Pittsburgh S2 Street Map: Slope-Sensitive Mapping Tool for Efficient Network Analysis

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Abstract

Pittsburgh S2 Map is a cutting-edge tool designed to analyze and visualize street slopes in Pittsburgh, Pennsylvania, with a focus on identifying truck-suitable routes under specific slope constraints. The tool leverages advanced computational techniques and fast network flow technology to deliver optimized routing solutions for heavy vehicles while ensuring rapid, precise, and user-friendly performance - all without disclosing the underlying proprietary methods.

Key Features

- **Comprehensive Network Analysis:** Integrates reliable, publicly available street network data with advanced computational methods to evaluate slope conditions in Pittsburgh.
- **Slope Evaluation & Threshold Filtering:** Identifies streets that meet defined slope thresholds precisely, ensuring that only suitable routes for vehicles are highlighted.
- **Optimized Routing:** Utilizes state-of-the-art algorithms to rapidly generate distance matrices and compute the shortest paths adhering to user-specified slope constraints.
- **Interactive Visualization:** Offers dynamic, color-coded maps that allow users to intuitively explore optimal routes, with visual cues indicating low, moderate, and high slope areas.

Benefits

- **Enhanced Safety:** Ensures that only routes with acceptable slope conditions are selected, minimizing the risks associated with steep grades for heavy vehicles.
- **Operational Efficiency:** Rapid analysis and route computation enable logistics and transportation planners to make faster, data-driven decisions.
- **Commercial Readiness:** Designed for scalability and ease of integration, this map is well suited for deployment in commercial applications, offering a competitive edge in route optimization and urban planning.
- **User-Friendly Experience:** The interactive interface and clear visualizations enhance engagement for both technical and nontechnical users.

Market Applications

- **Transportation & Logistics:** Optimize truck routing by identifying streets that meet specific slope criteria, thereby reducing fuel consumption and operational hazards.
- **Urban Planning & Infrastructure:** Assist city planners and public works departments evaluate and maintain road networks by quickly identifying slope-sensitive areas.
- **Smart City Integration:** Enhance IoT-enabled urban mobility platforms with real-time slope-based routing solutions that improve navigational accuracy and public safety.

- **Residential Safety during Extreme Weather:** Provide basic drivers with alternative routes to avoid steep streets during extreme weather conditions, such as snowy or icy days, thereby reducing the risk of accidents and ensuring safer travel.
- **Academic and Commercial Research:** Serve as a robust platform for further research and development in transportation analytics without compromising proprietary processes.

Case Study 1: Three Weight Groups of Vehicles with Three Drives (FWD, RWD, 4WD) in Two Road Conditions (Dry, Snow)

Vehicle Weight Classifications

Vehicle weight classes in the United States are defined by Gross Vehicle Weight Rating (GVWR) and are commonly grouped into light-duty, medium-duty, and heavy-duty categories. The U.S. Department of Transportation (DOT) and Federal Motor Carrier Safety Administration (FMCSA) use a classification scheme **(Classes 1 through 8)** based on GVWR [9]. Below are three relevant vehicle groups with their GVWR ranges:

Table 1: Overview of Light, Medium, and Heavy Vehicle Classes

Category	**Class Included**	**GVWR Range (lb)**
Light-Duty	Class 1–2	0–10,000
Medium-Duty	Class 3–6	10,001–26,000
Heavy-Duty	Class 7–8	26,001 and above

Drivetrain Classifications (Brief Overview)

Vehicles can be categorized by how engine torque is delivered to the wheels:

- **Front-Wheel Drive (FWD)**: Power to front axle. Common in smaller cars, simpler layout.
- **Rear-Wheel Drive (RWD)**: Power to rear axle. Typical in pickups, performance cars, and heavier trucks.
- **Four-Wheel Drive (4WD)**: Power can go to both front and rear axles, aiding traction on steep or slippery surfaces.

Traction-Limited Gradeability Expressions

Following *Fundamentals of Vehicle Dynamics* [10], and **not** using small-angle approximations, the maximum slope θ (in radians) a single-axle "van" can climb without wheel slip is:

$$\boxed{\theta_{\mathrm{FWD}} = \arctan\Big(\frac{\mu\, c}{L + \mu\, h}\Big), \quad \theta_{\mathrm{RWD}} = \arctan\Big(\frac{\mu\, b}{L - \mu\, h}\Big), \quad \theta_{\mathrm{4WD}} = \arctan(\mu).}$$

Where:

- μ = tire–road friction coefficient [12],
- b = distance from front axle to CG,
- c = distance from rear axle to CG,
- h = CG height [8],
- $L = b + c$ = wheelbase.

These formulas give the maximum grade in radians; to convert to % slope or degrees, apply the usual conversions.

Vehicle Dataset in Two Road Conditions

Table 2: Vehicle Dataset on Dry Asphalt Road ($\mu = 0.75$)

Make	Model	Year	Group	Drive	u	$\theta\%$
Mazda	CX-5	2017	1	4WD	0.75	75.00
Toyota	Corolla	2019	1	FWD	0.75	33.95
BMW	3-series	2012	1	RWD	0.75	50.40
Ford	F-150	2016	1	RWD	0.75	44.45
Chevrolet	Silverado 3500HD	2020	2	RWD	0.75	64.54
Freightliner	M2 106	2019	3	RWD	0.75	8.00

Table 3: Vehicle Dataset on Snow-Covered Road ($\mu = 0.15$)

Make	Model	Year	Group	Drive	u	$\theta\%$
Mazda	CX-5	2017	1	4WD	0.15	15.00
Toyota	Corolla	2019	1	FWD	0.15	7.61
BMW	3-series	2012	1	RWD	0.15	8.72
Ford	F-150	2016	1	RWD	0.15	7.60
Chevrolet	Silverado 3500HD	2020	2	RWD	0.15	10.02
Freightliner	M2 106	2019	3	RWD	0.15	1.31

In Tables 2 and 3, $\theta\%$ denotes the maximum grade (in percent) each vehicle can achieve under the specified friction coefficient μ. The `Group` column corresponds to the categories of light duty (1—-2), medium duty (3—-6), and heavy duty (7—-8) discussed earlier.

Mapping Tool: Slope thresholds. Figure 1 shows four subfigures that illustrate different maps under slope thresholds of 10%, 20%, 30%, and 40%. These outputs are generated by our mapping tool to highlight the regions where traction or gradeability may become critical.

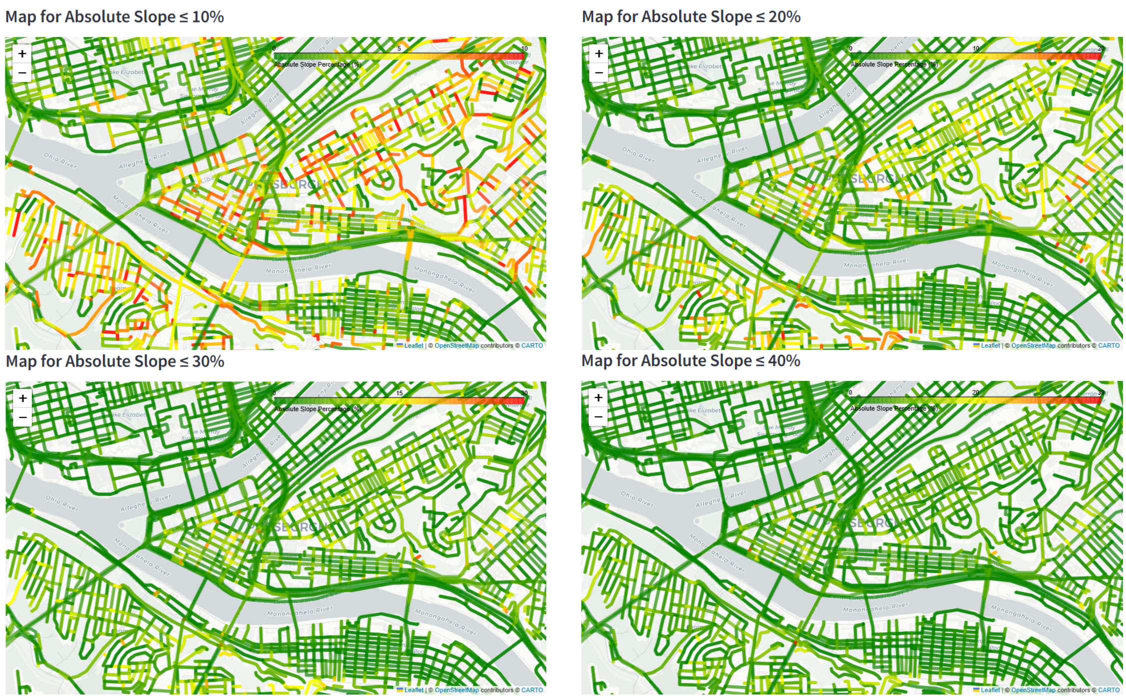

Figure 1: Examples of mapping tool outputs for varying slope thresholds (10%, 20%, 30%, 40%).

Mapping Tool: Shortest Path Figure 2 presents a 6×2 matrix of sub-figures, each row corresponding to one of the six vehicles listed above and each column representing a different road condition (dry vs. snow). These outputs are generated by our mapping tool to illustrate the feasible shortest path between Carnegie Mellon University and Duquesne Heights, given the maximum gradeability (integer-truncated) of each vehicle under the specified friction scenario. If a vehicle cannot handle the required slope in snow (e.g., Freightliner M2 106), a "No Path" placeholder is shown instead.

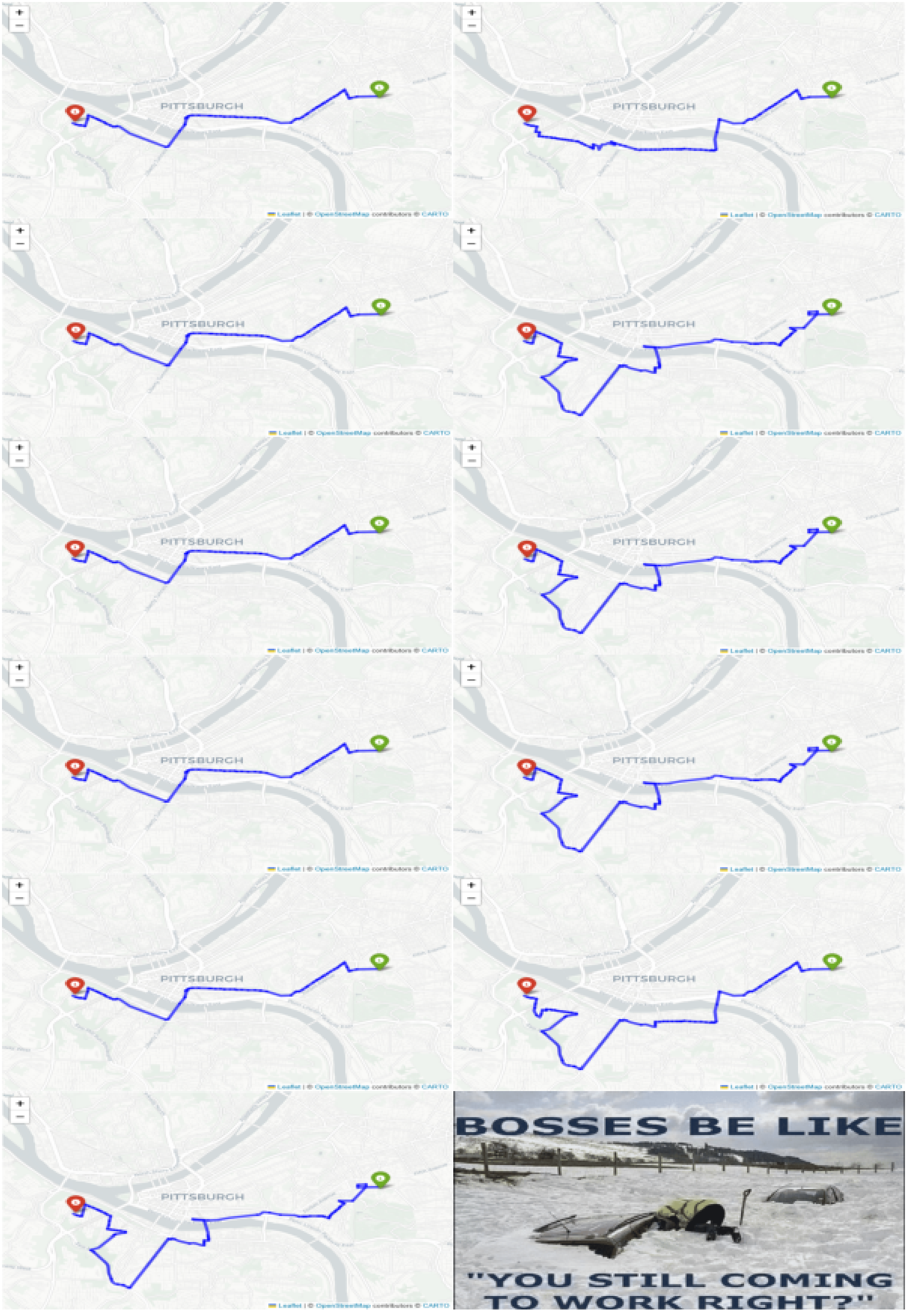

Figure 2: Combined matrix of paths for all vehicles and road conditions (Dry vs. Snow).

Case Study 2: Bike& Scooter Network Analysis in Two Road Conditions(Dry, Snow)

Pittsburgh's journey toward becoming a bike- and pedestrian-friendly city has been remarkable. Once ranked as the "Worst City in the US to ride a bike" in the mid-1990s, the city has undergone significant transformation over the past few decades. The installation of the river trail system in the late 1990s and the opening of the first modern bike lane in 2007 marked the beginning of a new era for non-motorized transportation. Today, Pittsburgh is nationally recognized for having the second fastest 20-year growth in bike commuters [4] and ranked 13th out of the 60 largest US cities in bike commuters [2]. On the other hand, Pittsburgh has also embraced electric scooter sharing in recent years. A study by the e-scooter provider Spin revealed that over 480,000 e-scooter trips with a fleet ranging between 750 and 1,500 units, averaging at least one trip per scooter per day [5].

In light of the increasing number of bike and numerous e-scooter riderships, we integrate findings from both official guidelines and anecdotal evidence regarding max gradeability in Pittsburgh. City and transportation authorities set conservative standards for bike infrastructure: the AASHTO Bicycle Facility Guide recommends a maximum grade of about 5% for dedicated bike paths, with sustained climbs ideally kept to 2% for comfort [7]. For electric scooters, Pittsburgh's pilot program (in partnership with Spin) indicated that shared e-scooters can ride up to a 15% grade under ideal conditions, though performance depends on the rider's weight [3].

For everyday biking in Pittsburgh, cyclists reach the consensus that gradients of about 5–8% or less are considered comfortable for most riders, with 10—- 12% manageable over short stretches. Nonetheless, many routes feature hills around 15%, which represent the practical upper limit for regular commuters [1].

Under winter conditions, the effective gradeability decreases significantly. A standard bike on ice may struggle on even a 2–3% slope due to reduced traction. With the addition of studded tires, however, a bicycle might manage moderate inclines (approximately 5–10%) [6]. Electric scooters, which lack specialized winter equipment, become nearly unviable on snowy or icy slopes, as even flat frozen surfaces pose risks of slippage [11].

Table 4: Estimated Maximum Gradeability for Bicycles and Electric Scooters

Vehicle Type	Dry Asphalt	Snow/Ice Conditions
Bicycle (manual)	∼15%	∼5% (with studded tires)
E-Scooter	∼15%	0–2% (generally unviable)

Mapping Tool: Shortest Path Figure 3 presents a 2×2 matrix of sub-figures, while the first and second rows correspond to a manual bike and an electric scooter and the first and second columns represent riding on the dry asphalt road and snow-covered. These outputs are generated by our mapping tool to illustrate the feasible shortest path between Eastside Bond Apartment in East Liberty and Mercurio's - Pittsburgh in Shadyside, given the maximum gradeability of each one as collected in our survey. If one of them cannot handle the required slope in snow (e.g. E-Scooter on a snowy day), a "No Path" placeholder is shown instead which is replaced by the meme.

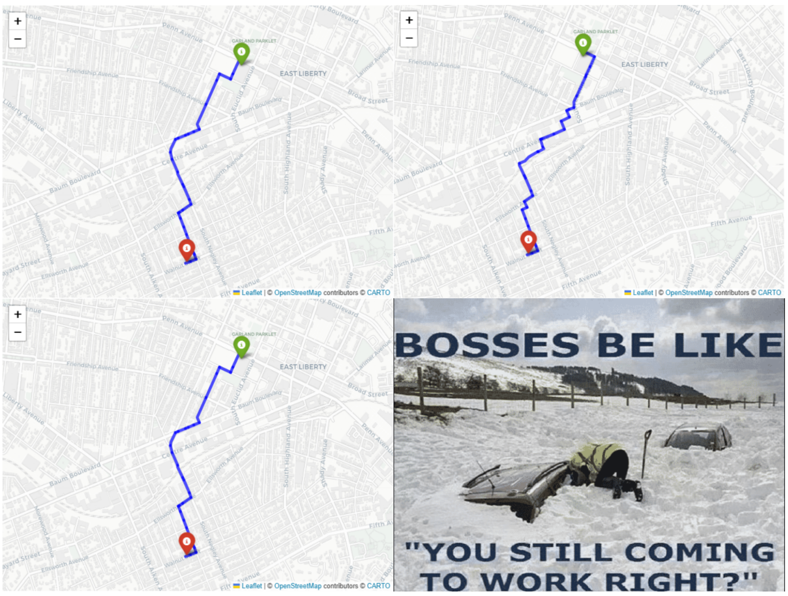

Figure 3: Combined matrix of paths for all Bikes& E-Scooters and road conditions (Dry vs. Snow).

Conclusion

Pittsburgh S2 Street Map stands as a state-of-the-art commercially viable solution to address the challenges of slope-sensitive routing in urban environments. By balancing advanced network analysis with an intuitive interface, the tool delivers significant operational benefits while safeguarding its proprietary methodologies. This application not only serves as a valuable asset for logistics, urban planning, and smart city initiatives in commercial success, but also enhances resident safety by effectively mitigating risks under diverse weather conditions.

Appendix A

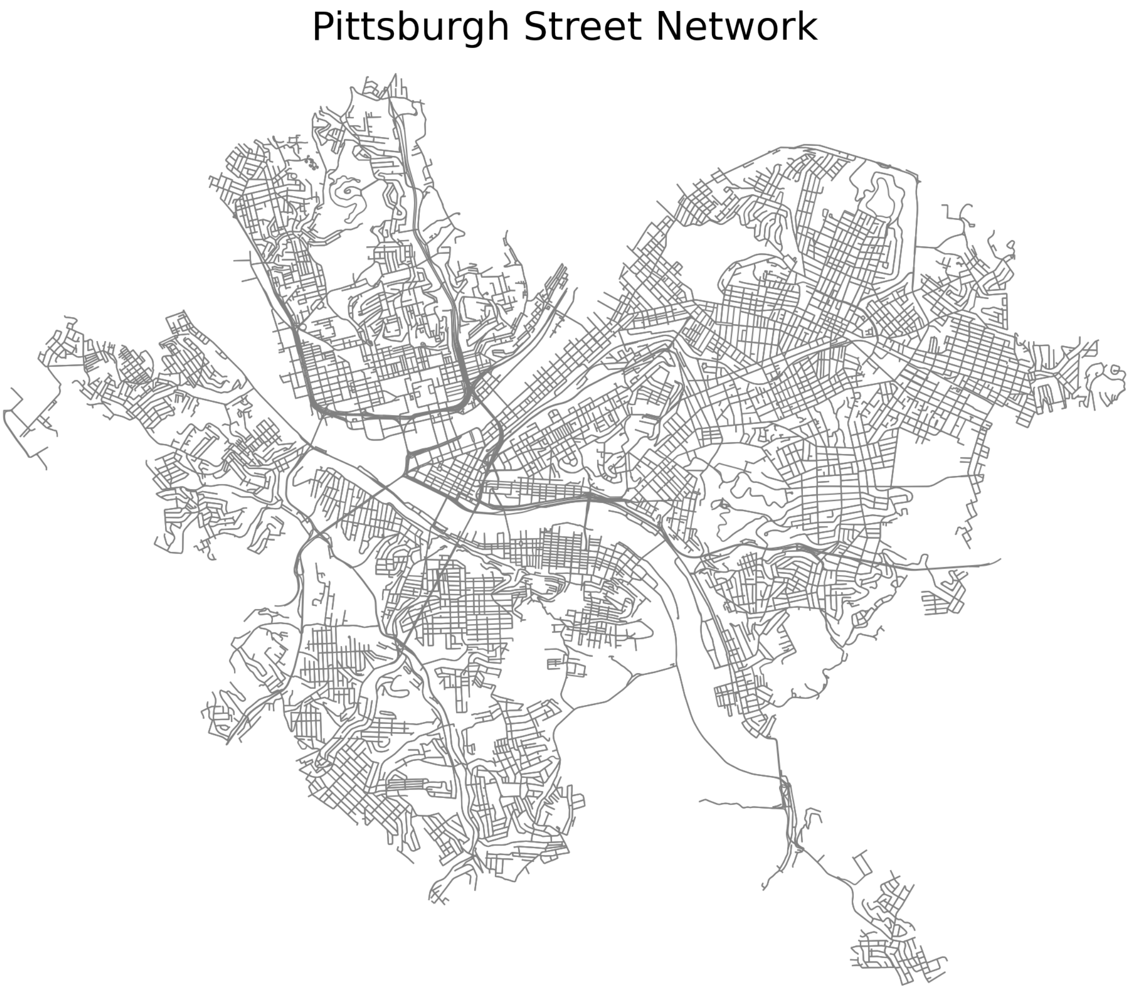

Figure 4: Pittsburgh Drive Network

Appendix B

Figure 5: Pittsburgh Bike Network

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