Using the Impact Modification Factor to Link Road Safety and Environmental Performance under the Safe System Approach

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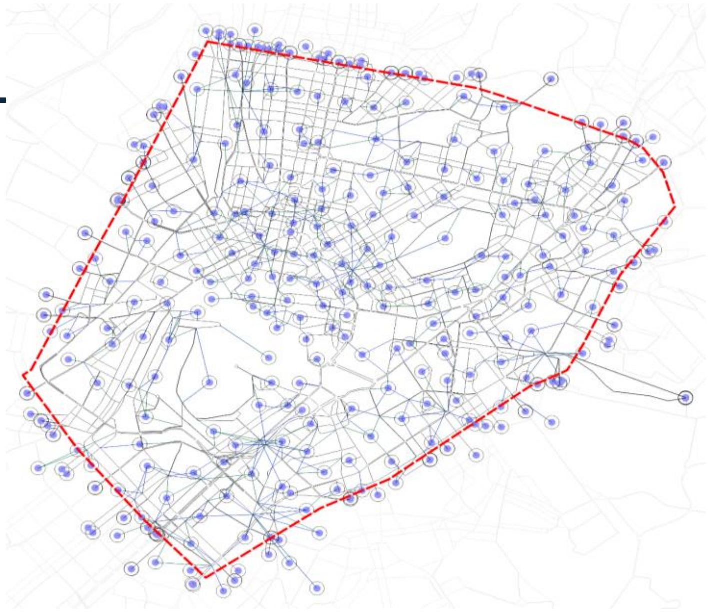
Introduction

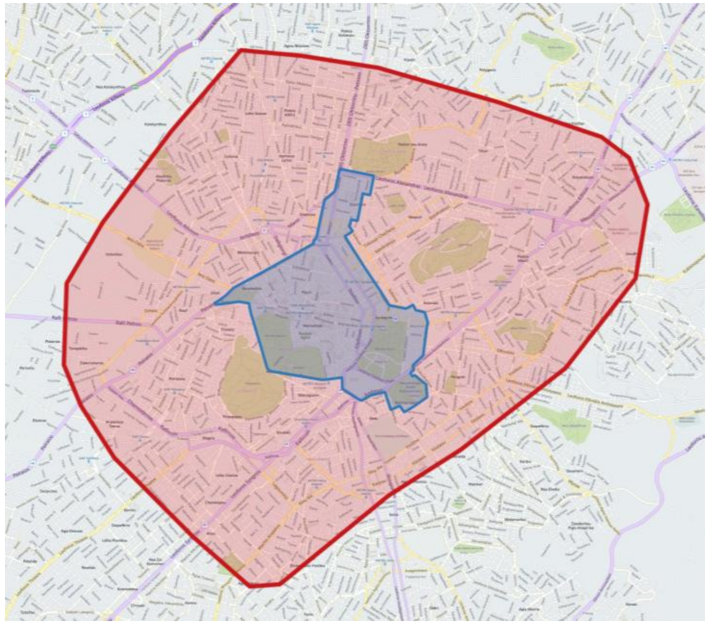
1. Road Safety & environmental sustainability are both **critical priorities** in urban transport, yet interventions often affect them differently.
2. On one hand infrastructure improvements can slow speeds leading to **increased travel times** and **higher emissions.**
   On the other hand traffic management for emissions may **raise speeds, impacting safety**.
3. Traditional assessments **treat safety and environment separately**, making integrated trade-off analysis difficult for decision-makers.
4. **Proactive infrastructure-based methods** (iRAP) assess safety from road design and speed limits.
5. **Simulation-based emission models** (London Emission Model, LEM) estimate CO_2 and NOx from traffic flow and speed.
6. **This paper proposes the Impact Modification Factor (IMF)** which is a unified metric to compare safety and environmental impacts on a common scale.

Objectives

1. Propose the **IMF as a top-down indicator** expressing relative change in safety and environmental performance before and after interventions.
2. **Develop an integrated assessment framework combining: traffic simulation (Aimsun Next), emission modelling (LEM), and iRAP road safety assessment**.
3. Apply the framework on the Athens urban network under 3 scenarios:
   - baseline,
   - infrastructure intervention, and
   - infrastructure + 30 km/h speed limit.
4. Identify road segments where both safety and environment improve simultaneously vs. segments with trade-offs.
5. Explore the **potential of IMFs to support transferability** of results between comparable road segments in different urban contexts.

Methodology — Study Area & Scenarios





Study Area:

Athens urban road network -> arterials and urban streets with varying geometry, lane layout, speed limits, and traffic volumes.

1. **Baseline Scenario (B):** Existing traffic conditions and infrastructure characteristics.
2. **Infrastructure Intervention (I1):** Changes in road geometry, lane configuration, and traffic management measures.
3. **Infrastructure + Speed Management (I2):** I1 combined with a zonal 30 km/h speed limit reduction.

Simulation Model:

Aimsun Next microscopic simulation, calibrated with field data (volumes, speeds, travel times, turning movements).

1. **Outputs per segment**: traffic flow, average speed, travel time, density, used as inputs for LEM and iRAP.
2. **Emission Estimation-London Emission Model (LEM)**: CO2 and NOx calculated per segment per scenario (in grams), using simulation outputs as input.

Methodology — iRAP & IMF Calculation

Road Safety Assessment- iRAP Protocol:

1. Each segment described by: lane width, number of lanes, speed limit, intersection type, area type, traffic volume.
2. **Outputs: Star Rating Scores (SRS) and Fatal and Serious Injury (FSI)** risk for pedestrians, cyclists, motorcyclists, vehicle occupants.

Impact Modification Factor: IMF = Indicator_after / Indicator_before

All datasets integrated at segment level via a common identifier for joint analysis.

	IMF < 1	IMF >1
Emissions	Negative Outcome	Positive Outcome
FSI risk	Safety Improvement	Deterioration

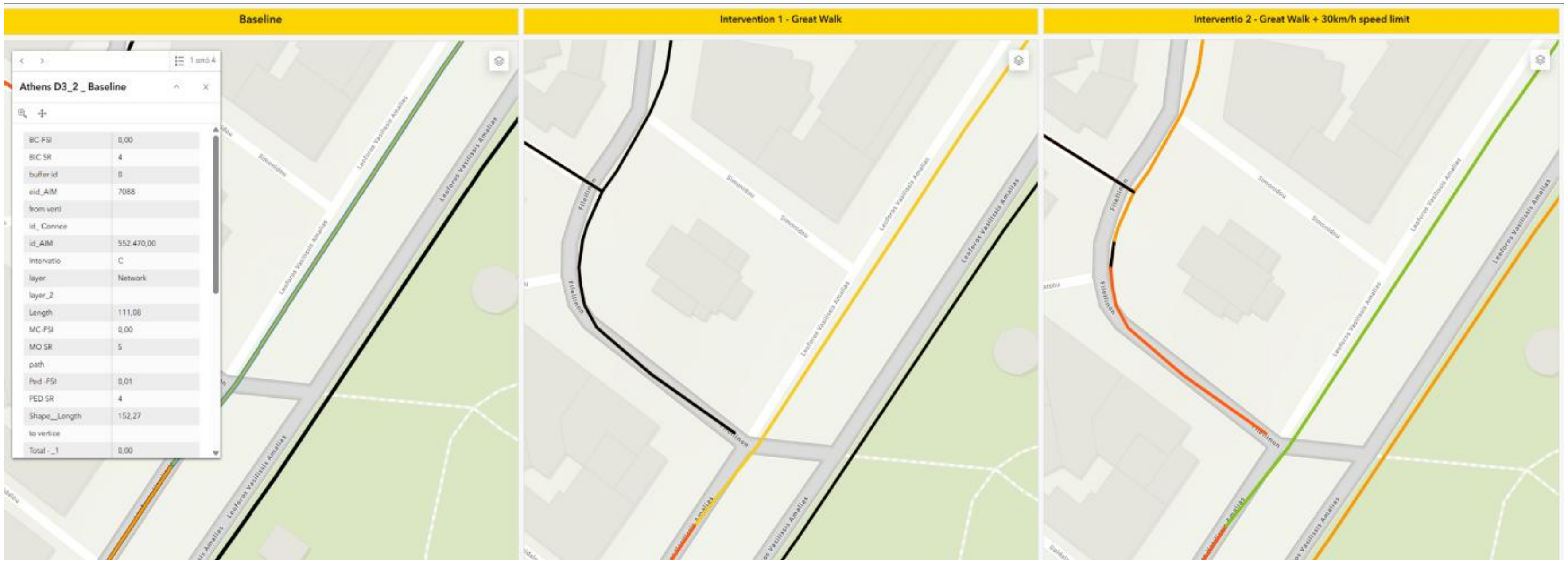
Results-Road Safety (iRAP)

Network-Level Safety Findings:

- Infrastructure interventions (I1) led to noticeable FSI improvements across the network.
- Combined scenario (I2: infra + 30 km/h) produced greater gains, especially for pedestrians and cyclists.

iRAP IMF Results - Example Segments:

- Eleftheriou Venizelou: Bicyclists IMF1=1.08, IMF2=0.19; Pedestrians IMF1=0.09, IMF2=0.22.
- Leof. Konstantinou: All user groups IMF2 well below 1.0 - consistent improvement under speed management.
- Sina: IMF1 approx. 1.0 (no change from infra alone); IMF2 approx. 0.60 (significant gain with 30 km/h).



- Two-lane arterials: largest safety improvements. Wider divided roads: mixed results.

Results -Emissions (LEM)

PHOEBE

Emission impacts varied significantly by road type and traffic conditions:

- Ardittou (I1):
  - **NOx IMF**=1.29 (+**29%),**
  - CO2 IMF=1.42 (+42%) geometry changes increased congestion and travel time.
- Ardittou (I2):
  - NOx IMF=1.97,
  - CO2 IMF=1.12 speed reduction partially controls CO2 but worsens NOx.
- Vas. Sofias:
  - Moderate increases in I1 (IMF approx. 1.07-1.17);
    - smaller increase in I2 smoother flow at 30 km/h.
- Akadimias:
  - Large NOx spike in I1 (IMF=2.37);
  - partially contained in I2 (IMF=1.30) congestion-sensitive corridor.

Key Insight:

- **Infrastructure changes alone often increase emissions** on congested arterials.
- The **30 km/h zonal policy provides more consistent emission** control in several segments.
- **Narrower streets** with consistent flow tend to **improve on both safety and emissions** simultaneously.

Integrated IMF Analysis

Comparing safety and emission IMFs jointly reveals trade-offs and synergies:

- Out of 291 road segments, 96 showed safety IMF < 1 network-wide safety improvements confirmed.
- Central corridors (Fillelinon, Vasilissis Amalias): both safety and emission IMFs improved win-win segments.
- Trade-off segments: **safety improved (FSI IMF < 1) but emissions worsened** (emission IMF > 1) lower speeds increased travel times.
- IMF framework enables apples-to-apples comparison across indicators in different units (crashes vs. grams).
- Narrower sections with consistent flow tended to improve on both dimensions simultaneously.
- IMFs support transferability: comparable segments can use IMF values from one network as initial estimates for another.

Discussion

- Propose the **IMF as a top-down indicator** expressing relative change in safety and environmental performance before and after interventions.
- Develop an integrated assessment framework combining:
  traffic simulation (Aimsun Next),
  emission modelling (LEM), and
  iRAP road safety assessment.
- Apply the framework on the Athens urban network under 3 scenarios: baseline, infrastructure intervention, and infrastructure + 30 km/h speed limit.
- Identify road segments where **both safety and environment improve simultaneously** vs. segments with trade-offs.
- Explore the potential of IMFs to support transferability of results between comparable road segments in different urban contexts.

Conclusions & Future Work

- The IMF proved effective for integrated road safety and environmental assessment across different road types and scenarios.
- Combining infrastructure changes with 30 km/h speed management provided the greatest safety gains - consistent with Safe System principles.
- **Environmental impacts are not straightforward,** as lower speeds can improve some pollutants but increase total emissions via longer travel times on congested roads.
- The ratio-based IMF is scale-neutral - one comparable number for indicators as different as NOx grams and pedestrian FSI risk.
- Wider divided roads and high-capacity roads showed more mixed results - road type significantly moderates intervention effectiveness.
- The framework is well-suited for decision support in urban transport planning, helping navigate trade-offs between safety, sustainability, and mobility.

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