

UrbanPulse: Road Network Quality as a GDP Multiplier

Implementation of a Spatial Agent-Based Economic Model

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Context: The "Infrastructure Gap"

Theoretical Context

In rapidly growing urban environments, industrial capacity often outpaces infrastructure development. While factories (*Capital*) are available, the workforce (*Labor*) faces significant time loss due to congestion.

Core Premise

"Time is Money"

In our model, every minute spent on the road is a minute **not** producing GDP.

The Simulation Gap

Existing economic models often treat "Labor" as a static resource. They fail to account for the **spatial friction** of commuting in dense road networks.

Research Question & Hypothesis

Research Question

How does road network quality affect industrial output and Urban GDP in a closed-loop economy?

Hypothesis

Strategic road upgrades increase goods produced, which in turn generates higher Urban GDP.

- Roads influence GDP *indirectly* by reducing commute time.
- The key question is *when* added capacity significantly extends agents' effective production time.

Design Evolution: Learning from Failure

Failed Experiment 1: Road Closures

Idea: Set road capacity to 0 during construction.

- **Problem:** Agents already on the road got stuck forever.
- **Fix:** Use a **construction penalty** (very low speed) instead of full closure.

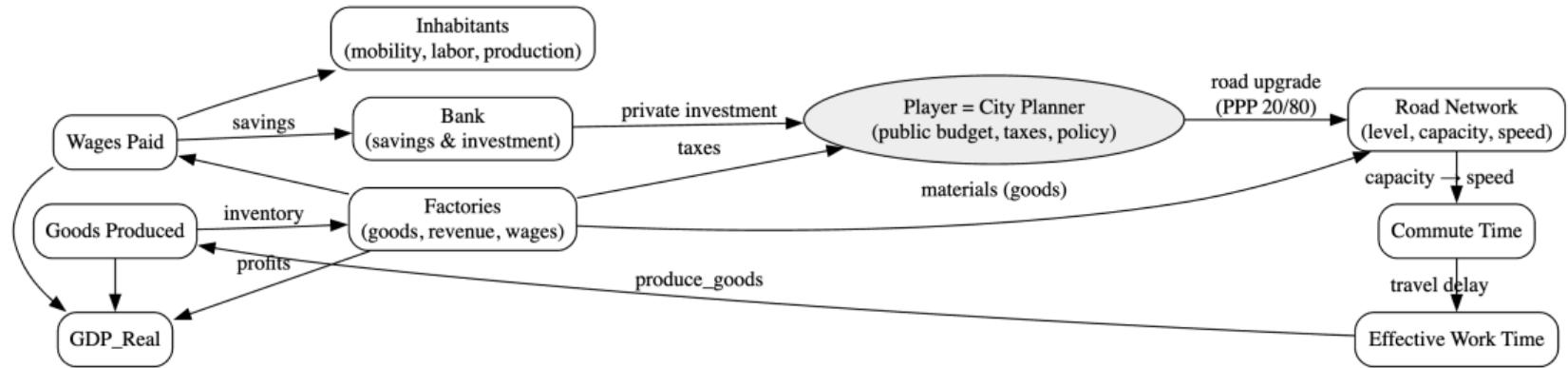
Failed Experiment 2: Full Consumption Model

Idea: Agents buy goods at markets.

- **Problem:** Too complex, too many params to care about.
- **Fix:** Abstract consumption via the **Bank**:

Wages → Savings → Investment

Current Model Flow (Stabilized Design)



System Architecture: Species Definition

Our implementation in GAMA utilizes 4 primary agent types:

Species	Key Variables	Primary Behavior
Inhabitant	money, time_buffer, status	Commuting, Working, Banking
Road	level, capacity, speed_rate	Dynamic Pathfinding Weights
Building	type, total_revenue, goods	Production, Paying Wages/Tax
World	gdp_current, city_budget	Macro-economic calculation

Interaction Topology:



Map

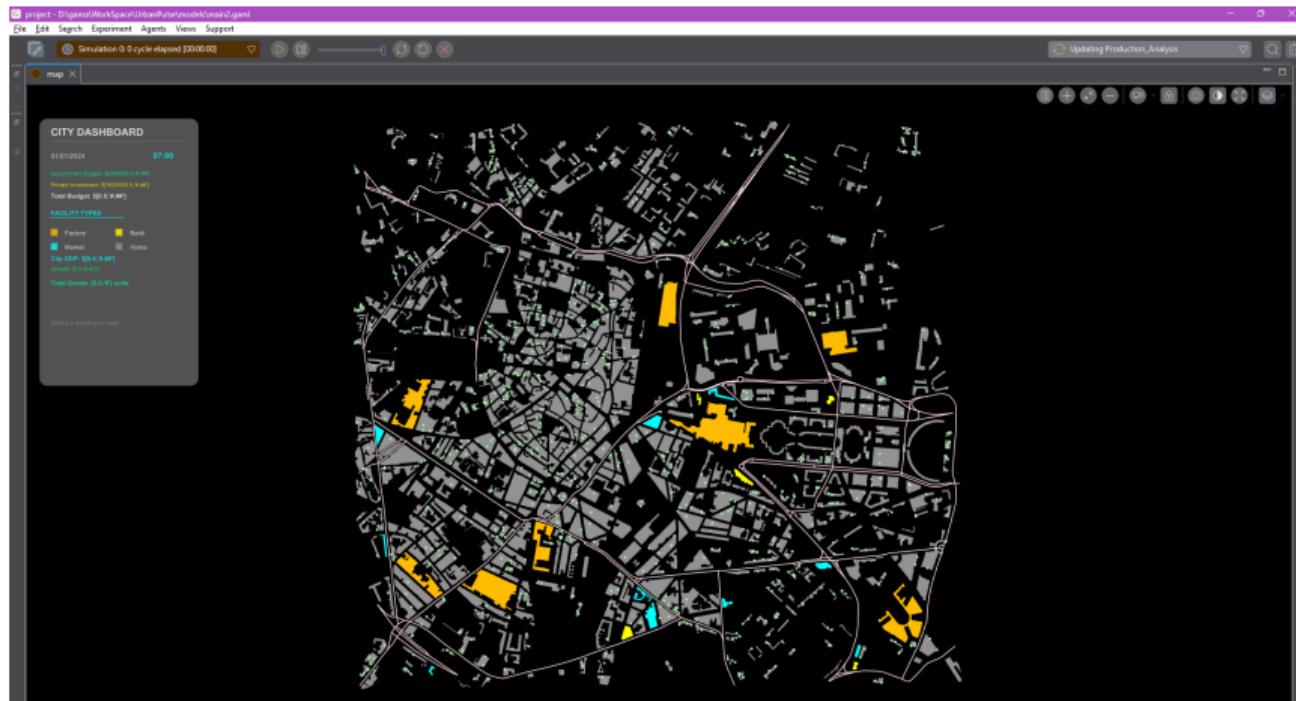


Figure: Final Map

Spatial Environment & Graph Logic

We utilize GIS data to construct a navigable graph representing a dense urban layout. The map of Montpellier is taken from exercises used during the coursework.

Dynamic Edge Weighting: We update edge weights every step based on congestion physics.

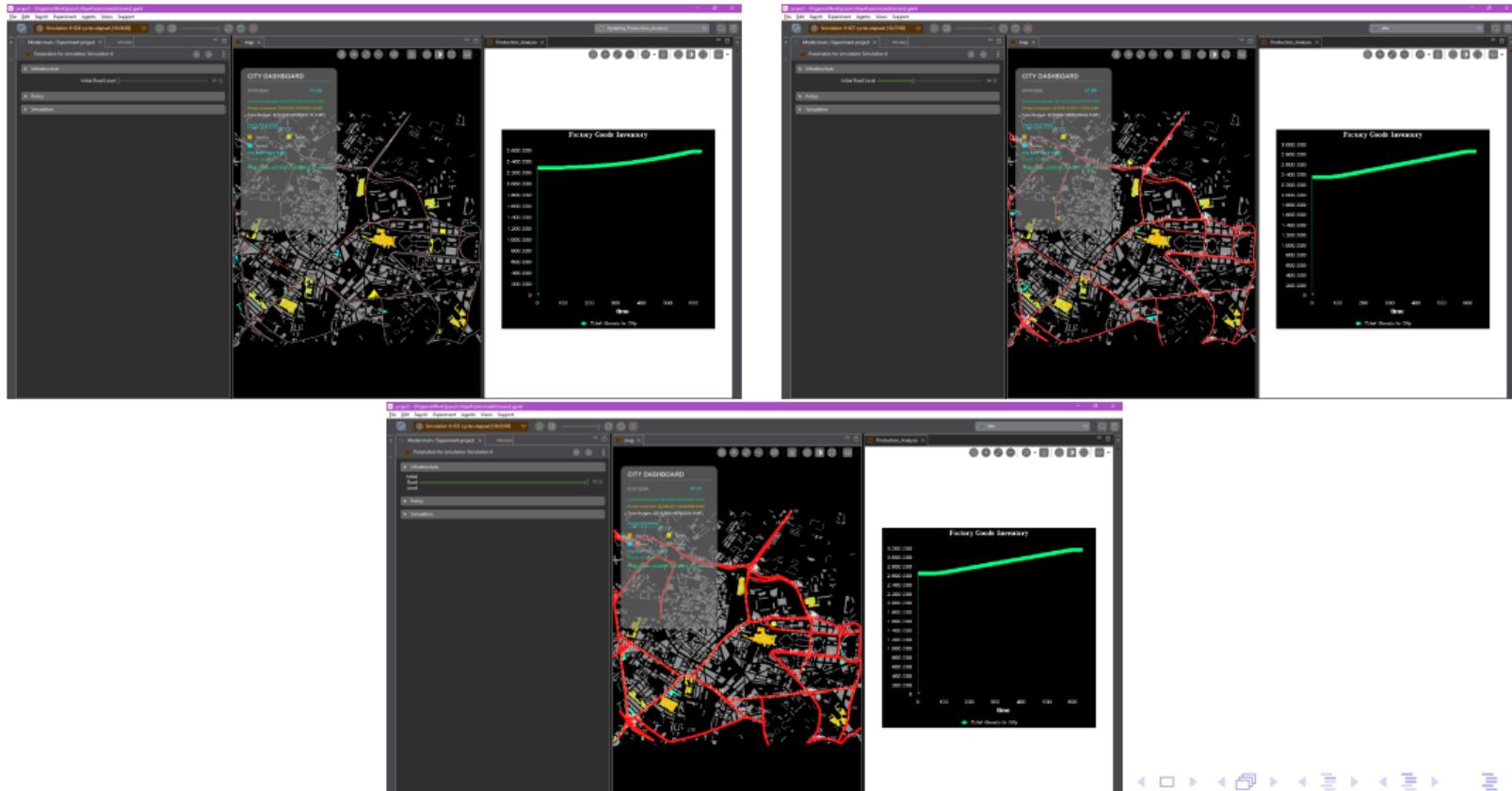
```
reflex update_speed {  
    // Weight = Travel Time  
    new_weight <- road as_map (each:::  
        each.shape.perimeter / each.speed_rate  
    );  
}
```

Congestion Physics: Speed degrades exponentially as density increases.

$$Speed = 5\text{km}/h \times e^{-\frac{\text{Drivers}}{\text{Capacity}}}$$

- Level 1: Low Capacity (High friction).
- Level 2: Capacity $\times 2$.
- Construction: Fixed $0.5\text{km}/h$.

Different level of road effect to the speed and quantity of productions



Agent Behavior: Production Logic

The economic output is strictly coupled to the agent's spatial location.

The Production Reflex

```
reflex produce_goods when: status = "working" {  
    // Only produce if PHYSICALLY at the factory  
    if (location overlaps workplace.shape) {  
        ask workplace {  
            goods <- goods + 1.0;  
        }  
    }  
}
```

Implication: If an agent is stuck in traffic due to a Level 1 road, status remains "moving", and goods (GDP) are **not produced**.

The Economic Engine (Real Output)

To separate real economic activity from pure monetary circulation, we track **Output-Based GDP** alongside explicit production metrics. Infrastructure spending is treated as a *cost*, not as output.

Daily GDP Calculation (23:59)

$$GDP_{Real} = \text{Value of Goods Produced} + \text{Total Wages} + \text{Corporate Profits}$$

Observed Metrics

- **Goods Produced (Units):** Direct measure of real output.
- **GDP_{Real}:** Monetary aggregation derived from production.

Interpretation

- Infrastructure affects GDP only through changes in production.
- Joint tracking separates monetary effects from real output growth.

The Model as a Serious Game

- The user plays the role of a **city planner**, investing in road upgrades under limited public and private budgets.
- Autonomous agents (inhabitants, factories) generate mobility, work, and production dynamics.
- Road capacity affects travel speed, indirectly influencing working time and goods production.

Feedback:

- **Goods Produced** (real output)
- **GDP_{Real}** (monetary output)

Human-in-the-Loop Interaction

- ① Select a congested road → budget check
- ② Select a factory → materials, payment, construction

Simulation Results: Road Capacity Exploration

Experimental Setup

- Sweep over Initial Road Level
- Fixed random seed per run
- One-day simulation horizon

Observed Metrics

- **Goods Produced:** real output
- **GDP_{Real}:** monetary aggregation

Objective

- Quantify how road capacity affects production
- Compare real output vs. GDP
- Identify linear vs. diminishing returns

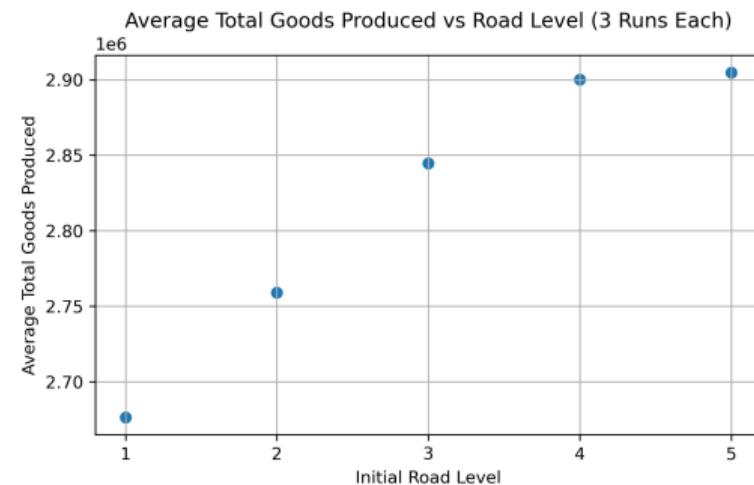


Figure: Road capacity vs. output

Conclusion & Perspectives

Conclusion

The "UrbanPulse" model demonstrates that **Urban GDP is spatially constrained**. Without efficient infrastructure, capital (Factories) and Labor (Inhabitants) cannot interact effectively. The interactive model proves that **human strategic decision-making** is required to identify bottlenecks.

Future Perspectives

- **Supply Chain Closing:** Implement a "Market" action where citizens *buy* the goods they produce.
- **Different Transportation:** Introduce other mean of transportation to increase effective road capacity without simple widening.