Modeling Urban Evacuation Process

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Motivation

Evacuation is an important process to save people from the danger of fire and other hazards.

It’s important to consider the efficiency of the evacuation process in urban spaces beforehand.

Common Approach, Mathematical Models based on a common assumption:
“ Since evacuees are familiar with the environment,
they will always choose the optimal evacuation routes,
which leads to the optimal evacuation process of the whole region.”

Is it True?

Motivation

- An individual evacuee cannot recognize the status of all road network.
  - He or she only knows about the road segment they are encountering.
- Witnessing smoke or fire can impact driver's emotional status which can impact their route-finding.
- Therefore, it's not always the case for the drivers to find the optimal path.
  - Empirically proven by Church and Sexton(2002), Langford(2010), Brachman(2012)
- Besides, the goal of individual drivers is to minimize their evacuation time, Not to minimize the clearing time of the whole region.

So, new approach is needed.

Agent Based Model description

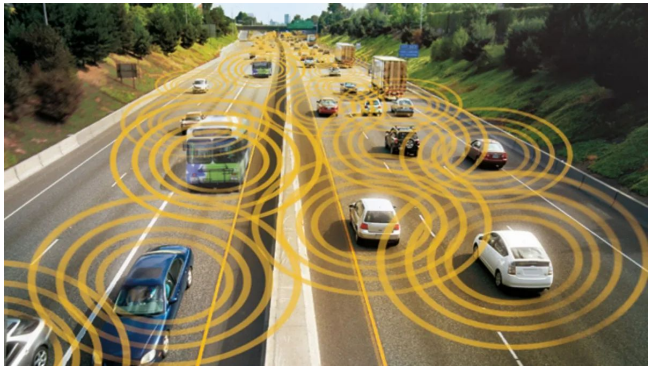
- Entities are evacuee vehicles moving through the road network.
- Entities want to get into the highway.
- Entities know the shortest path to their destination.
- But emotional status and road status can impact the route-finding.
- More congested the road, more likely to make a detour. (cognitive behavior)

Agents

Individual Drivers
departing from their houses and moving through the road network, to get into the highway

{ID, houseNodeID, depart_time,
velocity, emotional_status, path, hold_count}

- Velocity: default 10m/s (close to 25 mph which is a speed limit of the residential area)
- Emotional status scalar value: 1 (tentative value)
- Path: default found by Dijkstra algorithm
- Hold count: default 0

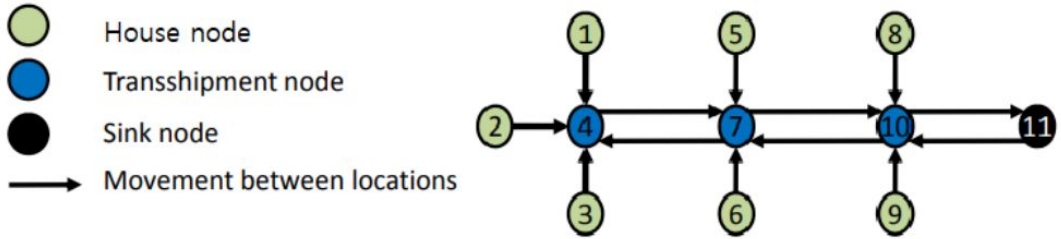


Model Input 1: Road Network

- Nodes {ID, supply, sinknode, depart_time, hold}
  - Supply: the amount of vehicles departing from the node
  - Sinknode: the nodes connecting the highway and the other road segments
    Destination of the entities.
  - Hold: the amount of vehicles which can stay at the node

- Arcs {from_node, to_node, capacity}
  - Capacity: the amount of vehicles each road segment can hold.
  - On average, the length interval is 80m.

<Forward Star network>



Model Input 2: Fire perimeter and EZ

f_1 =3 *if the fire has burned homes*

2 if the fire poses a significant threat to homes

1 if the fire poses a minimal threat to homes

f_2 =3 *if wind speed and air temperature are extreme*

2 if wind speed and air temperature are above average

1 if wind speed and air temperature are at or below average

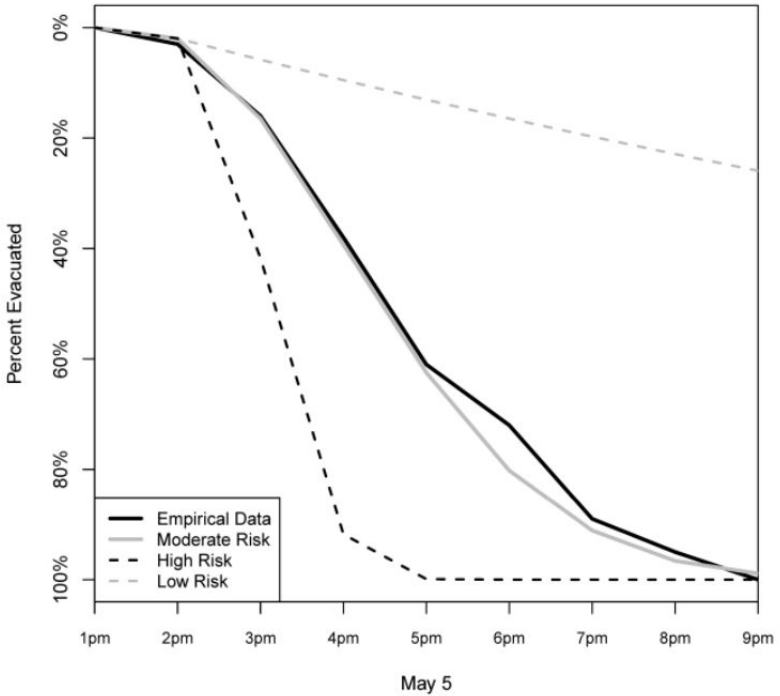
f_3 =3 *if all residents have been ordered to evacuate*

2 if some residents have been ordered to evacuate

1 no evacuation order issued

$$f_{bar} = \frac{(f_1+f_2+f_3)}{3}$$

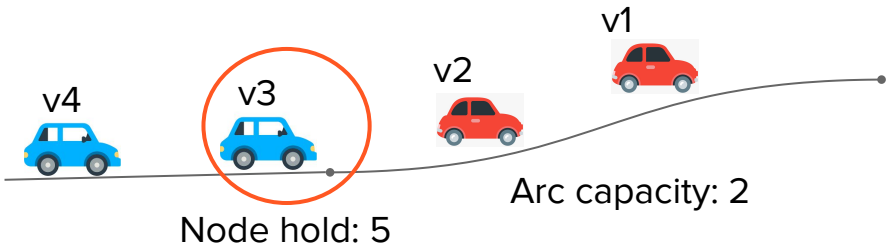
Rayleigh Probability Model: $P_{evac} = exp(-T^{F_{bar}}/50)$



Now, each agent knows when to depart!

Interactions rules: Entities and Environment

- First come, first served.
- A vehicle can enter into the road segment
  only when the number of vehicles in the road segment is less than the road capacity
- Otherwise, the vehicle should stay stop at the current node.
  - Then, the Hold count value will increment by 1



Can vehicle 3 get into the next arc?

Interactions rules: Entities and Entities

- When there are more vehicles than 80% of the capacity of the road (congested)
  - the Emotional status value will increment
  - the velocity gradually decreases until 3.5m/s *(Highway Manual's assumed min speed 7mph)*

- When there are fewer vehicles than 30% of the capacity of the road
  - the Emotional status value will decrease
  - the velocity increments until 25m/s *(Highway Manual's recommended max speed 55mph)*

- As the Hold count value increases
  - the Emotional status value will increase by random probability

- When the Hold count is greater than 0
  - Make a probability based decision regarding Emotional status whether to make a detour or stick to the shortest path

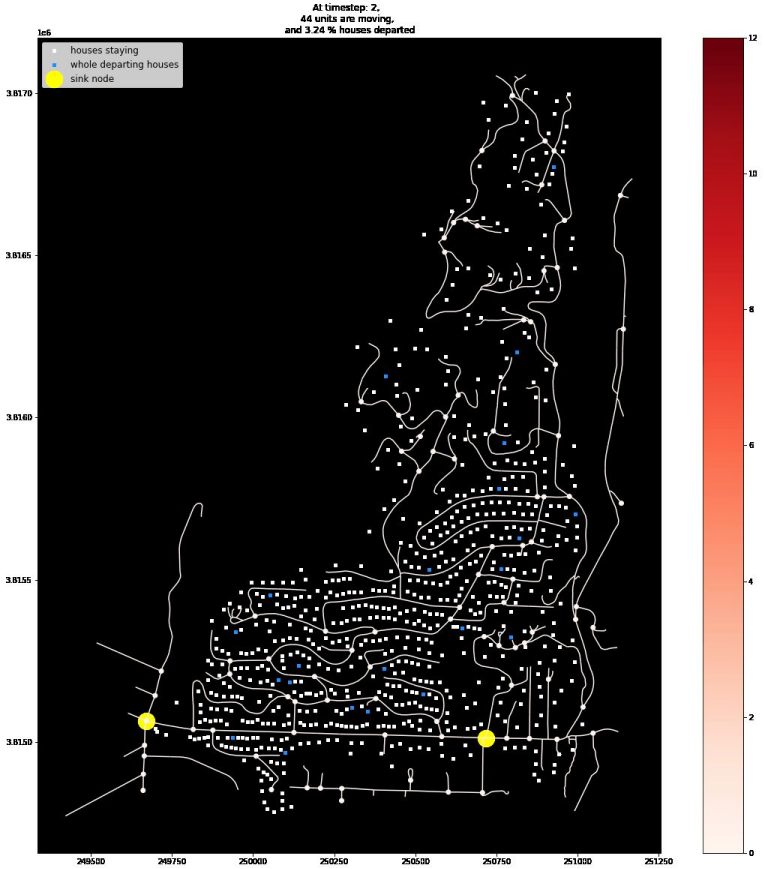
Calibration is required!

Expected Outputs

The timely simulation of evacuation process.

The GIF shows the mathematical model result.

The flow is not consistent because
vehicles hold themselves
to minimize clearing time of the whole region.



Calibration and Validation

An example from the mathematical model.

Would it fit the commercial transportation software (VISSIM and Paramics) result based on the real-time survey?

		Vital Report		Langford(2010) Rayleigh				OSM Rayleigh			
				Staggered		Not Staggered		Staggered		Not Staggered	
		1car/house	2car/house	1car/house	2car/house	1car/house	2car/house	1car/house	2car/house	1car/house	2car/house
total cars		763	1526	693	1386	693	1386	678	1356	678	1356
% of cars	**50%**	8:23	15:43	8:00	14:00	7:10	13:20	9:00	15:30	8:10	14:50
	75%	12:04	24:16	11:30	20:20	10:40	19:50	14:10	23:30	12:50	22:50
	90%	15:28	30:25	15:00	25:50	14:10	25:10	18:20	31:30	17:00	30:30
	95%	16:44	32:40	16:10	28:10	15:20	27:30	19:50	34:20	18:30	33:20
	100%	18:49	34:58	17:40	30:50	16:50	30:10	21:10	37:10	20:00	36:10

Future Validation

- ABM model can track each individual's movement along the road network,
  Which is not possible with mathematical model.
- Real-time survey data contains 500 individual paths of evacuees.
  The future validation can rely on the departing time and arrival time of those paths.

Current Status

- Commercial software simulation based on the real-time survey is done. (prepared for validation)
- Road network is built in Forward Star network format.
- Rayleigh probability model is built for departure_time assignment.
- In an experiment of the probability based decision making
  regarding the emotional status value. *(Fang, J., El-Tawil, S., & Aguirre, B., 2016)*