Project Elective Proposal: Comprehensive Subsea Cable Vulnerability Index (SCVI) 3.0

Focus: Physical, Operational, and Geopolitical Resilience Modeling
Course: Project Elective (PE)
Semester: Semester 6
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Abstract

Submarine cables carry over 99% of global transoceanic data traffic, yet existing resilience models largely ignore the intersection of physical fragility and geopolitical friction. This report outlines a semester-long project to construct the **Subsea Cable Vulnerability Index (SCVI)**. This unified framework combines *physical metrics* (seismic risk, repair vessel availability) with *geopolitical metrics* (transit state alignment, ownership diversity). By quantifying risks ranging from anchor drags in the Malacca Strait to "kill switch" risks in hostile Exclusive Economic Zones (EEZs), the SCVI will provide a rigorous ranking of national digital sovereignty.

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1 1. Introduction and Objectives

The objective of this project is to move beyond anecdotal assessments of internet risk and establish a quantitative methodology for ranking nation-states based on their exposure to subsea cable disruptions.

Unlike standard indices that focus only on bandwidth capacity, the SCVI 3.0 integrates **four distinct dimensions of vulnerability**:

1. **Physical Topology:** Graph theory metrics of connectivity.
2. **Environmental Exposure:** Natural hazards and maritime chokepoints.
3. **Operational Sovereignty:** The capability to repair and maintain the network.
4. **Geopolitical Friction:** Risks arising from cable ownership and transit through hostile waters.

2 2. The SCVI 3.0 Indicator Framework

The index will be calculated using a weighted aggregation of 16 distinct indicators across four pillars.

2.1 Pillar I: Physical Network Robustness (25%)

Focus: Graph theory and topological redundancy.

- **I.1 Route Diversity Score (HHI):** Calculated using the Herfindahl-Hirschman Index (HHI) on cable paths.

$$HHI_{route} = \sum_{i=1}^{N} s_i^2$$

  Where s_i is the market share of capacity on a specific geographic route (e.g., West vs. East). High HHI indicates dangerous concentration (e.g., all cables going through the Red Sea).

- **I.2 Node Betweenness Centrality:** A graph metric measuring how often a country lies on the shortest path between two other nations. High centrality increases the risk of becoming a target in regional conflicts.

- **I.3 Landing Station Diversity:** Geospatial calculation of the average distance between Cable Landing Stations (CLS). Measures resilience against localized disasters (e.g., tsunamis hitting a specific coast).

- **I.4 Algebraic Connectivity:** The second smallest eigenvalue of the graph Laplacian (Fiedler value), representing the robustness of the network against partitioning.

2.2 Pillar II: Geographic & Environmental Exposure (25%)

Focus: Maritime hazards and chokepoints.

- **II.1 Chokepoint Dependency Ratio:** The percentage of national bandwidth that traverses recognized maritime chokepoints (e.g., Malacca Strait, Suez Canal, Luzon Strait).
- **II.2 Seismic Hazard Exposure:** The length of cable segments lying within high-risk seismic zones (Peak Ground Acceleration greater than 0.4g).
- **II.3 Shallow Water Vulnerability:** The proportion of cable length within the country's EEZ that lies at depths less than 200m (the "aggression zone" for fishing trawlers and anchors).
- **II.4 Conflict Zone Proximity (New):** Weighted distance of cable routes to active maritime conflict zones (based on Lloyds Joint War Committee listed areas).

2.3 Pillar III: Operational Sovereignty (25%)

Focus: The ability to restore connectivity without foreign aid.

- **III.1 Sovereign Repair Vessel Capacity:** A count of cable repair ships flagged to the nation. Essential for repairs during conflict when foreign commercial vessels may refuse to enter the zone.
- **III.2 Mean Time to Repair (MTTR) Estimate:** Modeled estimate of the time required for a repair ship to mobilize and reach the country's EEZ centroid.
- **III.3 Legal Protection Framework:** Qualitative score (0-5) assessing national legislation regarding Cable Protection Zones (CPZs) and penalties for cable damage.
- **III.4 Maintenance Consortium Membership:** Binary indicator of participation in regional repair agreements (e.g., SEAIOCMA).

2.4 Pillar IV: Geopolitical & Ownership Security (25%)

Focus: Trust, alignment, and corporate control.

- **IV.1 Ownership Diversity Score (New):** Measures the balance of cable ownership types. Where types include: *Hyperscalers* (Google/Meta), *State-Owned Enterprises*, and *Private Consortia*. High dependence on a single entity type (e.g., 100% Hyperscaler) creates systemic risk.
- **IV.2 Transit State Alignment Score (New):** Quantifies the risk posed by neighboring countries. Calculated by mapping cable paths against Exclusive Economic Zones (EEZ). Where $Align_{neighbor}$ is derived from UN Voting Affinity or

bilateral treaty status. Low alignment with a neighbor hosting your cables equals high risk.

- **IV.3 High-Risk Supplier Dependency:** Percentage of infrastructure manufactured by vendors deemed "High Risk" (e.g., restricted entities lists).
- **IV.4 Neighboring Stability Score:** Average "Political Stability Index" (World Bank) of all countries directly connected via first-hop submarine cables.

3 3. Semester Implementation Plan

Table 1: **Project Timeline**

Phase	**Key Activities**
Phase 1: Data Mining (Weeks 1–4)	• Scrape TeleGeography & Packet Clearing House for cable maps. • Integrate UN Voting Data for "Alignment Score". • Collect AIS data for Repair Vessel locations.
Phase 2: Coding (Weeks 5–8)	• **Python/NetworkX:** Build the global cable graph. • **GeoPandas:** Map cables against EEZ boundaries to calculate Transit Risk. • Implement HHI logic for Ownership and Route diversity.
Phase 3: Analysis (Weeks 9–12)	• Calculate SCVI scores for 30 key nations (G20 + Maritime hubs). • **Case Study:** India's vulnerability vis-a-vis the "Pakistan Route" vs. "Singapore Route". • **Case Study:** The Pacific Island nations' reliance on Hyperscalers.
Phase 4: Reporting (Weeks 13–14)	• Develop Streamlit Dashboard for visualization. • Final Report and Presentation.

4 4. Expected Outcomes and Innovation

By the end of the semester, this project will deliver:

1. A **novel dataset** linking physical cable paths with political EEZ boundaries.

2. A **ranking system** that penalizes countries for having high bandwidth but low sovereignty (e.g., relying entirely on cables owned by foreign tech giants passing through hostile waters).
3. **Policy Recommendations** for diversifying not just routes, but cable ownership models.