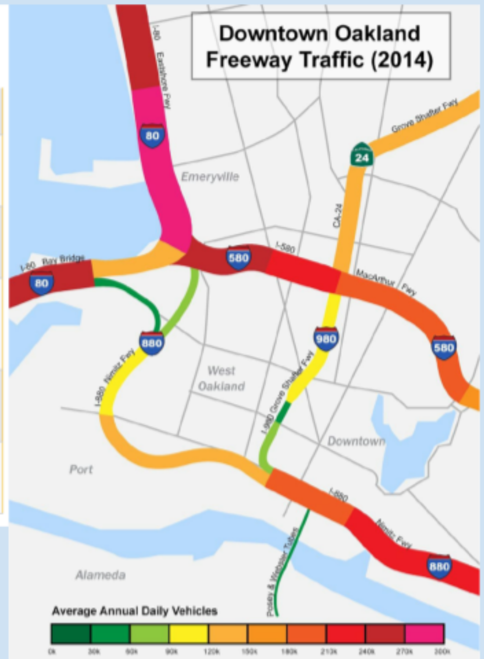
Let's examine the portion of I-980 between West Grand Ave and I-880 in more detail. We'll look at its right-of-way capacity and consider how to reposition it as a boulevard and rail tunnel that can carry many more people than the current highway, and provide a higher capacity. I-980 currently carries about 6,240 people in its peak hour and 73,000 vehicles per day. The highway has an hourly capacity of 18,870 vehicles or 22,643 people per hour(1). With new rail infrastructure in the same alignment, trains could carry over 50,000 people per hour(2) through the corridor – more than double the capacity of the existing highway.

From a vehicular traffic perspective, I-980 is also well suited to boulevard conversion. Although the highway is built to handle nearly 19,000 vehicles per hour, only 5,200 vehicles currently use it during peak periods. Despite the current congestion on I-80 and I-880, I-980 carries less than 30% of their traffic — a clear indication that this infrastructure is poorly positioned and deserves reconsideration. Many avenues and boulevards in the Bay Area can handle 6,000 vehicles per hour and handle up to 63,000 vehicles per day such as Octavia Boulevard in San Francisco and with additional interconnection into the Oakland street grid, the I-980 corridor would only require capacity for 45,000-60,000 vehicles.

Figure 3. ConnectOakland's data on commute time using a potential BART central station (left) and traffic along I-980 (right)

Central Station Makes Existing Transit Easier

	Current	980 Corridor	Difference
Amtrak to BART	11 min (0.5 miles) (Lake Merritt)	2 min (0.1 miles) (Jack London)	9 minutes shorter
Amtrak to Ferry	10 min (0.5 miles)	2 min (0.1 miles) (Jack London)	8 minutes shorter
Ferry to BART	16 min (0.8 miles) (12th St)	2 min (0.1 miles) (Jack London)	14 minutes shorter
Caltrain to Downtown	*29 min via Muni & BART (11 miles)*	8 min (0.4 miles)	21 minutes shorter with no transfer
Ferry to Downtown Oakland	16 min (0.8 miles)	*8 min via streetcar (0.8 miles)*	8 minutes shorter

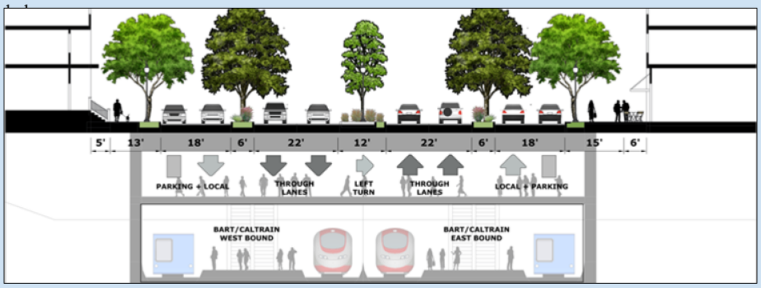


Proposal

With this proposal, ConnectOakland's neighborhood plan has successfully attracted private, public and professional stakeholders over the years. Today, many local leaders and community activists in West Oakland are backing the plan, with Mayor Libby supporting the removal of this underused section of the motorway.

Many are calling for the removal of the I-980 freeway between 20th and 8th Streets in downtown Oakland. This 46-acre underutilized automotive infrastructure has the potential not only to significantly increase housing supply but also to connect historically underinvested West Oakland to the city's core through a high-quality pedestrian network and a human-friendly public realm district. The sunken façade will reduce the cost of underground parking and enhance the vitality of this new neighborhood by expanding a second Transbay subway station with a new BART station.

Figure 4. Dimensional front view of the proposed boulevard with BART central station tunneled



Specific plans for downtown Oakland, released as a draft in the fall of 2019, tie the removal of I-980 with broader equity and housing goals. A housing and transportation policy with significant equity impacts centers on the long-term future of I-980, stating: "Study the long-term viability of replacing I-980 with a multiway boulevard to better connect West Oakland to downtown; Create opportunities for new housing and other uses, use revenue from public lands to repair inequities created by I-980, and support walking, biking, and mass transit." The plan suggests that a multi-lane boulevard may be the best alternative to I-980. The plan claims that the highway's transformation will add 5,000 new residential units and 1.5 million square feet of commercial space. While much work remains to be done, the removal of I-980 will advance many community goals while providing an opportunity for equitable development.

Connect Oakland Vision transforms the I-980 freeway into a ground-level boulevard through a transit tunnel. The remaining freeway land at present will be public land. The land can be built for new developments such as housing, retail or institutional facilities to meet Auckland's needs.

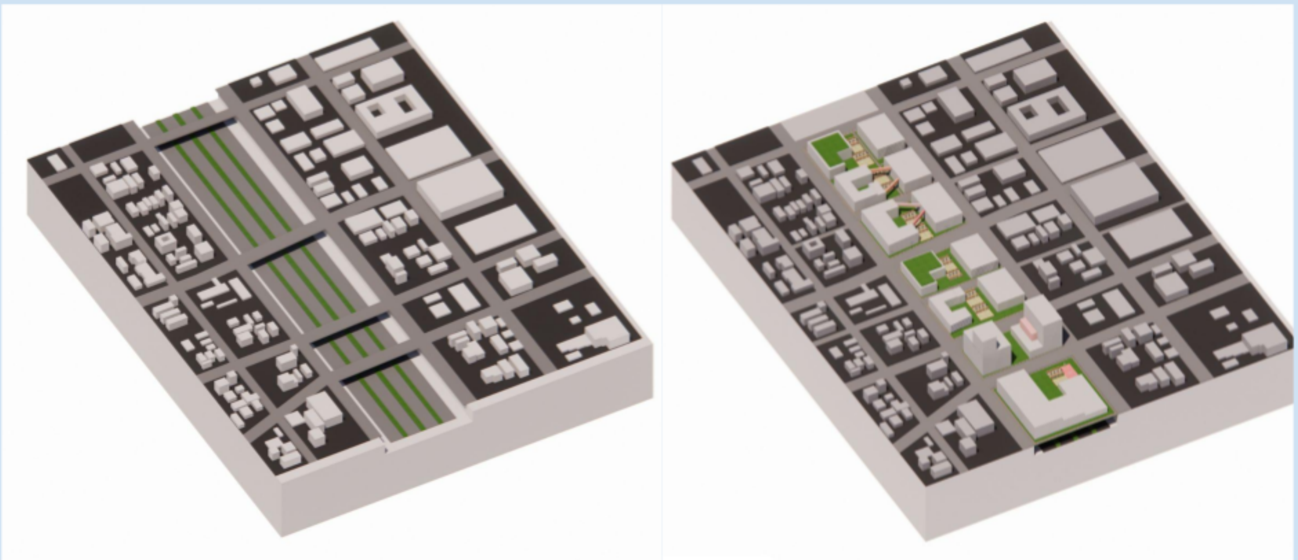
Figure 5. ConnectOakland's vision of new connections between West Oakland and Downtown

The tunnel can accommodate multiple BART lines, Amtrak's Capitol Corridor, Caltrain, California High-Speed Rail or any other electrified rail service. Electrifying buses will make tunnels easier to build, as gasoline- and diesel-fueled trains and road tunnels require expensive ventilation systems.

Our Contribution

We believe that while successful in raising interest in specific circles, so far the project's idea has not spread widely among ordinary voters who could use their vote to make this project happen. One of the problems, as is with many infrastructure projects, seems to be its abstractness. By creating a digital twin consisting of a 3D model, animations of cars and pedestrians, and providing quantifiable data on pedestrian routes, we hope to breathe new life into this project. We also hope that our project serves as a proof of concept for using digital twin technologies in future infrastructure projects.

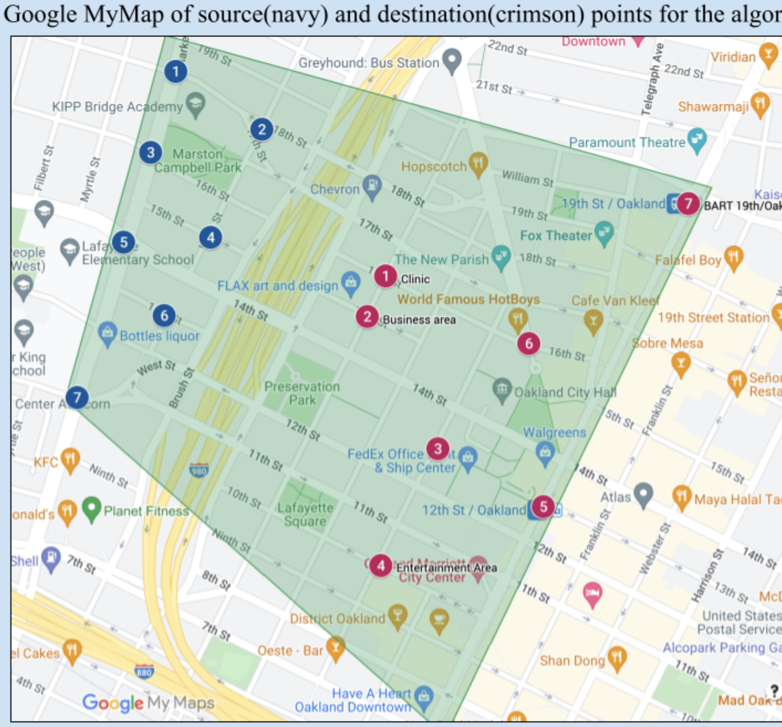
Figure 6. 3-D models of the current I-980 highway with adjacent blocks (left) and our project in its place (right)



Data & Methodology

Traffic Network Analysis

Figure 7. Google MyMap of source(navy) and destination(crimson) points for the algorithm



An integrated and connected Oakland would mean safe, quick, and effortless access to and from Downtown for West Oakland residents. It takes a vast effort, in both time and resources, and most importantly, data, to develop a city's digital twin. But that effort pays off in a multitude of ways, one of which is easy feedback(both citizen and quantitative) on proposed projects. As a first step, we analyzed the population that would be most affected by this project: pedestrians. To create an understanding of how this project could impact the pedestrian population of the West Oakland area, we needed to find how residents currently cross the highway, and how will their behavior change once our project is complete. Currently, these pedestrians are forced to cross two frontage roads and a chain link-fenced bridge over the highway.

We ran a pedestrian traffic network flow analysis and compared the results before and after. Network flow is a known problem in computer science and mathematics centered around finding the highest quantity that can move from point A to point B in a network of pipes or roads represented as vertices and edges in a graph. **Figure 8** shows a sample graph on which this algorithm is run. We represented various residential locations in West Oakland as blue-colored inputs of pedestrians into the network**(Figure 7)**. The crimson destinations were points of interest in Downtown Oakland such as BART stations, food service areas, centers of business, entertainment areas, and a clinic. The streets would be represented by edges of the graph, and intersections are the vertices. Each edge has a cost(c) and a capacity(u). In our case, we represented the time in minutes it takes to walk from one point to another as the cost, meanwhile capacity is pretty much unlimited for pedestrian crossings. We used an algorithm called Minimum Cost Maximum Flow, which essentially finds the optimal pathways for pedestrians to take to their destinations taking the least total time.

Figure 8. Example of graph representing a network of edges between vertices, where 1 is source and 8 is destination.

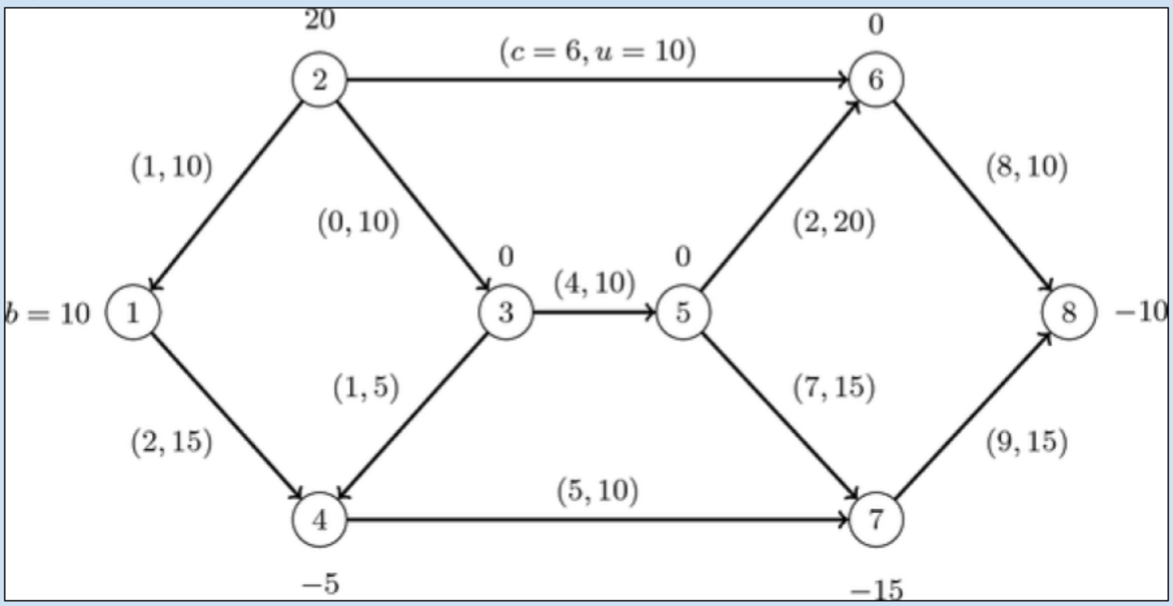
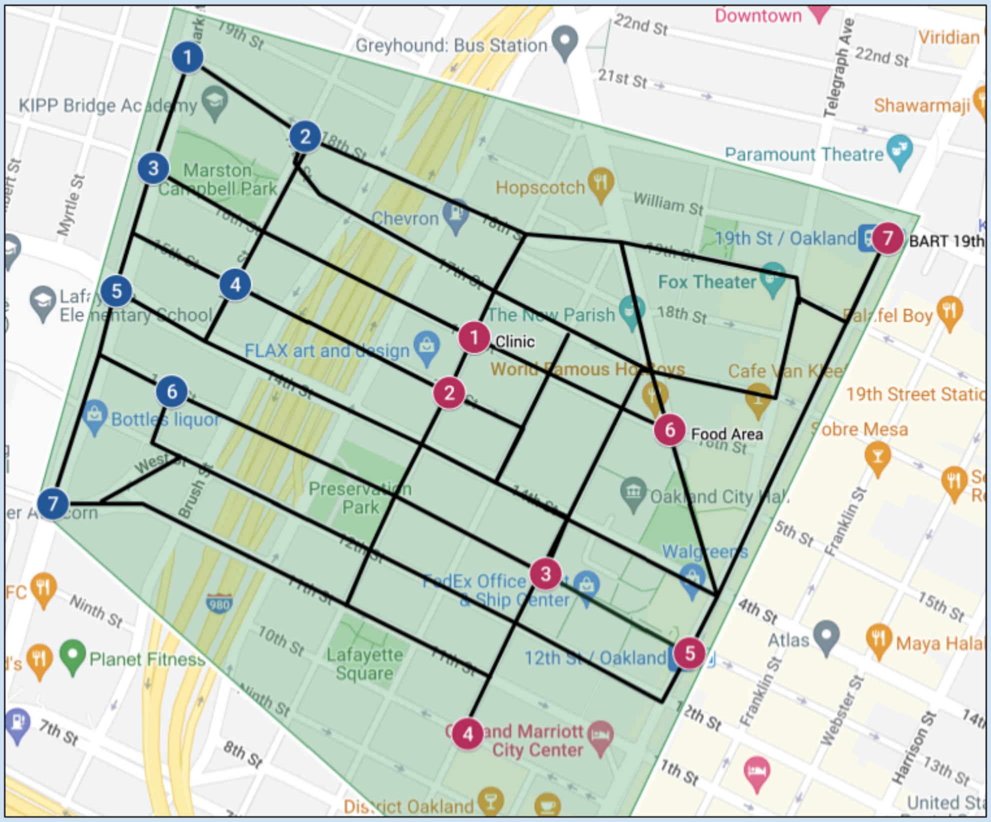


Figure 9. Google MyMap of street used as pedestrian paths in our Minimum Cost Flow algorithm



Software

Below is a table displaying software used and its part in our project:

Software	Usage
SketchUp	Creating of the 3-D model for the project
TwinMotion	Animation - moving cars and pedestrians along drawn routes, creating a cinematic video
Python + Google OR Tools	Programmed the algorithm solver in Python using Google's OR Tools library, designed to solve optimization problems like this one.
Google Maps	Maps visually representing the Min Cost Max Flow algorithm **(Figures 7 and 9)**

Limitations

To our knowledge, the City of Oakland does not have public data from any sensors tracking pedestrian or vehicular traffic in the area. The unavailability of real-world pedestrian data forced us to make several educated assumptions about the West Oakland pedestrian activity. With a total population of 25 250, we assumed the average West

Oakland resident walks downtown once a week. If spread across all daylight hours, around 225 residents cross the highway every hour. The truth is that accurate numbers are not as important in this demonstrative calculation whi

If this project is taken up by the City, one of the first steps would be to collect data on pedestrian and automobile traffic on the highway and above it. This code would not need many changes to be used on live pedestrian or automotive data, and it would provide instant knowledge on which streets bear the most load and have to be planned with an abundance of care.

Here are a few variables not taken into account in my analysis:

- Downtown Oakland is a major center of employment, but we couldn't find information on how prevalent is employment in Downton for West Oakland residents.
- Induced Demand
    - Once the project is implemented, demand for traveling via the newly updated corridor will increase.
- Real traffic data is not currently available
- Improvements to the corridor would draw more leisure visitors
- Other modes of transport like cars, bikes, public transport
- Residents would switch between modes of transport if one of the modes suddenly became more attractive
    - For example, a BART station underneath the boulevard along with a new Transbay line would drastically increase the number of BART commuters in the area

Results

Network Flow

In the following figure, we display the output of our Minimum Cost Maximum Flow algorithm. It provides a comparison between the current state of the area and its state when the project will be completed. It shows an aggregation of the total time all 225 pedestrians took to get to their destination and an average travel time per pedestrian. In short, the figures represent that the addition of only a few more streets crossing what is now I-980 can shorten the average walking time for all West Oakland residents by about **4.9%**. In the Appendix, we included the rest of the algorithm's output, in particular showing how much was each street used by pedestrians. GitHub repository with the code is also included in Appendix.

```
Time travelled across all pedestrians:  2985               Time travelled across all pedestrians:  2845
Time travelled per pedestrian:   14.560975609756097        Time travelled per pedestrian:   13.878048780487806
```

Figure 10

Transit 3-D Animation

The concept of the visual digital model of the real object is at the heart of the digital twin. We believe that showing residents how their neighborhood will look and feel after the project is completed is a great way to win their hearts and backing. We also wanted to show that this can potentially be implemented. We understand that citizens will have trouble imagining themselves immersed in a gray lifeless 3D model, so we created an animation video showing cars driving along the new houses and green spaces created by this project. This video is further available on our website on the ***3-D Model*** page. Below we provide a few images from the video.

Figure 11. Aerial view screenshot of our animation 3D model of ConnectOakland's project proposal

Figure 12. Screen capture of cars and pedestrians moving to their destinations in the animation video

Conclusions

The I-980 remains one of the nation's most hated highways, but so far that hasn't materialized into a concrete response from the municipal government. Yet, it has materialized into extreme asthma rates, economic slowdown, and isolation for neighborhoods around it. We hope that by providing the city with a way to deeply investigate all sides of this issue, including traffic and public opinion, by using digital twin technologies we help move the needle on this project's materialization.

The full benefits of a digital twin project reveal themselves once there is a two-way data exchange between the digital model and real-world sensors. One further development in light of our analysis would be placing sensors around the area that feed into traffic collection data. This data would show where exactly cars enter the area and where they are heading. After running the algorithm, the city would be able to see how the I-980 highway currently helps the few drivers, and also which streets would carry most of the traffic after its removal.

Moreover, with this case study, we've shown that it is attainable to create a digital twin model for any project. For some locations and projects, open data portals, programs such as ArcGIS, and other private sources can be used with great success to find data. With that being said, it is more challenging to create a complete digital twin, especially without government assistance. Yet such models can come in handy before the project has been officially accepted by the government, and once that stage is passed, these models can be a stepping stone to a full digital twin representation. Post-project completion, digital twin models can still be used for the optimization of traffic, parking policies, stop lights, welfare diagnostics, and other small but important changes.

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Appendices

Appendix 1.

Time travelled across all pedestrians: 2985

Time travelled per pedestrian: 14.56097560975

Arc	Flow / Capacity	Cost
0 -> 1	0 / 80	0
0 -> 7	20 / 80	60
1 -> 2	15 / 80	15
1 -> 8	0 / 80	0
2 -> 3	15 / 80	15
2 -> 9	0 / 80	0
3 -> 4	10 / 80	20
3 -> 10	30 / 80	30
4 -> 5	60 / 80	60
4 -> 3	0 / 80	0
5 -> 19	75 / 80	525
5 -> 4	0 / 80	0
6 -> 13	0 / 80	0
6 -> 7	0 / 80	0
7 -> 8	0 / 80	0
7 -> 14	70 / 80	350
8 -> 9	0 / 80	0
9 -> 10	50 / 80	50
10 -> 17	80 / 80	400
11 -> 4	50 / 80	200
13 -> 14	0 / 80	0
13 -> 20	0 / 80	0
14 -> 15	70 / 80	70
15 -> 21	50 / 80	200
15 -> 16	10 / 80	10
16 -> 15	0 / 80	0
16 -> 17	0 / 80	0
17 -> 16	30 / 80	30
17 -> 18	30 / 80	60
17 -> 22	20 / 80	120
18 -> 17	0 / 80	0
18 -> 23	30 / 80	120
18 -> 19	0 / 80	0
19 -> 24	15 / 80	60
19 -> 18	0 / 80	0
19 -> 27	60 / 80	420
20 -> 21	0 / 80	0
21 -> 25	20 / 80	120
21 -> 22	0 / 80	0
22 -> 26	20 / 80	20
23 -> 26	0 / 80	0
26 -> 27	0 / 80	0
27 -> 26	30 / 80	30

Time travelled across all pedestrians: 2845

Time travelled per pedestrian: 13.878048780

Arc	Flow / Capacity	Cost
0 -> 1	20 / 80	40
0 -> 7	0 / 80	0
1 -> 2	25 / 80	25
1 -> 8	10 / 80	20
2 -> 3	25 / 80	25
2 -> 9	0 / 80	0
3 -> 4	0 / 80	0
3 -> 10	70 / 80	70
4 -> 5	30 / 80	30
4 -> 3	20 / 80	40
5 -> 19	45 / 80	315
5 -> 4	0 / 80	0
6 -> 13	0 / 80	0
6 -> 7	0 / 80	0
7 -> 8	50 / 80	50
7 -> 14	0 / 80	0
8 -> 15	60 / 80	300
8 -> 9	0 / 80	0
9 -> 10	10 / 80	10
9 -> 16	40 / 80	200
10 -> 17	80 / 80	400
11 -> 4	50 / 80	200
13 -> 14	0 / 80	0
13 -> 20	0 / 80	0
14 -> 15	0 / 80	0
15 -> 21	50 / 80	200
15 -> 16	0 / 80	0
16 -> 15	0 / 80	0
16 -> 17	0 / 80	0
17 -> 16	0 / 80	0
17 -> 18	30 / 80	60
17 -> 22	50 / 80	300
18 -> 17	0 / 80	0
18 -> 23	30 / 80	120
18 -> 19	0 / 80	0
19 -> 24	15 / 80	60
19 -> 18	0 / 80	0
19 -> 27	30 / 80	210
20 -> 21	0 / 80	0
21 -> 25	20 / 80	120
21 -> 22	0 / 80	0
22 -> 26	50 / 80	50
23 -> 26	0 / 80	0
26 -> 27	0 / 80	0
27 -> 26	0 / 80	0

Appendix 2.

Network Flow code on GitHub: https://github.com/TheCHIRIk/i980netflow