Optimal equitable retrofitting policy of hillside road network

Addressing earthquake-induced landslide hazard

Debasish Jana[1], Sven Malama[1], Sriram Narasimhan[1], Ertugrul Taciroglu[1]

[1]University of California, Los Angeles

Debasish Jana, Ph.D.

Sven Malama, MASc

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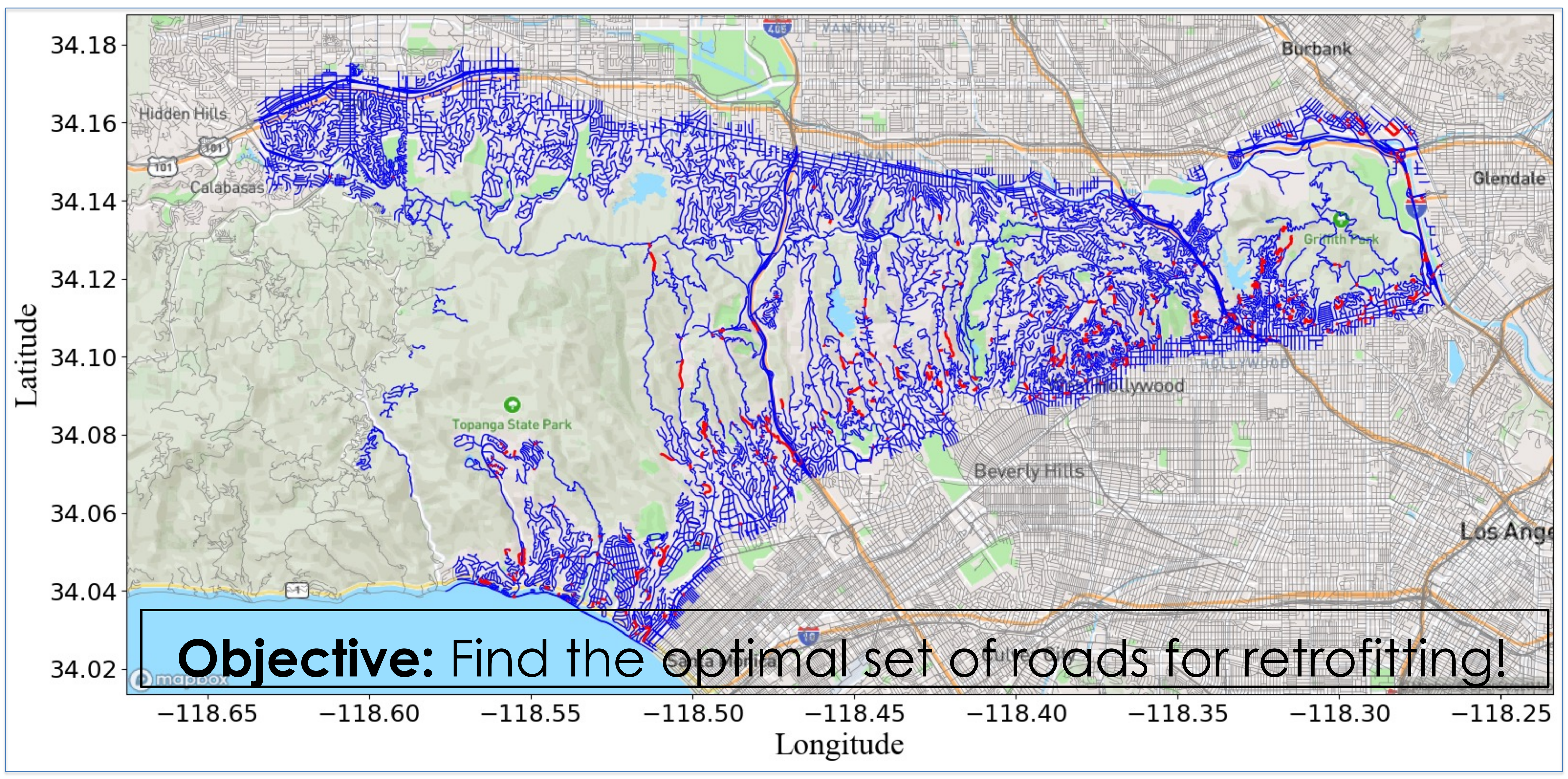
Incorporating **Graph Neural Network** module into Genetic Algorithm framework for **optimal retrofitting of roads** in a **large network** of 20k roads.

Motivation

- In the 1994 Northridge earthquake, hillside roads in Santa Monica, Mulholland Drive, and Malibu experienced **landslides**, impacting **critical road networks**.
- Pre-disaster road retrofitting is necessary to **prevent future disruptions**

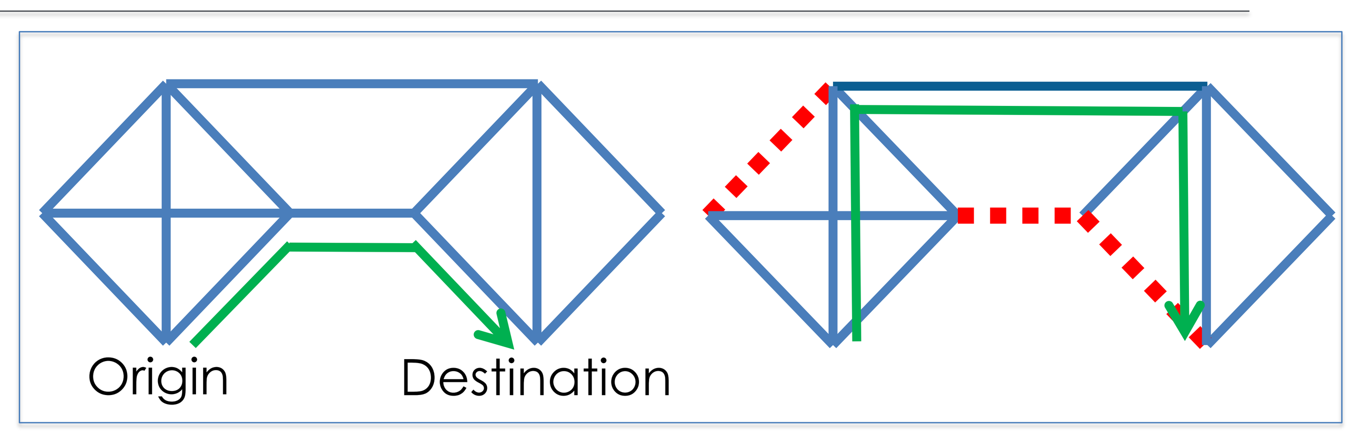


LA hillside road network (in blue) and retrofitted roads (in red) for $25M

Procedure

- **Genetic algorithms** (GA)[1] are utilized to search for optimal road sets for retrofitting.
- The fitness function attempts to **minimize the travel time delay for future hazards**

$E[\Delta\text{TSTT}] = \sum_{k=1}^{n} w_k \cdot \Delta\text{TSTT}_k$



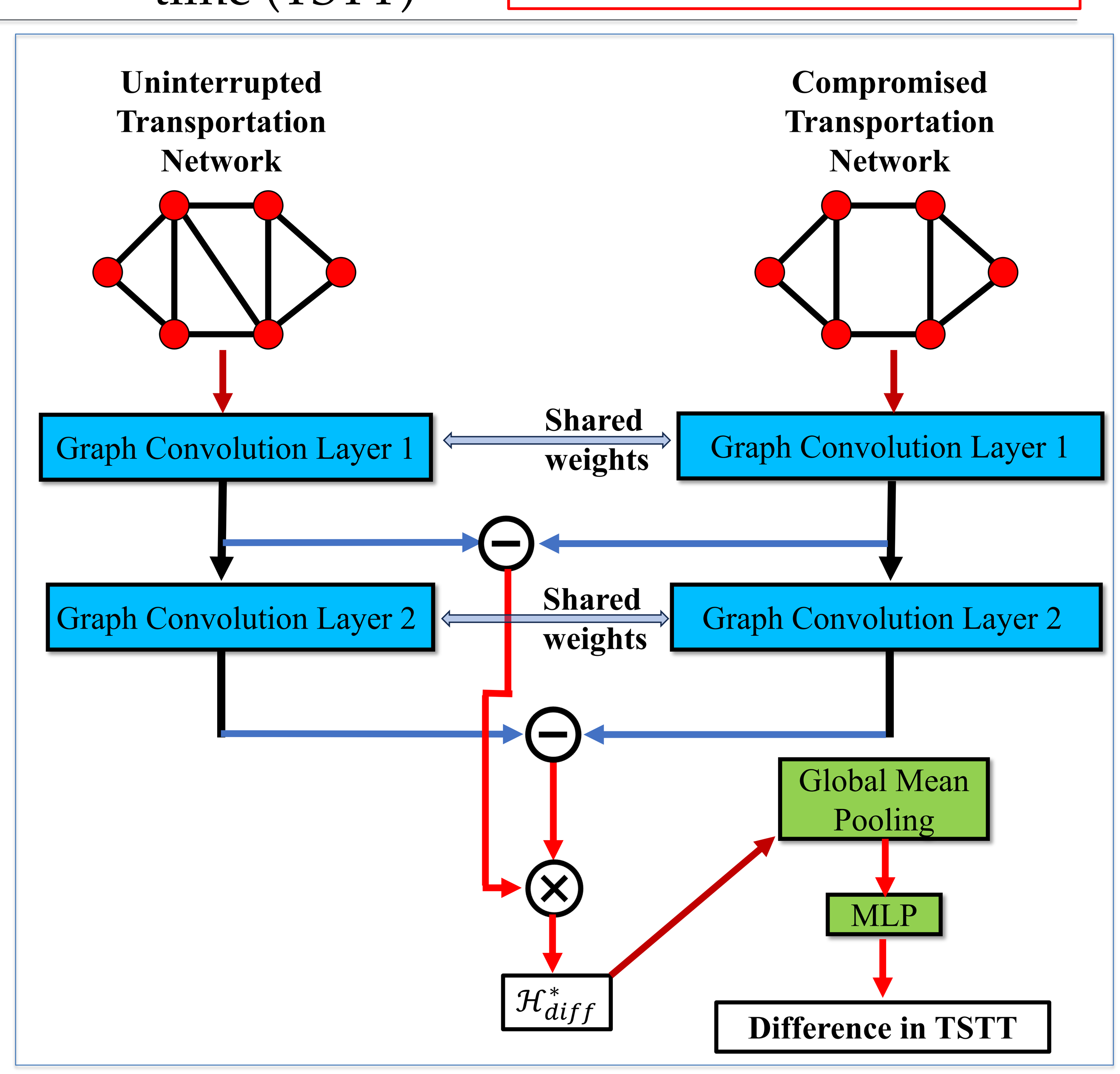
Uninterrupted Network — Compromised Network

t = Link travel time — x = Link flow

Total system travel time (TSTT) $\text{TSTT} = \sum_a (x_a \cdot t_a(x_a))$

Contribution

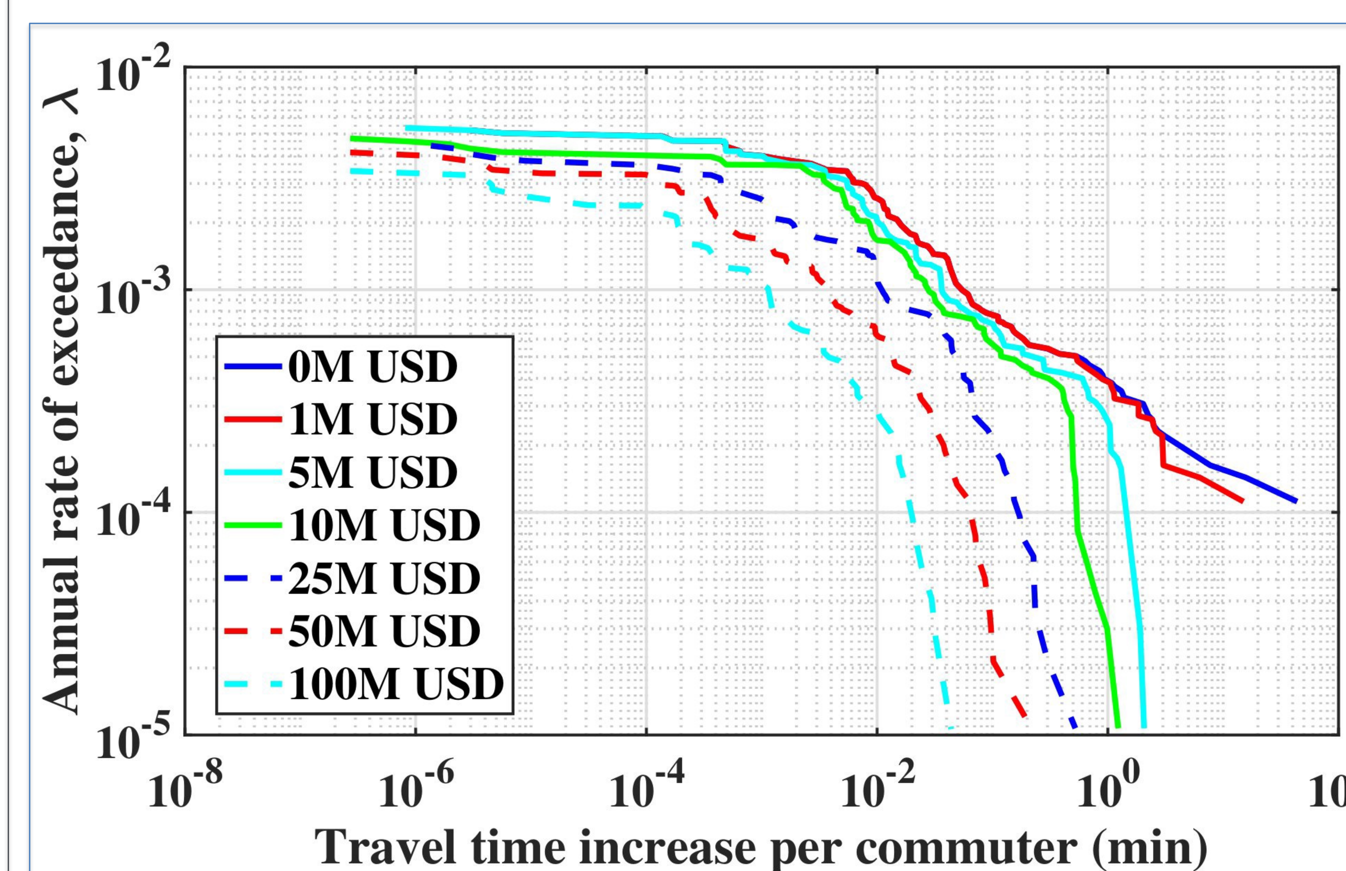
- An end-to-end framework for landslide - based risk assessment and retrofitting for large road networks
- Welfare-based optimization with genetic algorithms
- Siamese-GCN surrogate model for rapid ΔTSTT estimation to replace solving the computationally expensive traffic assignment problem (TAP)



Proposed Siamese Graph Convolution Network (GCN)

Results

- Increasing the budget results in a progressive shift of the retrofitted risk curve towards the bottom-left in comparison to the non-retrofitted risk curve.



Risk Curve for increasing budgets

Incorporating equity

Welfare Loss[3,4] $\Delta W_i = \Omega_i \cdot \lambda_{u,i} \cdot SVTT_i \cdot \Delta T_i$

- Ω_i: How society values equity USA, $\Omega_i = 1$
- $\lambda_{u,i}$: marginal utility of income
- $SVTT_i$: subjective value of travel time
- ΔT_i: change in TSTT

- Egalitarian retrofitting results in a smaller welfare gap for lower budgets.
- For higher budgets, welfare gaps diminish to negligible gaps.
- Road retrofit investment decision caters to diverse demographics in this scenario.

Welfare loss gap ($\times 10^{-7}$ utils/h/year)

Budget	Utilitarian	Egalitarian	Difference
$1M	33.6	23.5	10.1
$5M	15.8	14.1	1.42
$25M	3.22	3.91	-0.69

Conclusions

- Surrogate GCN emulates the performance of TAP with $R^2 = 0.96$ outperforms ANN[2] surrogate models

	ANN	GCN
Params.	3.3M	238K
R^2 (Test)	0.92	0.96

- Welfare-based optimization lowers the welfare gap.

Acknowledgments

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