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Slide 2

Let me start with the problem. On the left, you can see EPA data showing heat waves in the United States have increased dramatically - frequency, duration, and intensity are all trending upward over the past six decades.

This creates a real challenge for urban mobility. Traditional routing applications - like Google Maps - optimize for distance or time, but they completely ignore environmental comfort factors like shade. Heat stress is a documented barrier to walking and transit use, particularly for vulnerable populations.

So the question I'm exploring is: would you walk 5 minutes longer for shade? Can we build routing algorithms that consider comfort, not just distance?

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I had three research questions.

First: How much longer are people willing to walk for shade? What's the practical trade-off?

Second: How do optimal routes change by time of day? Is the best route at 8am different from noon?

And third: How do seasonal patterns affect route recommendations? Does a good summer route work in winter?

To answer these questions, I needed to build a comprehensive routing framework that accounts for time-varying shade conditions.

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I built this analysis using a four-step geospatial data science workflow.

Step one: Data acquisition using OSMnx for street networks, OpenDataPhilly for LiDAR building heights and tree canopy, and SEPTA for transit stop locations.

Step two: Spatial processing with GeoPandas - performing spatial joins, creating buffers, and calculating shade attributes for each street segment.

Step three: Network enhancement - adding shade attributes as edge weights to the street network. Each segment gets a shade score that varies by time and season.

Step four: Custom routing using NetworkX. I implemented time-specific cost functions where shade reduces perceived walking distance. The algorithm finds shortest weighted paths, where weights change by time of day.

The result is a dynamic network with time-varying attributes - the same street has different 'costs' depending on when you're traveling.

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I used four main data sources. Building heights come from OpenDataPhilly's LiDAR-derived dataset. Tree canopy is from the 2018 LiDAR survey at half-meter resolution. The street network is from OpenStreetMap, filtered to walkable paths. And transit stops are from SEPTA's data.

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I focused on University City, due to long computing times. This gave me a 3.2 square km area covering Penn and Drexel campuses, residential areas, and major transit corridors.

The network includes over 23,000 street segments, 16,000 buildings, and 60 SEPTA transit stops including 5 major stations on the Market-Frankford Line.

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Here you can see the tree canopy in green overlaid with building footprints

Slide 8

To capture time-of-day variation, I analyzed 8 scenarios: three times in summer, three in winter, and midday for spring and fall. This captures both daily and seasonal variation.

For shade calculation, I combined tree coverage and building shadows weighted 40-60. Research shows building shade is more effective because it blocks more sunlight.

The key innovation is the cost function shown at the bottom: Walking cost equals length times one minus 0.3 times the shade score. This means a fully shaded street effectively feels 30% shorter than an unshaded one. This parameter tunes how much people value shade versus distance.

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This shows the entire street network colored by shade score for all 8 scenarios. Red indicates no shade, green indicates good shade.

A few key patterns jump out: First, the dramatic variation across scenarios - from a mean of 0.25 in winter evening to 0.45 in winter morning. That's nearly double the shade availability.

Second, summer midday versus winter evening - the network literally transforms. Some streets go from green to red, others stay consistently shaded.

Third, certain corridors show consistent patterns - the north-south streets with tall buildings provide reliable shade, while east-west residential streets vary more by time of day.

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Comparing the four seasons at midday isolates seasonal effects. Summer shows mean shade of 0.33, winter 0.43 - interestingly winter is actually higher in this dataset, likely due to the low sun angle creating longer building shadows, though spring and fall are similar around 0.38-0.39.

The spatial patterns are clear - certain corridors maintain shade across all seasons, while others are highly variable.

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This heatmap provides a quick visual summary. The darkest cells represent optimal conditions for shade routing - winter midday and morning score highest at 0.43-0.45. The dark red cells show when shade routing offers minimal benefit - winter evening at 0.25.

The key takeaway: midday consistently offers better shade opportunities across all seasons, while evening shows the most variation.

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Here are the detailed statistics - winter morning offers the highest mean shade at 0.45, while winter evening is lowest at 0.25

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Now let's look at the practical question: what are the actual trade-offs?

I analyzed three example routes. Penn to 40th Street requires a 95-meter detour - that's 12% longer - but provides 38% more shade. The efficiency score of 3.2 indicates this is a high-value route.

Drexel to 34th Street is even better: only 8% detour for 28% shade gain, with an efficiency of 3.5.

Clark Park to 46th Street requires a larger detour at 15%, but still gains 42% shade with a moderate efficiency of 2.8.

The key insight: most routes offer 25-40% shade improvement for just 8-15% extra distance. In absolute terms, that's typically one to two extra blocks - maybe one extra minute of walking - in exchange for walking mostly in shade instead of full sun.

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The best scenarios tend to be Drexel routes in summer, while worst scenarios are winter evening for all routes

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This comprehensive analysis shows multiple dimensions. I'll highlight two key findings:

Looking at the middle chart on top - shade coverage by time of day - midday consistently provides the most shade across all seasons. The boxplots show midday has both higher median shade and less variation.

And looking at the routing efficiency chart on the bottom right, summer evening shows the highest efficiency - you get the most shade benefit per meter of detour. Winter evening shows the lowest efficiency - there's simply less shade available to optimize around.

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Here's Clark Park to 46th Street Station across four scenarios. The blue dashed line is the shortest path - what Google Maps would give you. The colored solid lines are the shadiest paths my algorithm recommends. The background shows the network shade distribution.

Looking at summer midday in the top left, you can see the algorithm routes differently than the shortest path, finding streets with better building shade. The detour is less than 1%, but shade improves by 9%.

Compare that to winter midday in the top right - the network looks different. More green overall due to low sun angles creating longer shadows. The algorithm still finds a better shaded path, but the improvement is smaller.

The key observation: optimal routes actually change between scenarios. It's not just that the same path is shadier at different times - the algorithm finds completely different paths because the shade distribution across the network changes.

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Here are some graphs that show metrics for all 8 scenarios for this example. The spring midday route had the highest benefit from shade optimization.

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The tree canopy data is binary - present or absent - I don't model seasonal leaf coverage separately. The shadow calculations are computationally intensive at about 2-3 hours for all scenarios. And I focused on shade as a single comfort factor.

Future work includes integrating additional environmental factors like air quality, developing this into a real-time API, and adding user preference controls so people can tune how much they value shade versus distance.

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