NICTA

Large-Scale Evacuation Planning

Actionable Evacuation Plans With Contraflows

Caroline Even, Victor Pillac, Pascal Van Hentenryck

http://org.nicta.com.au

Australian Government

Department of Broadband, Communications and the Digital Economy

Australian Research Council

NICTA Funding and Supporting Members and Partners

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About NICTA - ORG

- **NICTA**
  - 5 research groups
  - 3 business teams
  - 15 startups

- Optimisation Research Group (**ORG**)
  - ~60 staff & PhDs

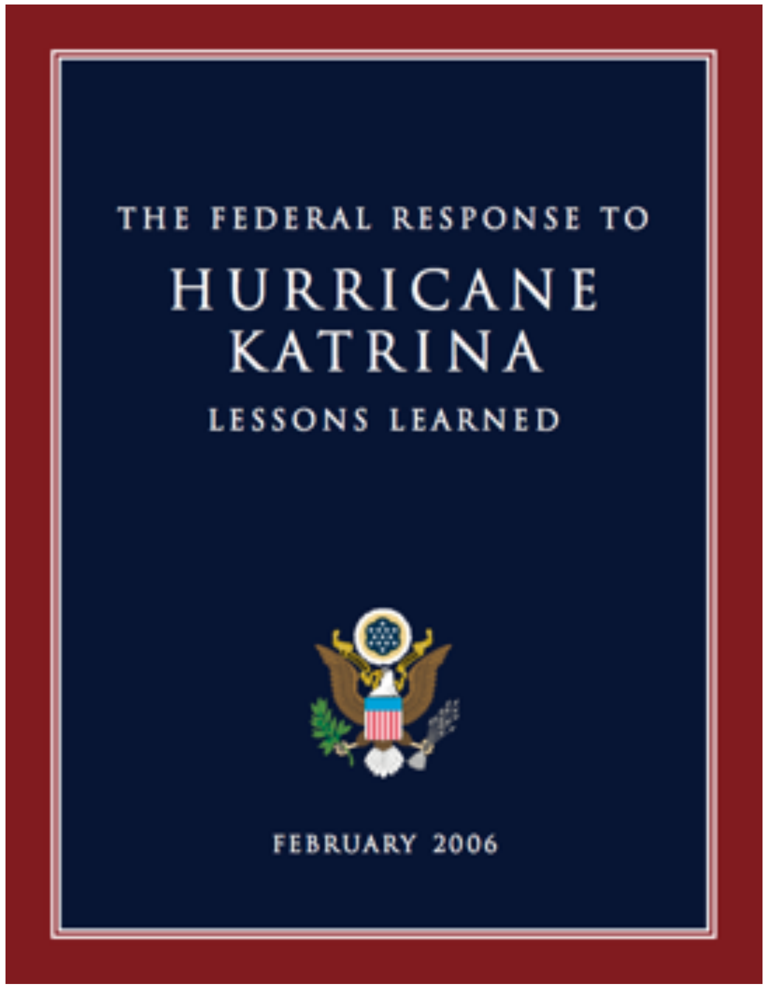
Credits

Victor
Pillac

Pascal
Van Hentenryck

Caron
Chen

Disaster management



"The Federal government must develop the capacity to conduct large-scale logistical operations."
(p 56)

- **Pre-Katrina:**
  Focus on providing situational awareness
  What is happening?

- **Post-Katrina:**
  Need for advanced decision support
  How can we mitigate negative effects and use resources more effectively?

Motivation

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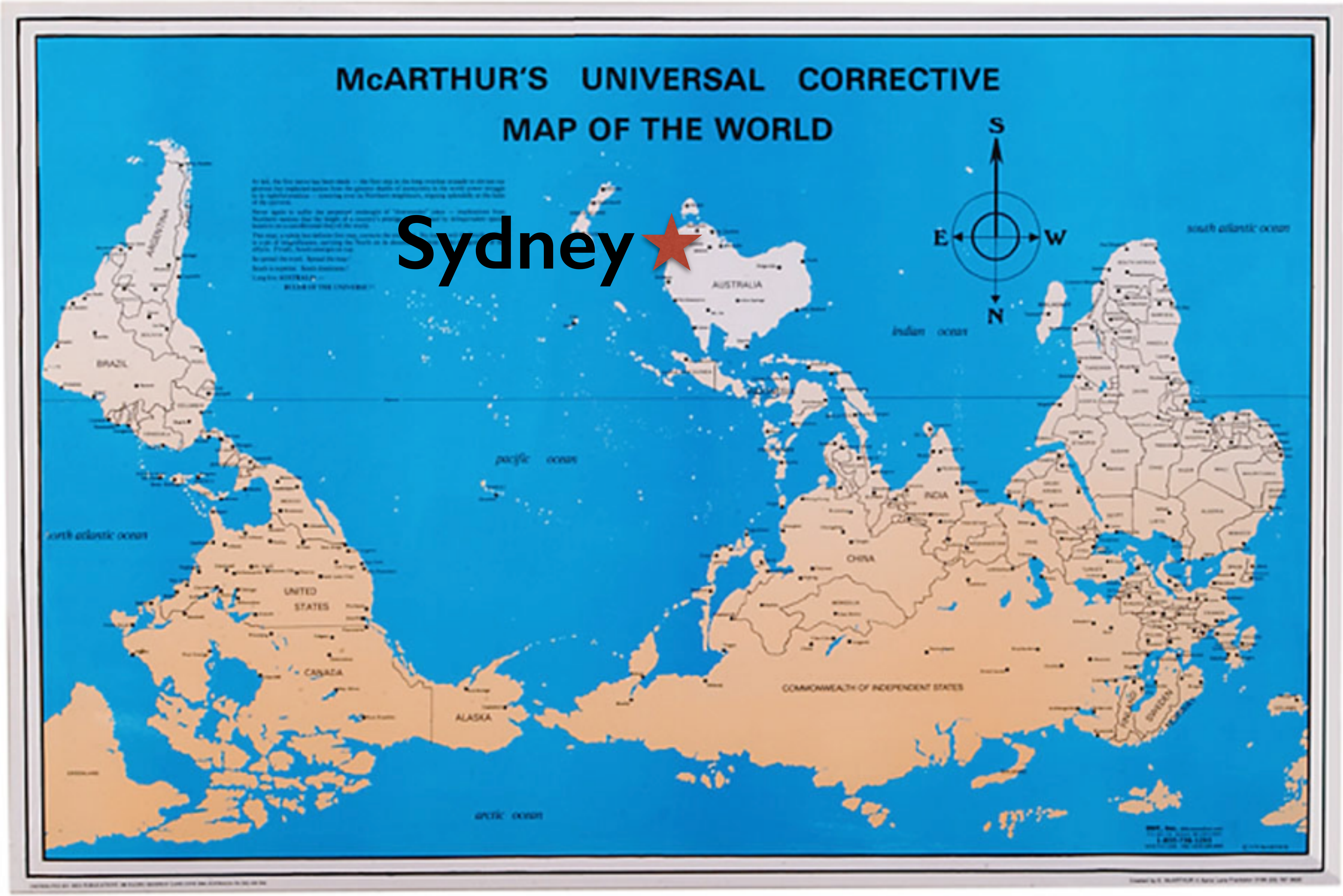
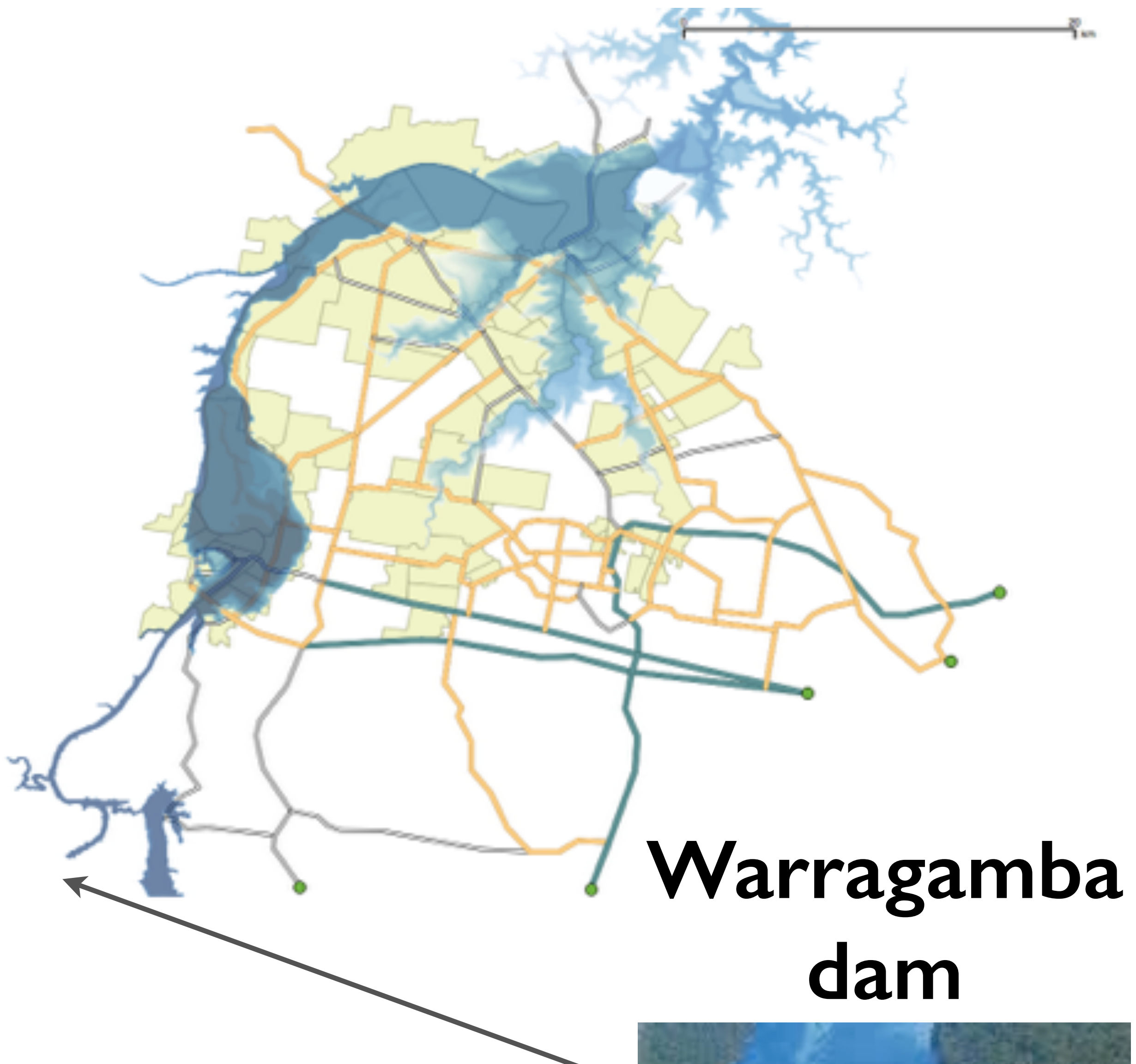


Motivation



Warragamba dam

smh.com.au
The Sydney Morning Herald

Environment

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Urgent flood prevention measures needed for Warragamba Dam

November 3, 2012

Tim Barlass

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A one-in-1000 flood around the Hawkesbury Nepean, such as that in Queensland early last year, would cause up to $8 billion in total damages affecting 14,000 homes and requires urgent preventative measures, according to a group of 10 western Sydney councils.

A one in 1000 flood is one that has a 0.1 per cent chance of happening each year.

The Western Sydney Regional Organisation of Councils last night called on the state government urgently to address threats of potential floods around the Hawkesbury Nepean.

A repeat of the 1867 flood would cause up to $1.7 billion in direct damages and $3 billion in total damages, the group said.

"This would affect an estimated 7600 homes, with about 1200 of those destroyed, WSROC president Tony Hadchiti said.

Flood prevention measures could include raising the wall of the Warragamba Dam, which filled to capacity in March, spilling water over the wall.

Infrastructure NSW last month backed the implementation of Hawkesbury Nepean Flood Plain mitigation measures as a key recommendation of its 20-year strategy "First Things First".

Cr Hadchiti said the flooding was a serious concern for key western Sydney councils including Liverpool, Penrith, Blacktown and Hawkesbury.

Motivation

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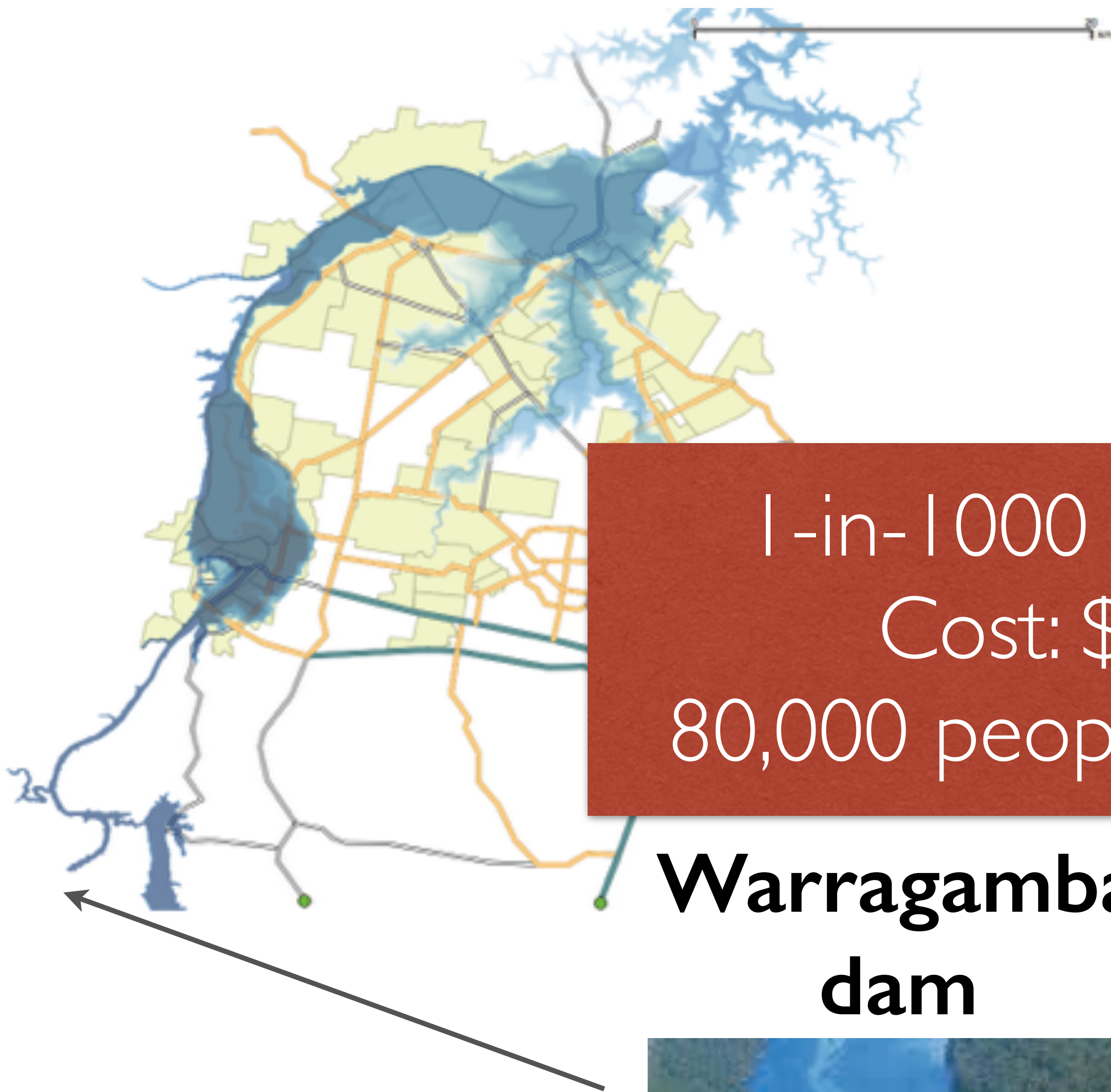

1-in-1000 flood event:
Cost: $8 billion
80,000 people to evacuate

smh.com.au
The Sydney Morning Herald

Environment

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Urgent flood prevention measures needed for

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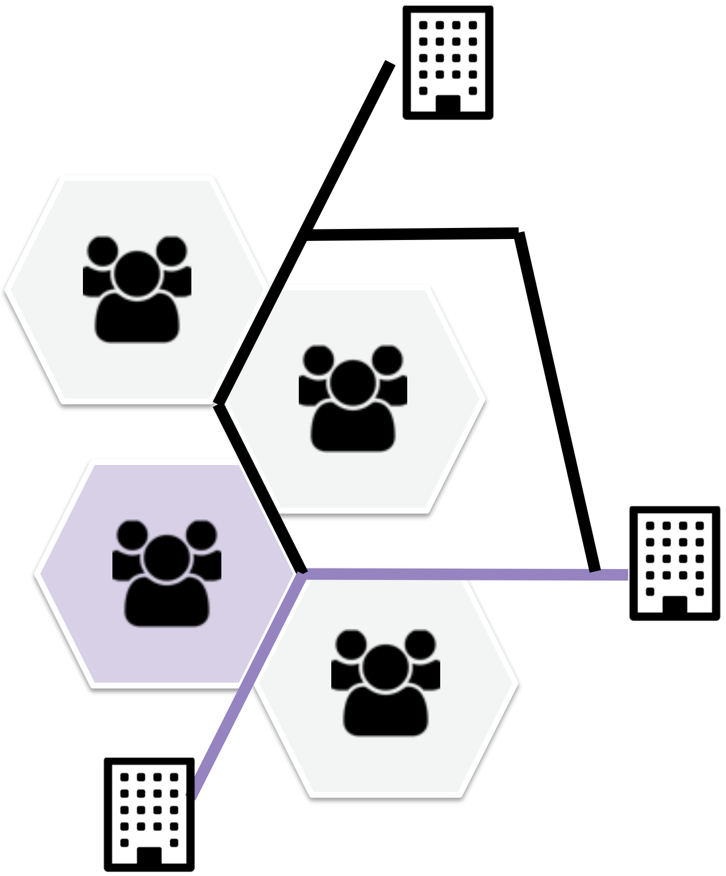
Warragamba dam

Evacuation planning

- **Decisions**
  - When to evacuate
  - Where to go?
  - Which route to follow?
- **Constraints**
  - Avoid congestion
  - Ensure safety of evacuees



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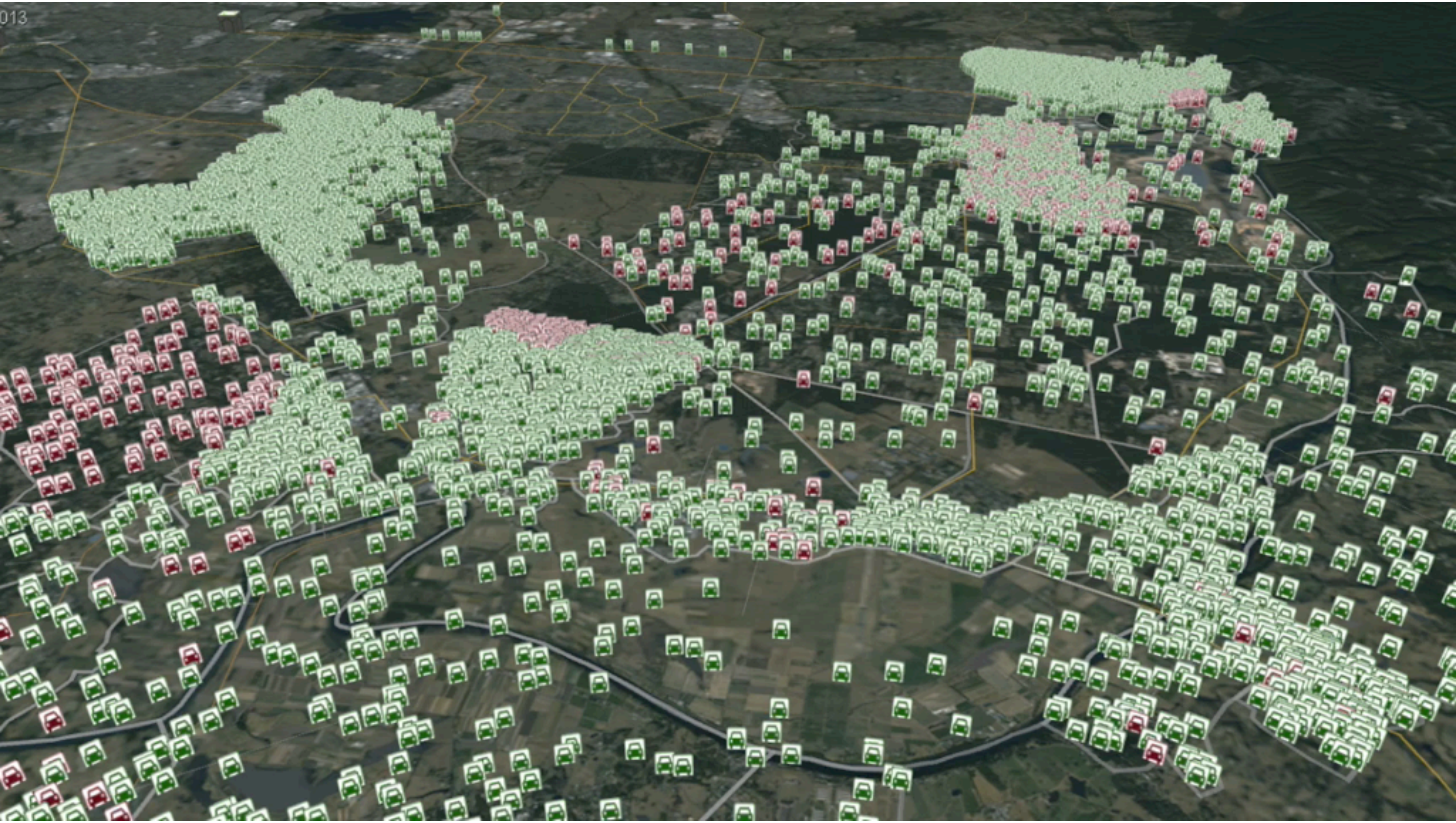
Evacuation of 80,000 persons



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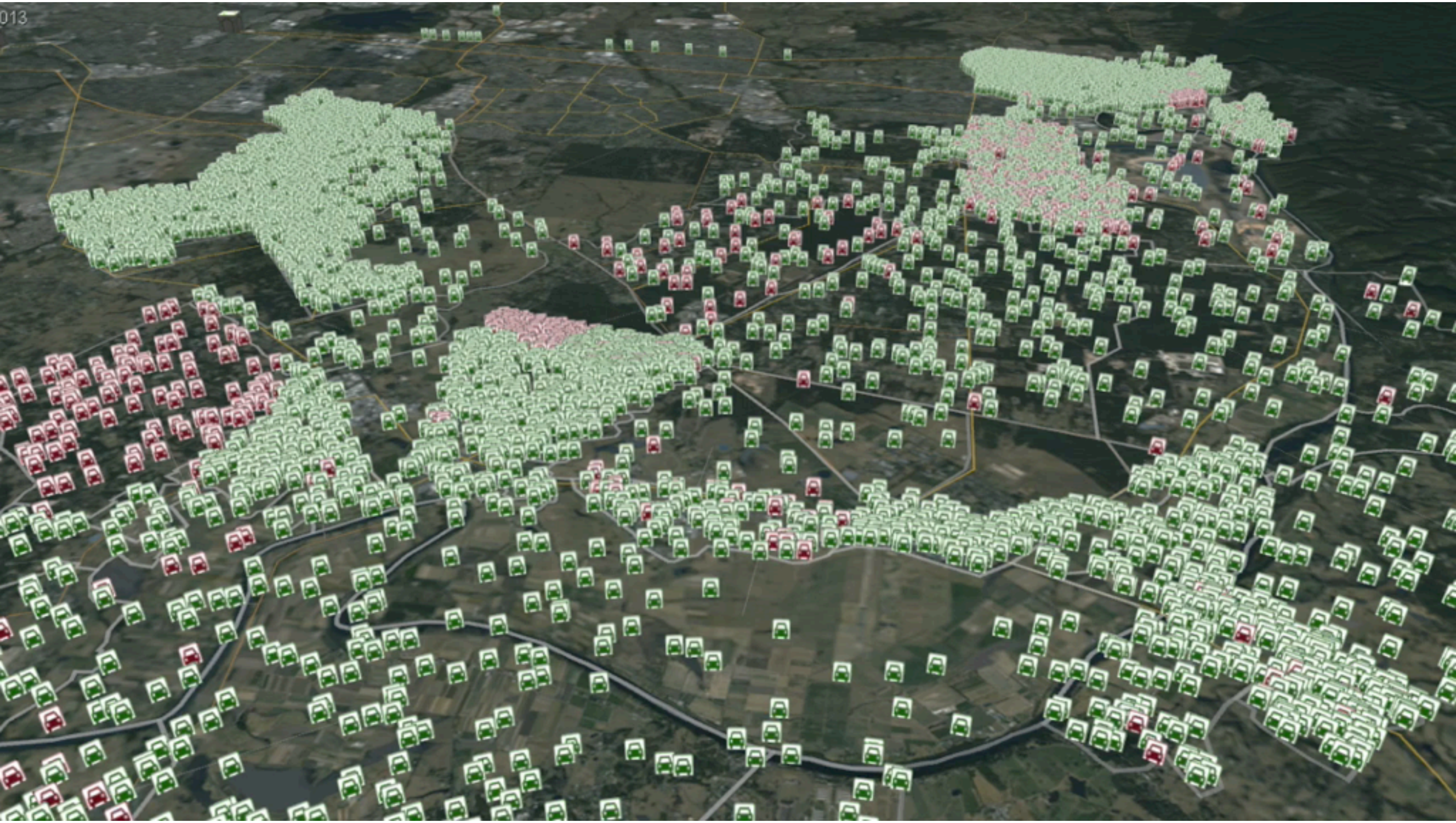
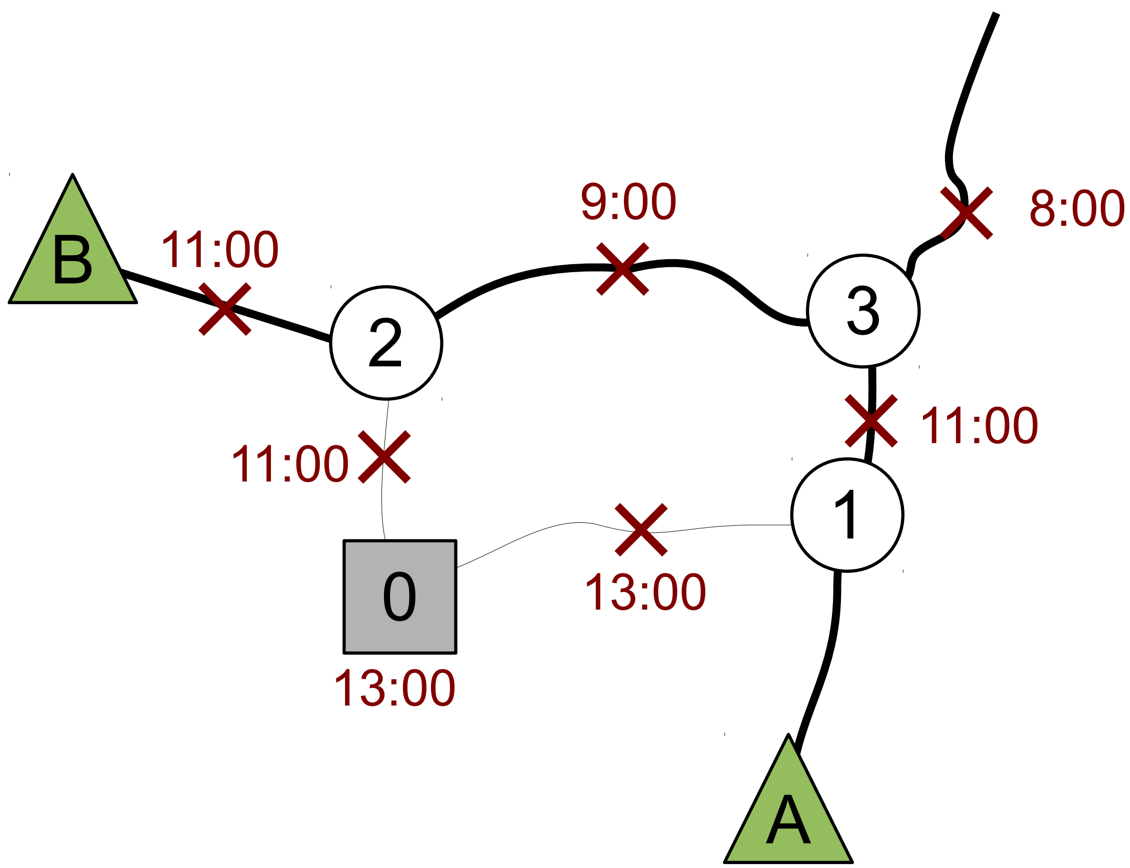
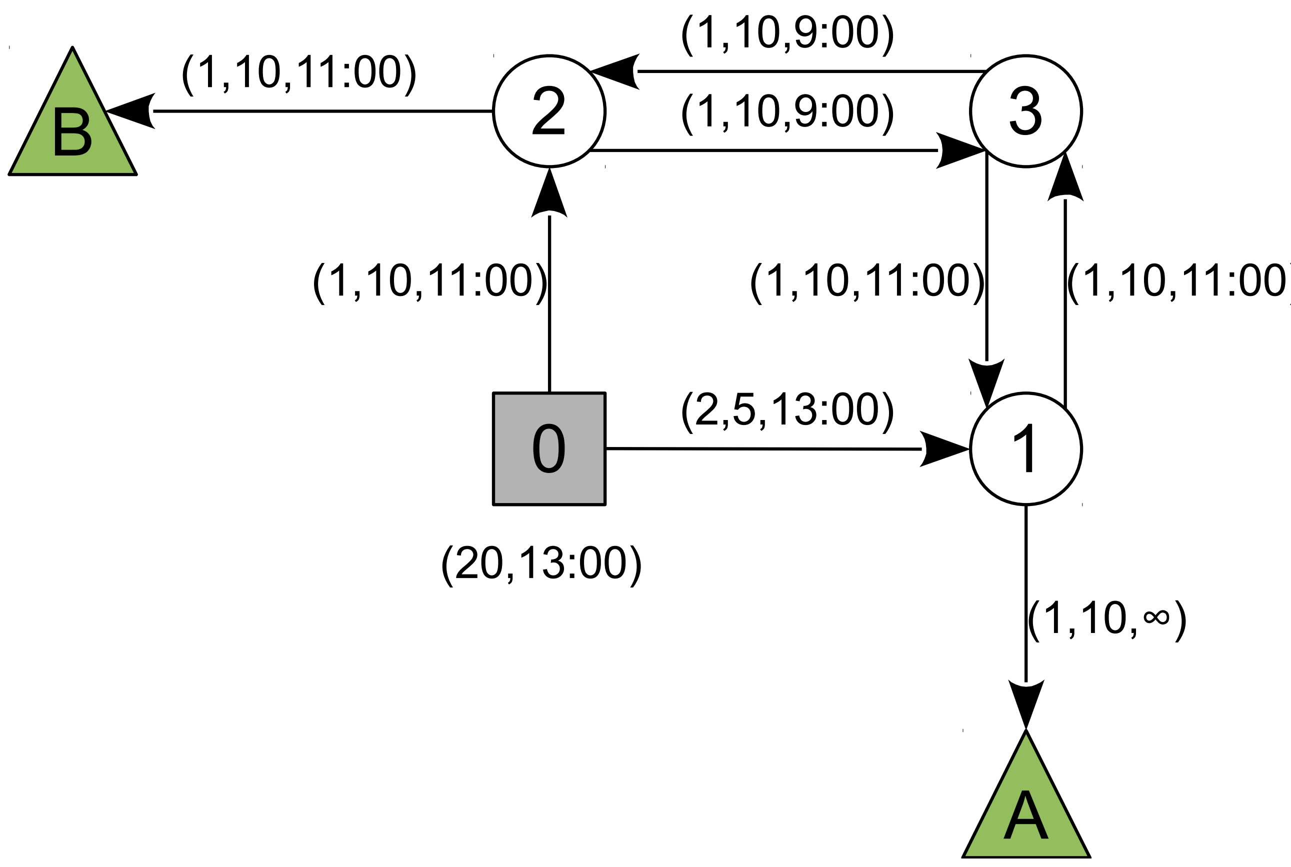


Evacuation Scenario

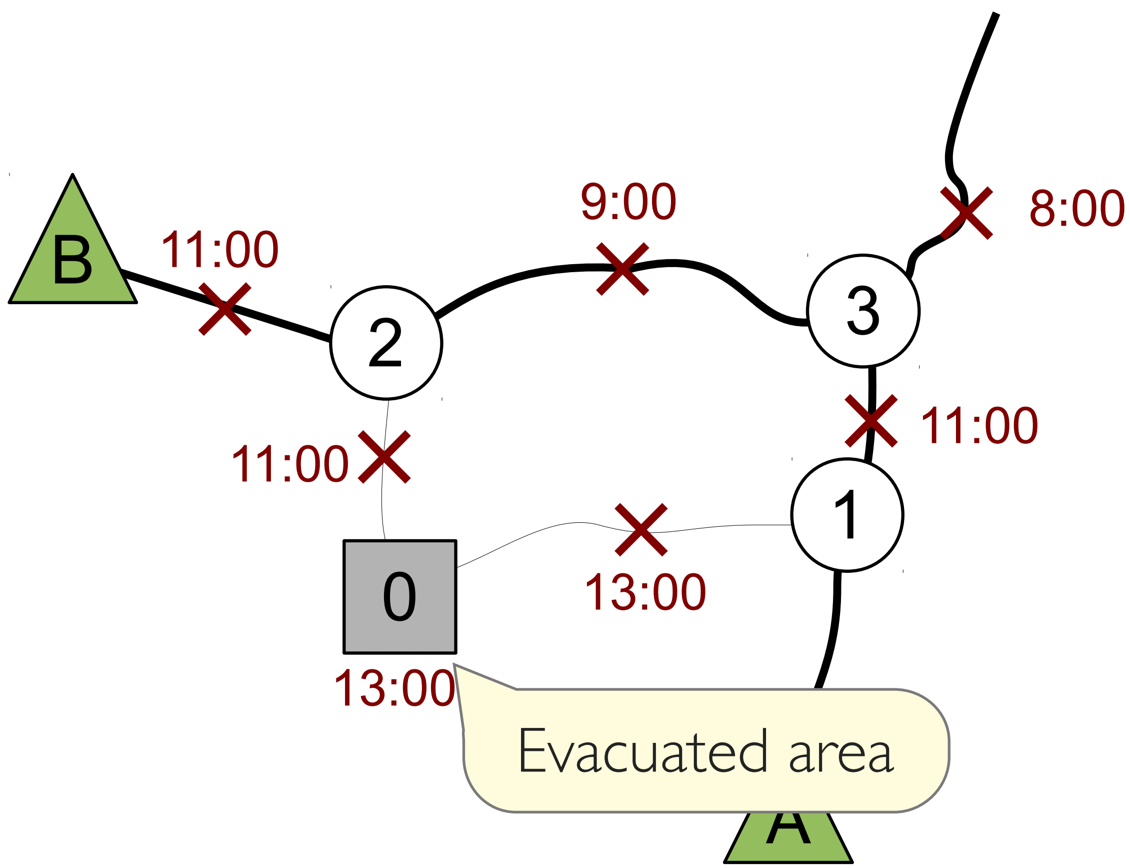


Real-world scenario



Evacuation graph

Evacuation Scenario



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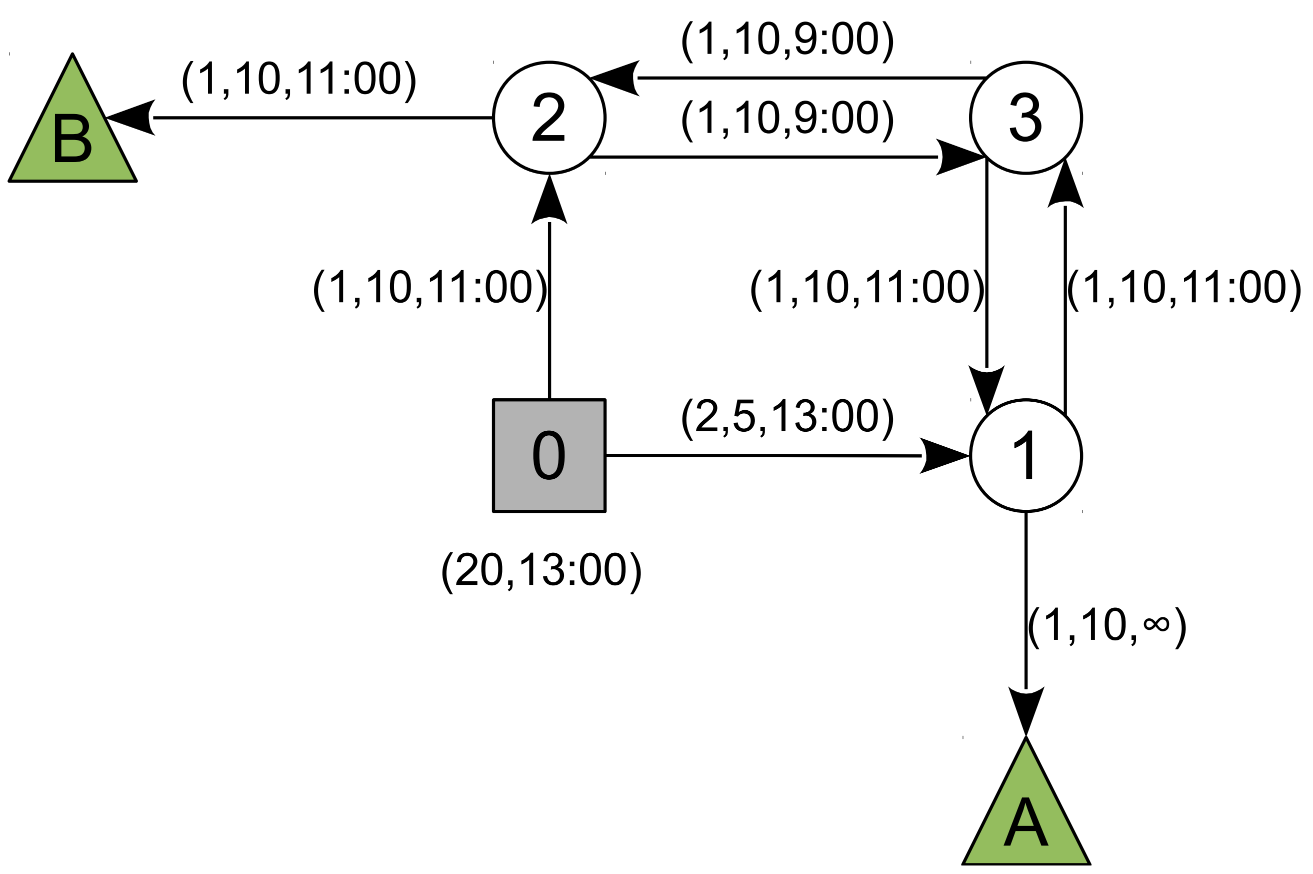

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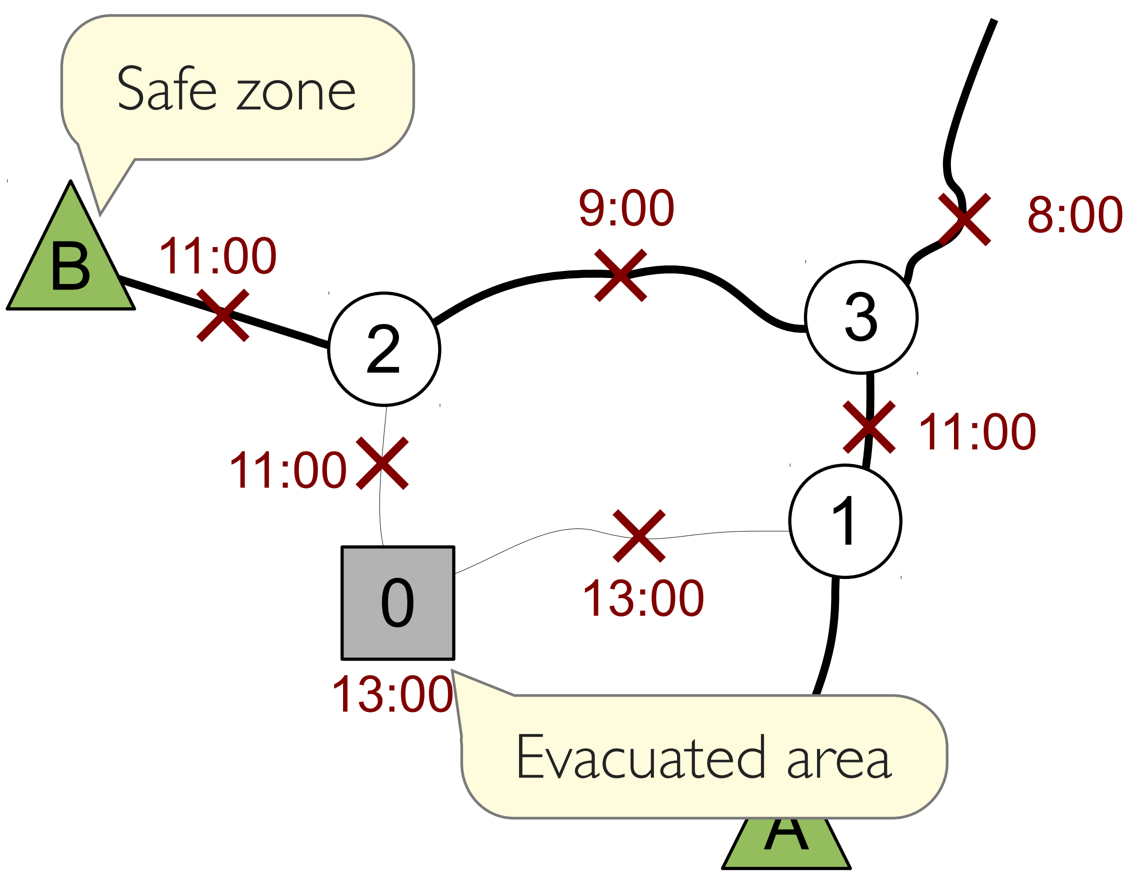
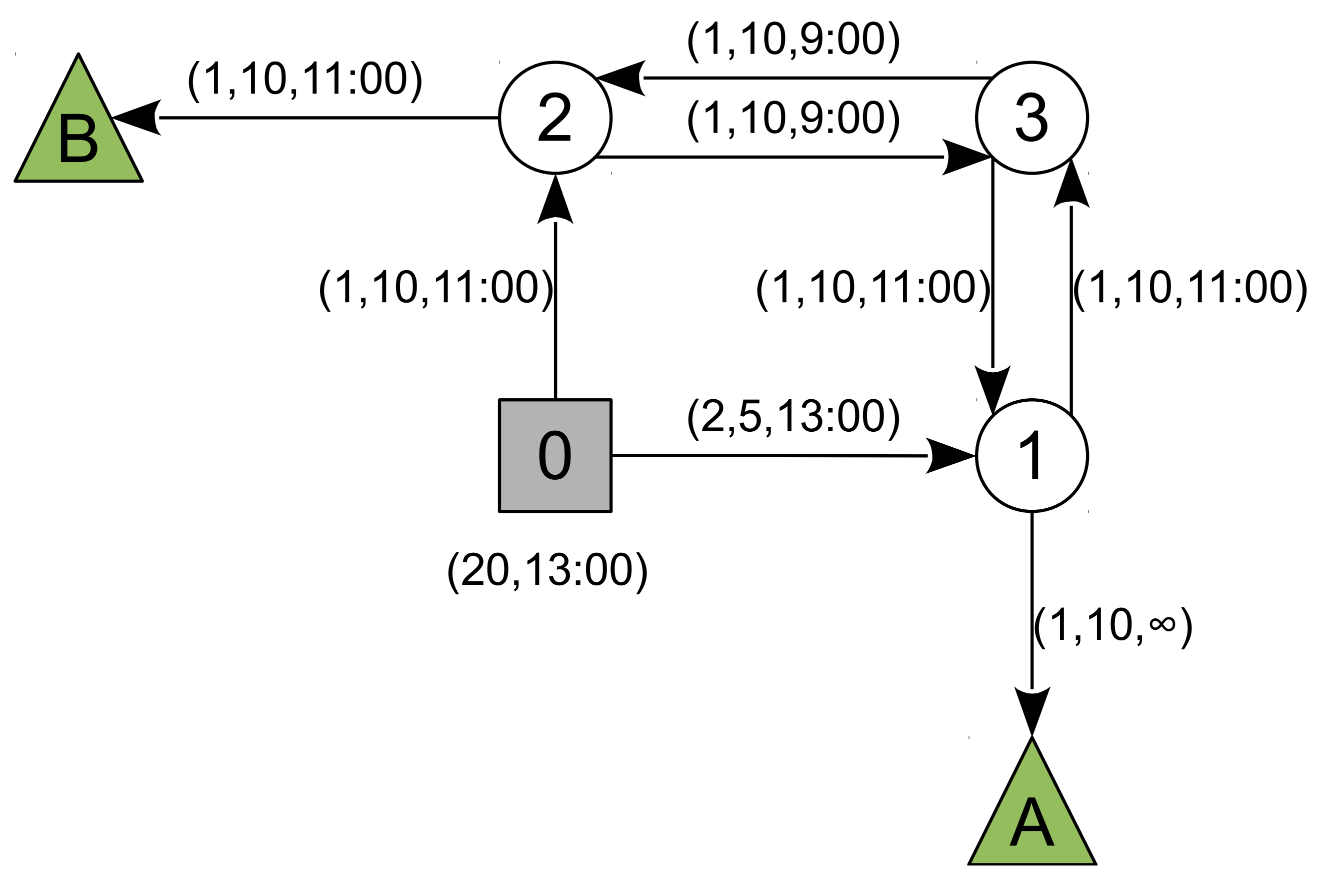
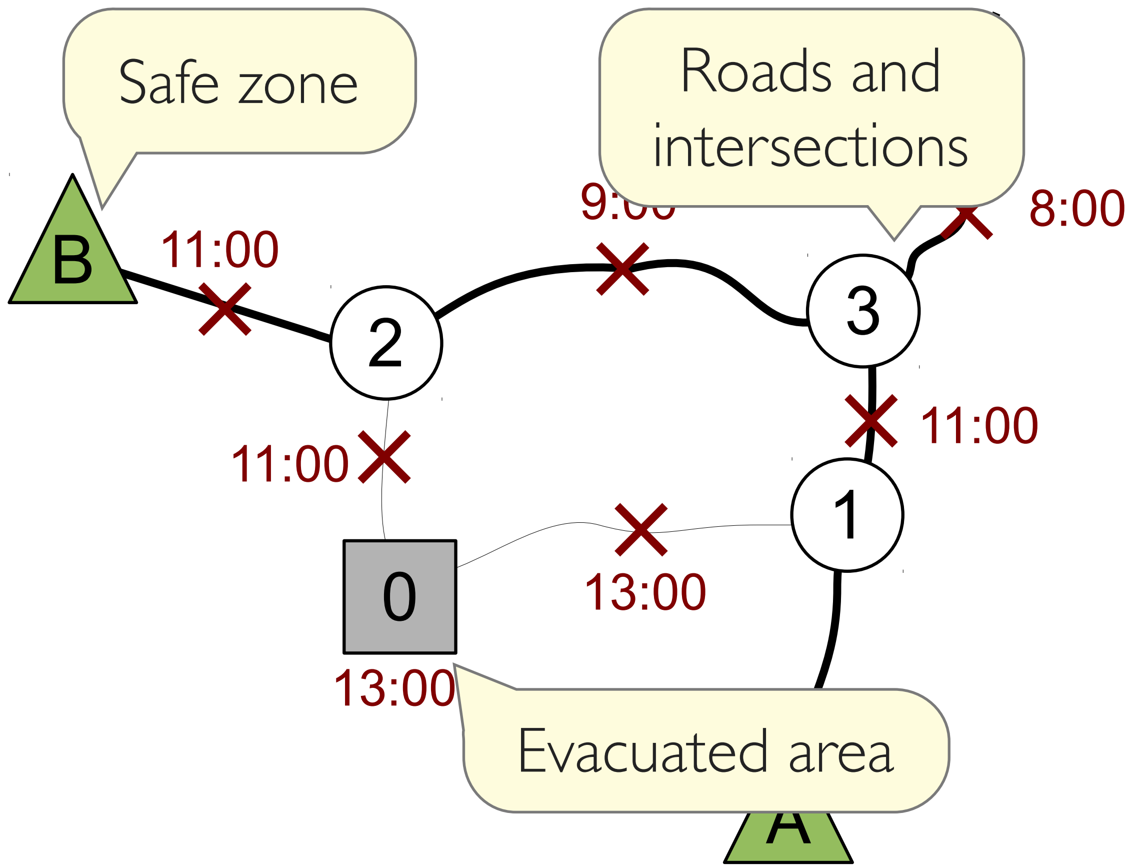




Real-world scenario **Evacuation graph**

Evacuation Scenario



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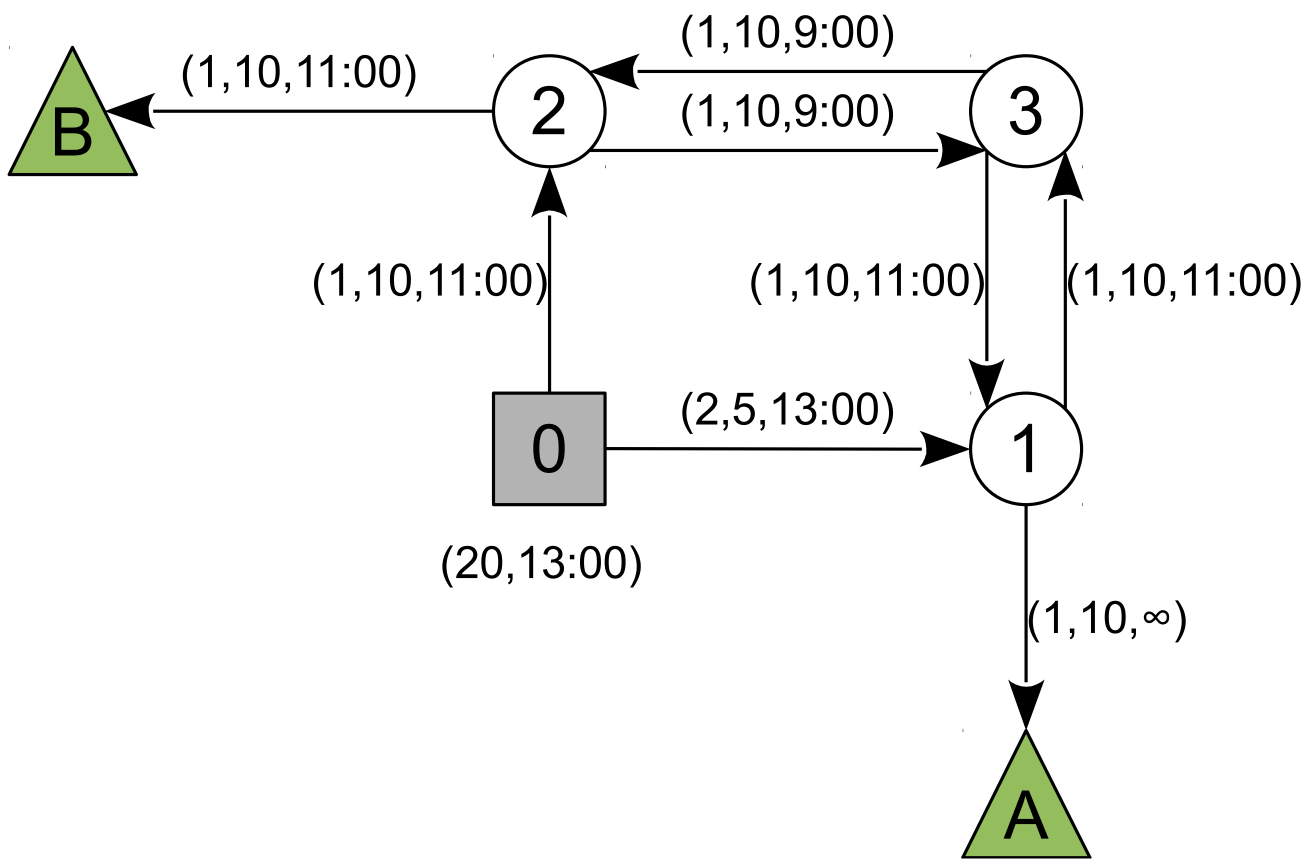

Evacuation graph

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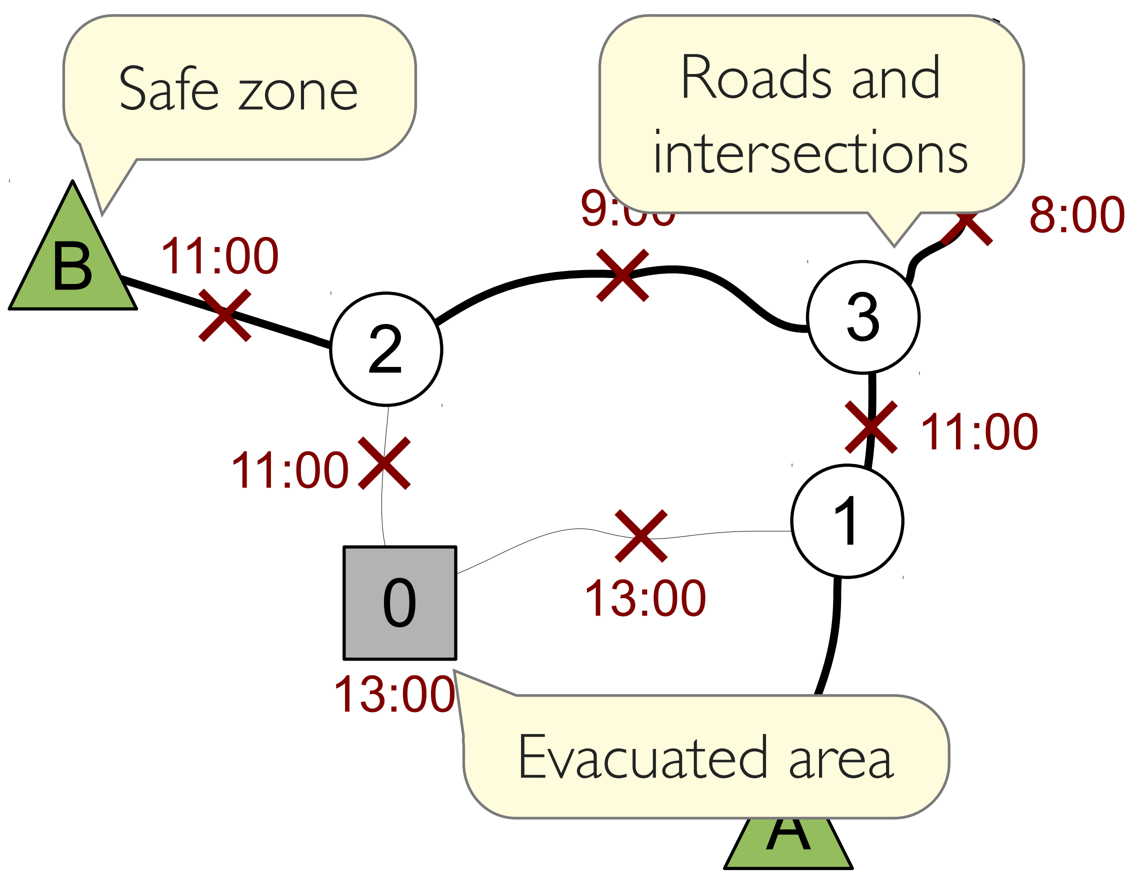

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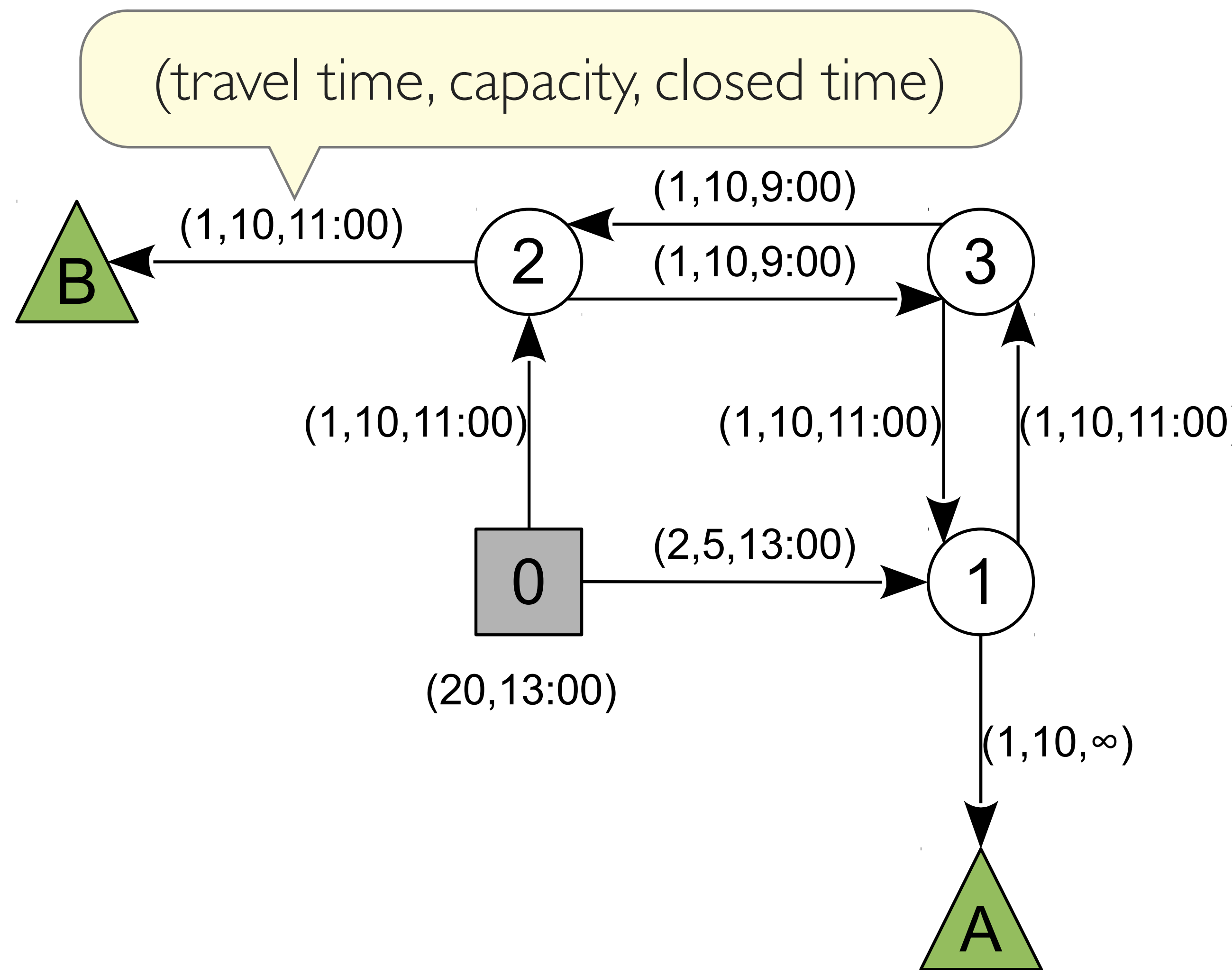

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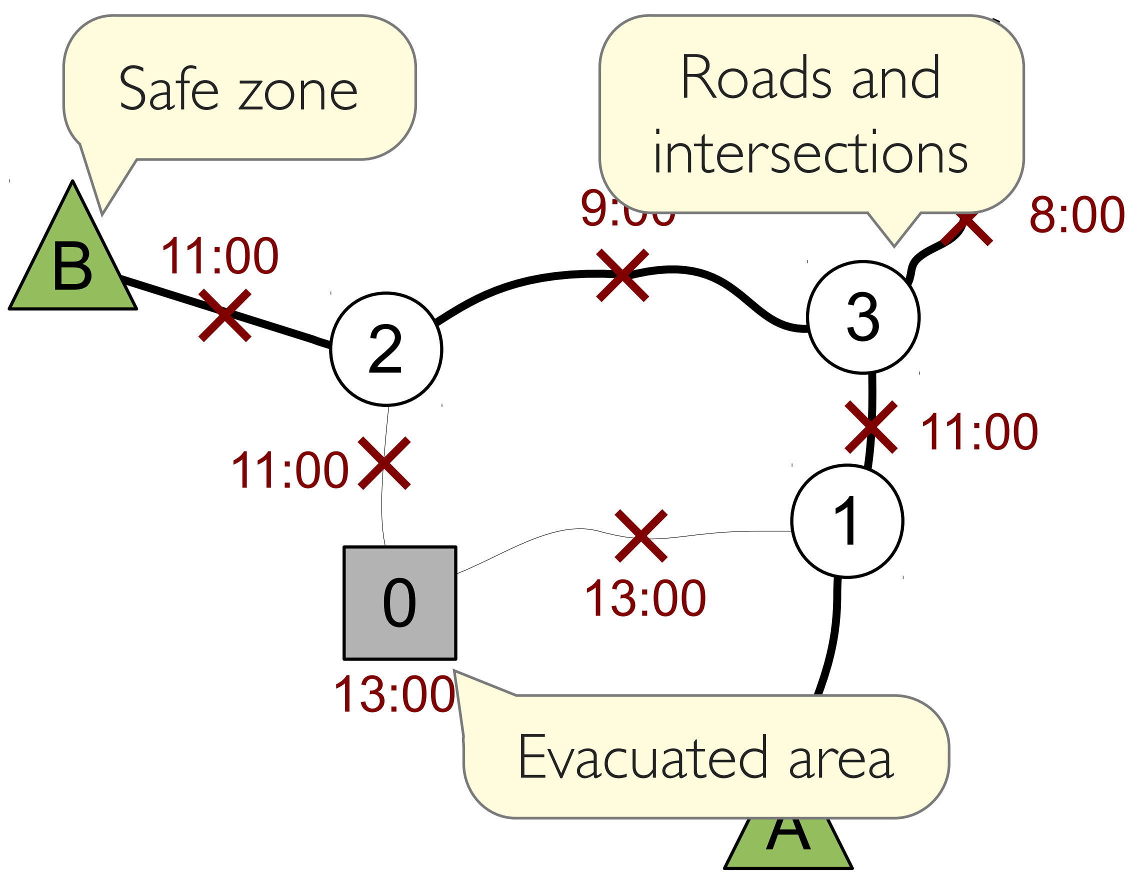

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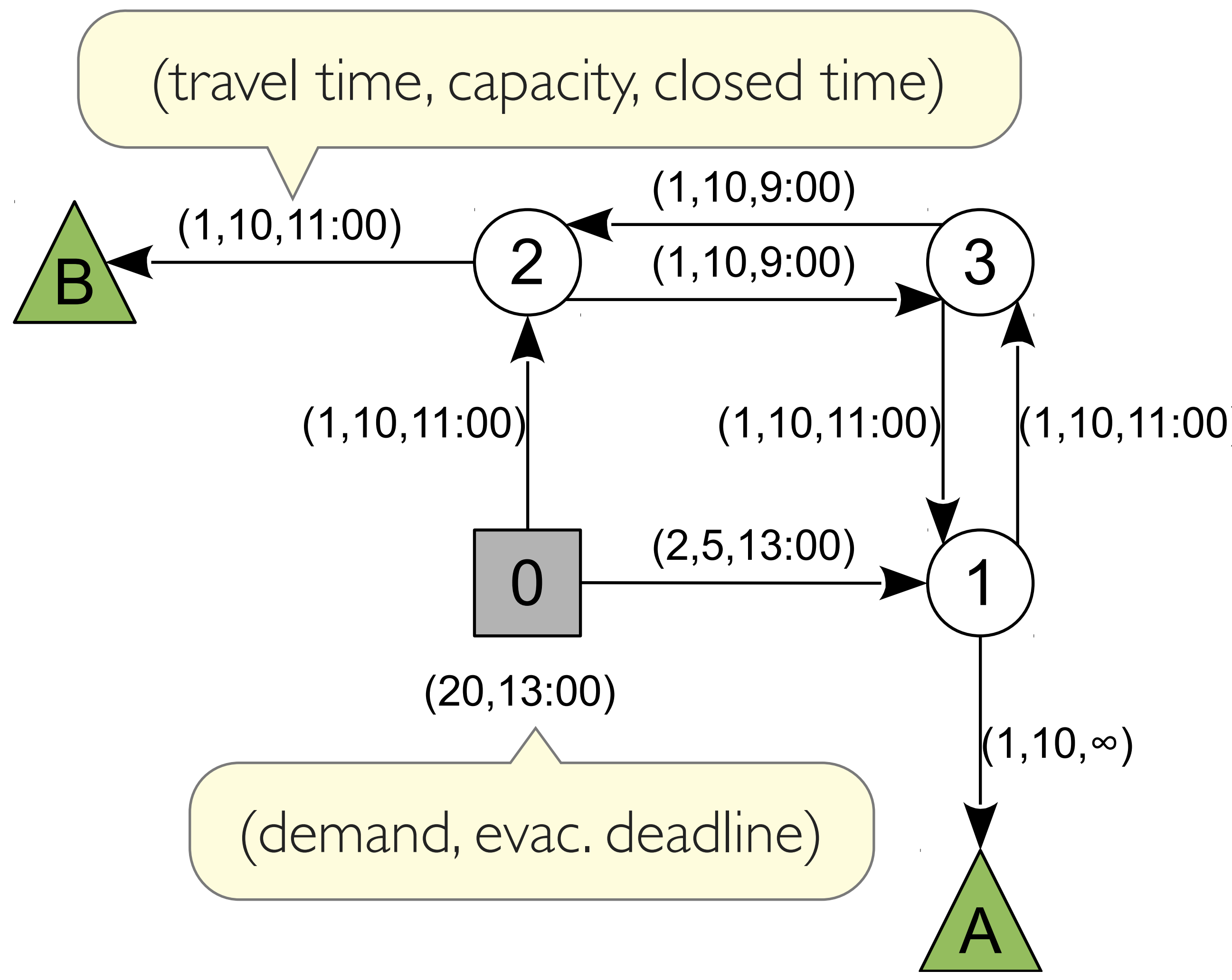

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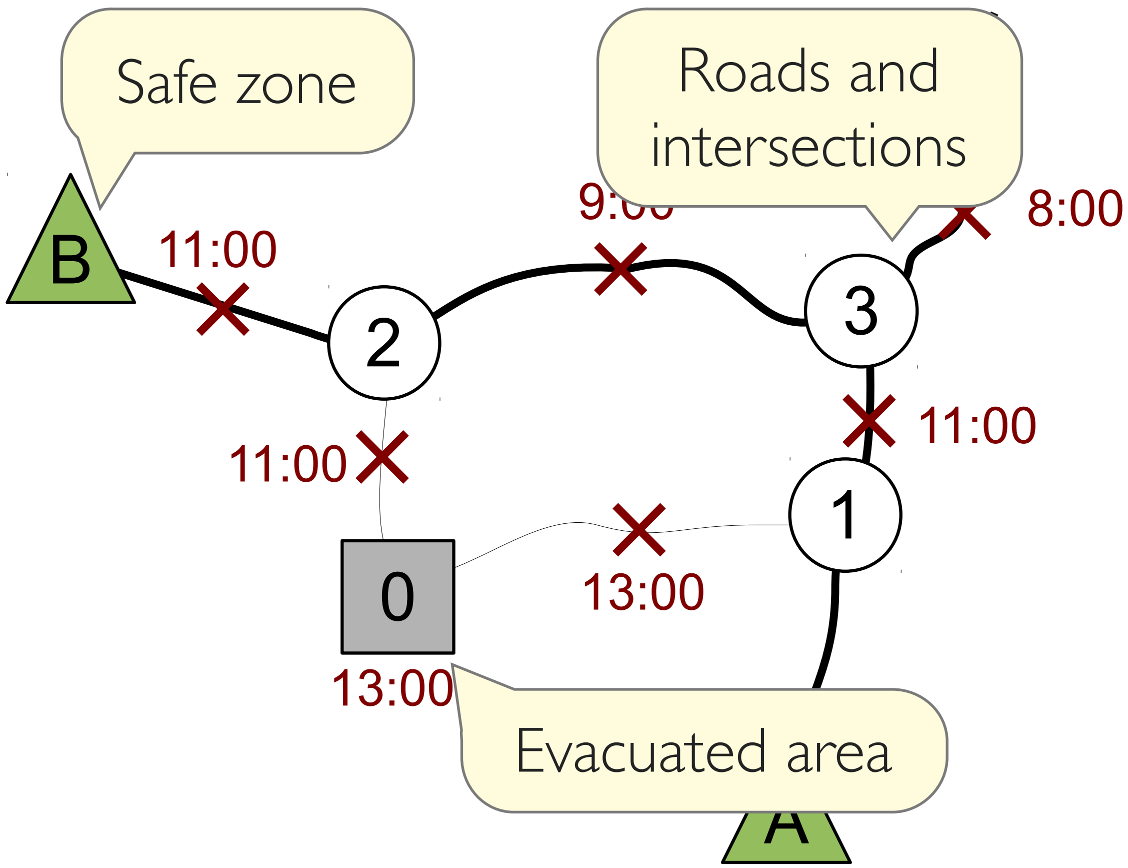

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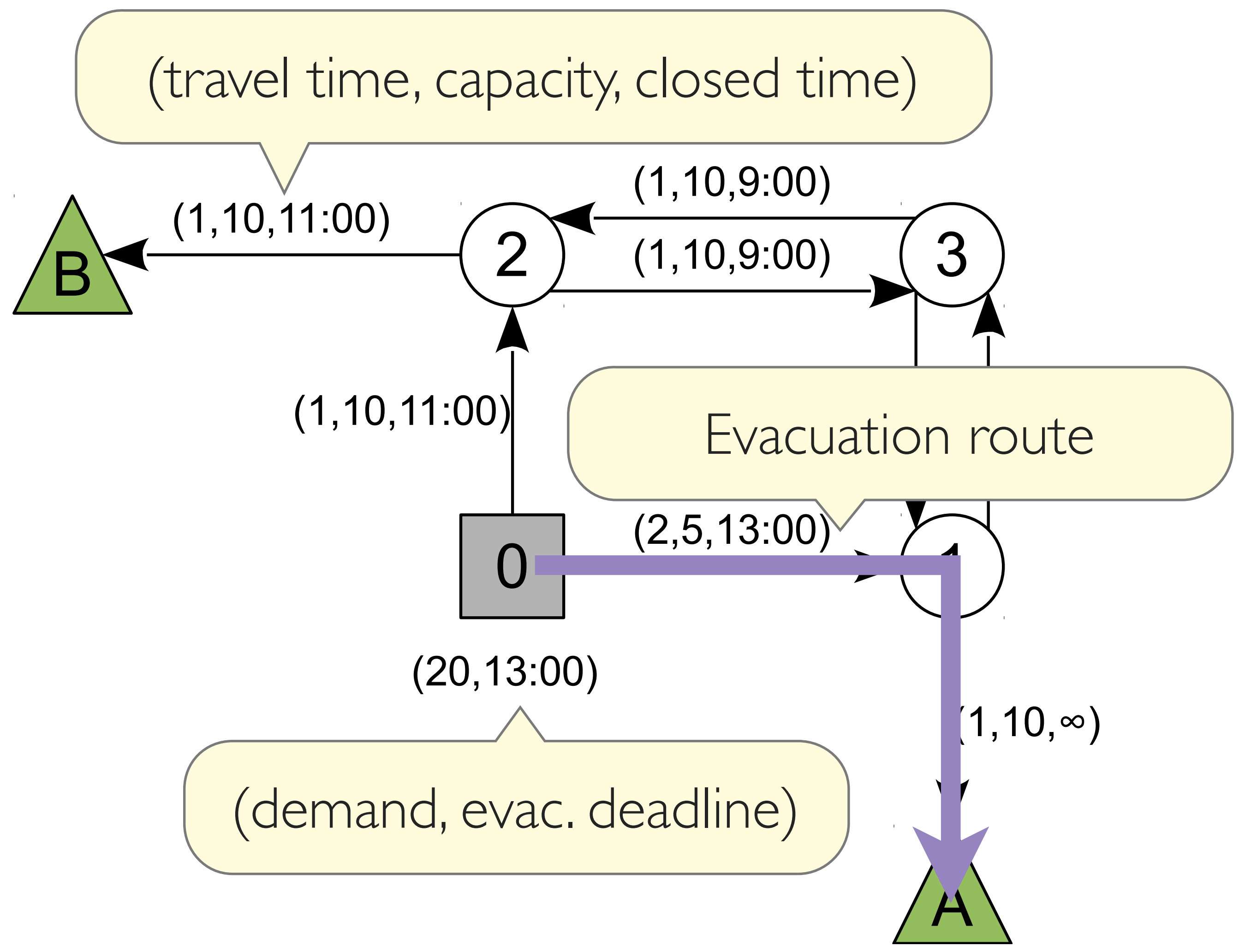

Evacuation graph

Contraflows

- Increase outbound capacity by changing lane direction
- In practice: highways and major roads

Houston, TX

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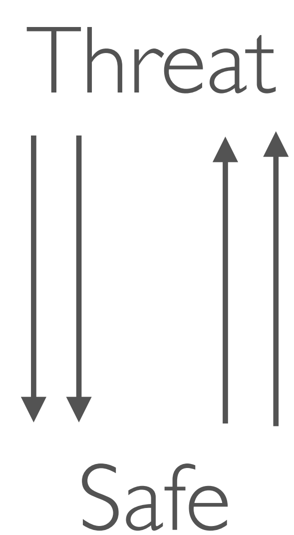
Houston, TX



Contraflows

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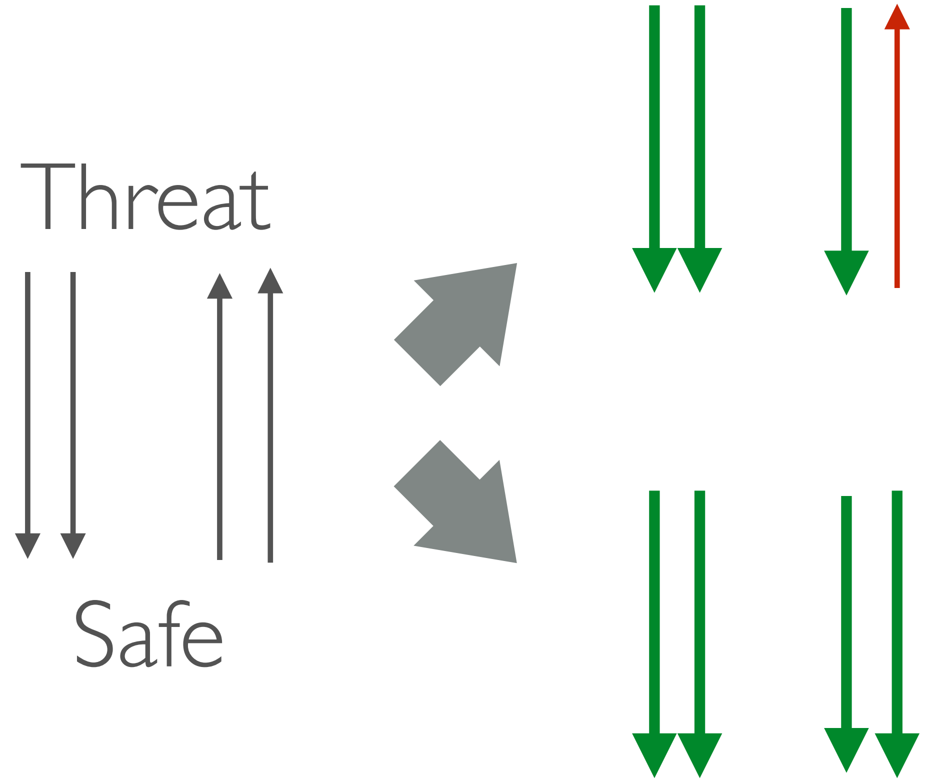
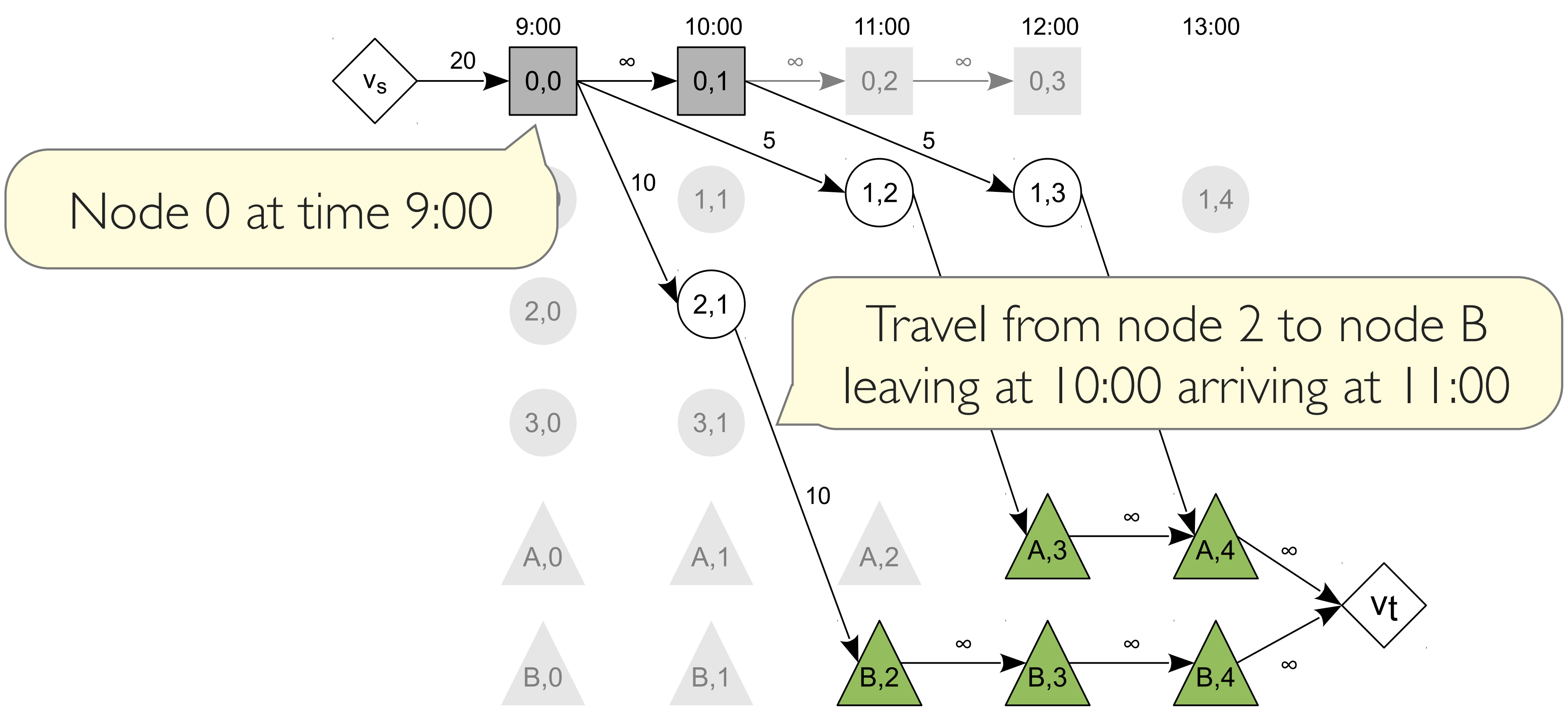
Houston, TX

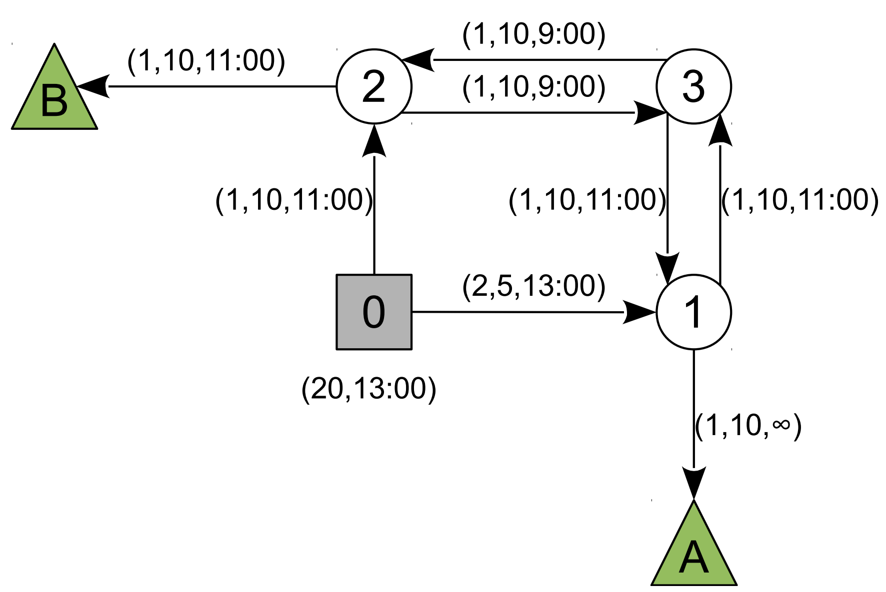


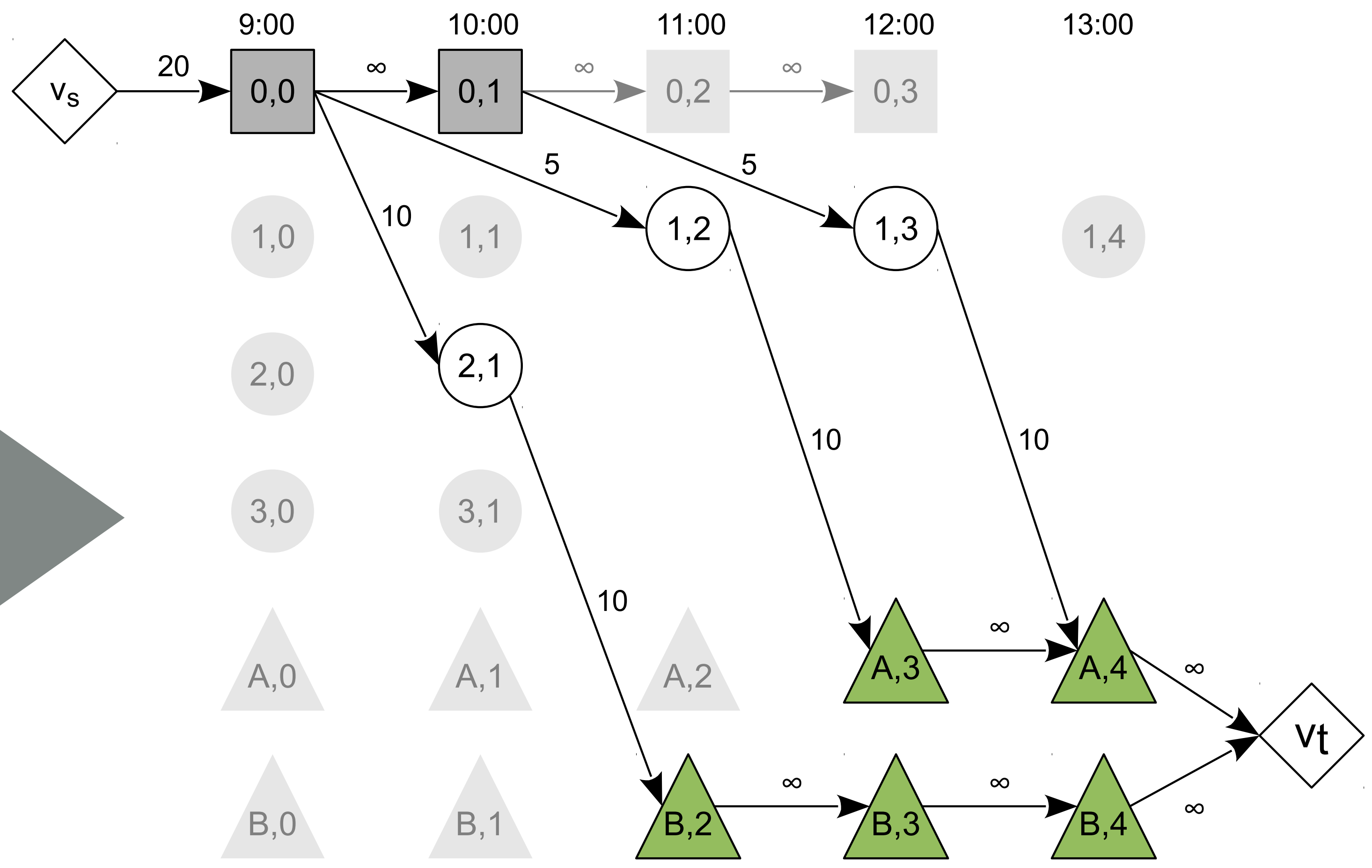
Evacuation Scheduling

- The problem is to schedule the evacuation over time
  - Given evacuation routes
  - Decide when each evacuee leaves
- Modeled using a Time-Expanded Graph:



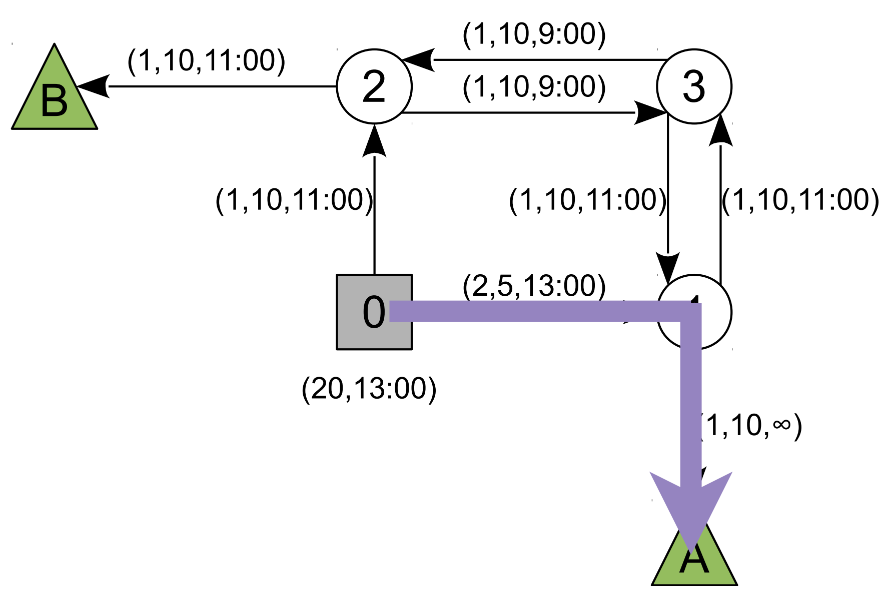
Evacuation Scheduling

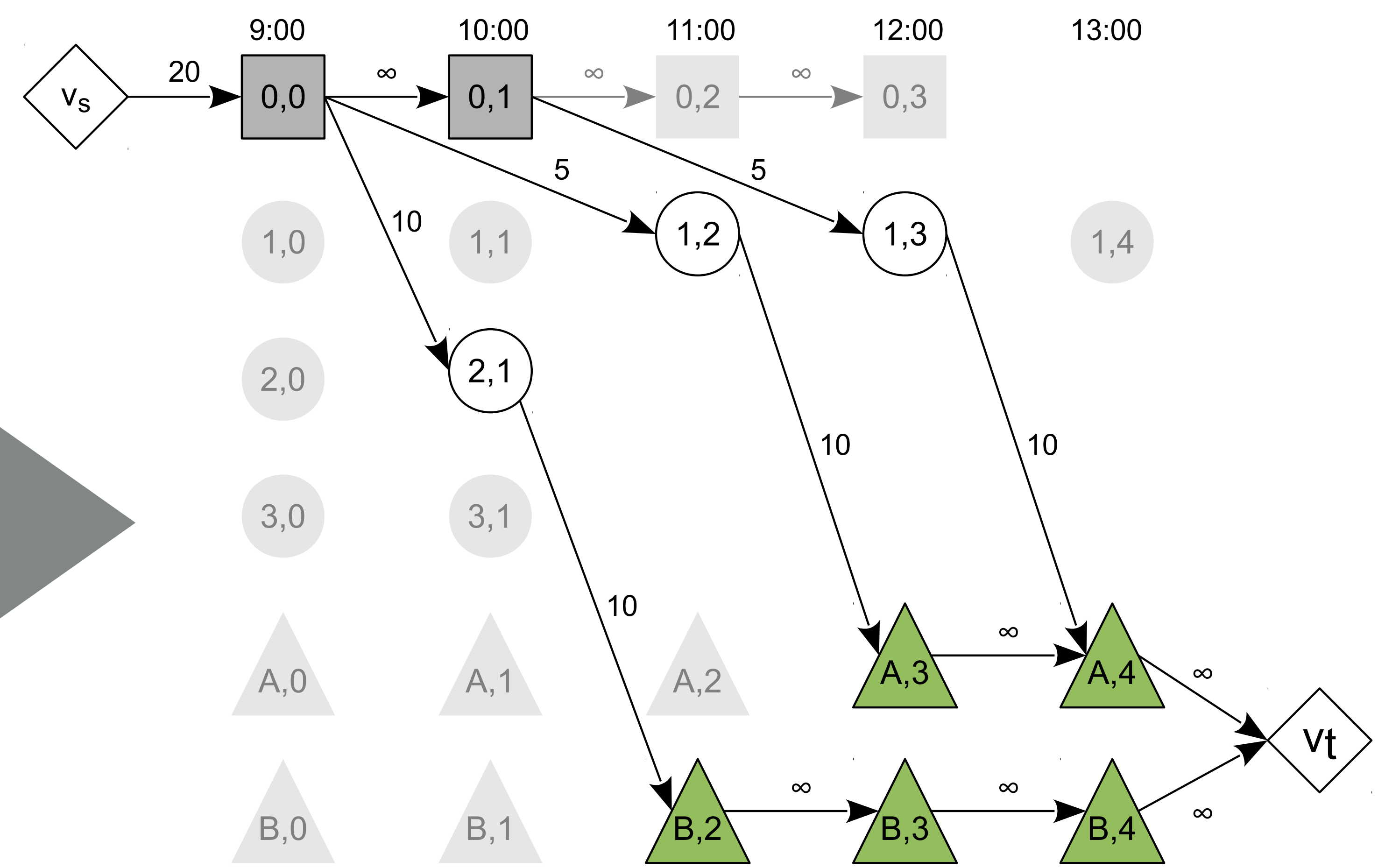




Evacuation route **Evacuation schedule**

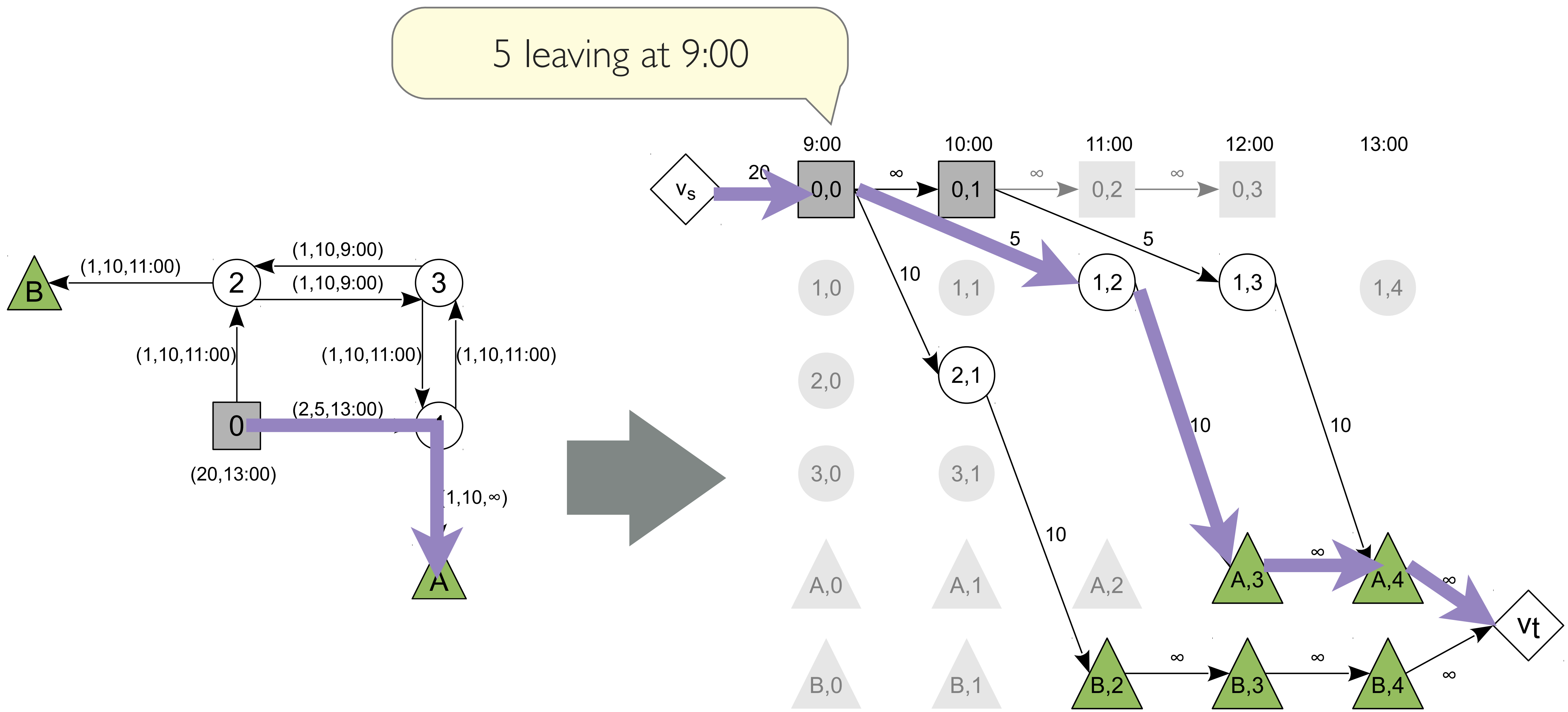
Evacuation Scheduling





Evacuation route **Evacuation schedule**

Evacuation Scheduling



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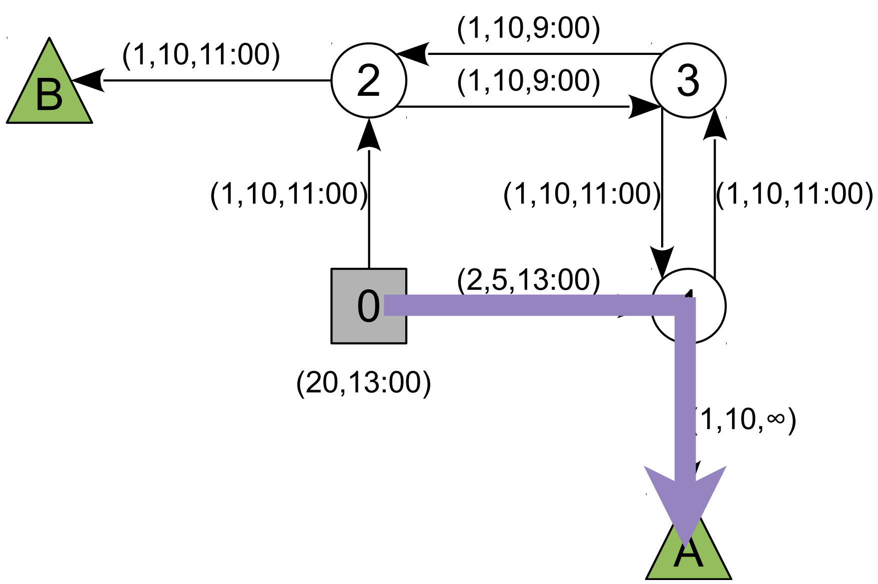

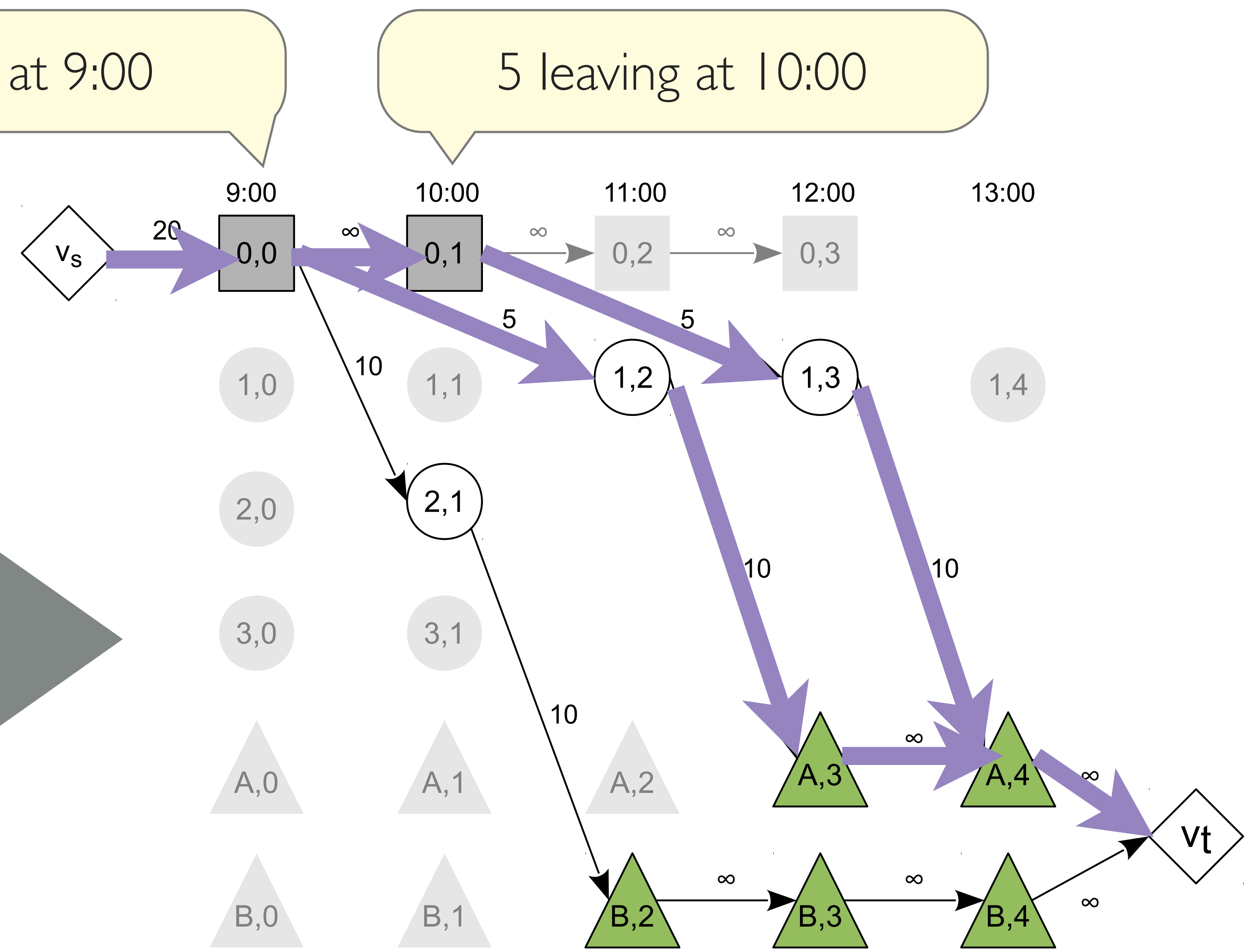

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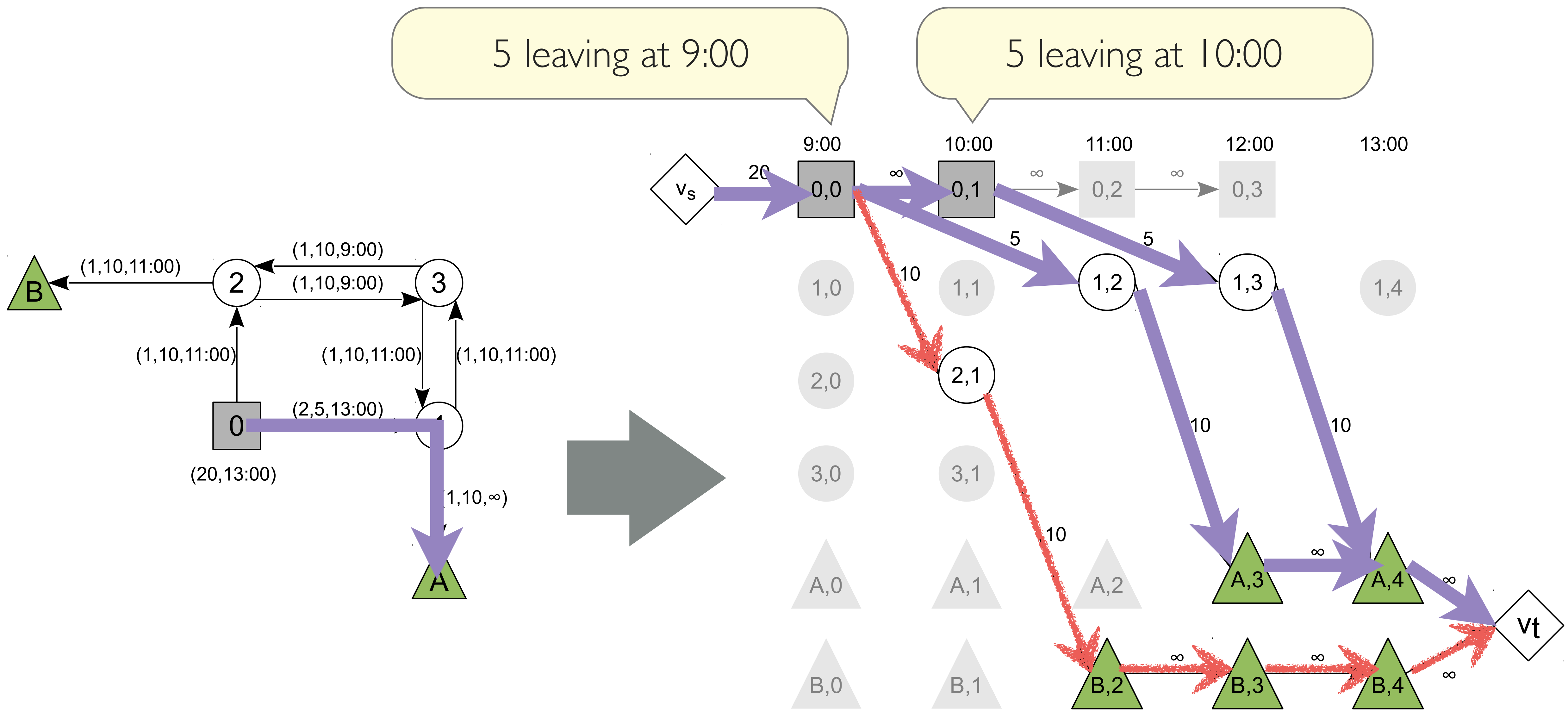
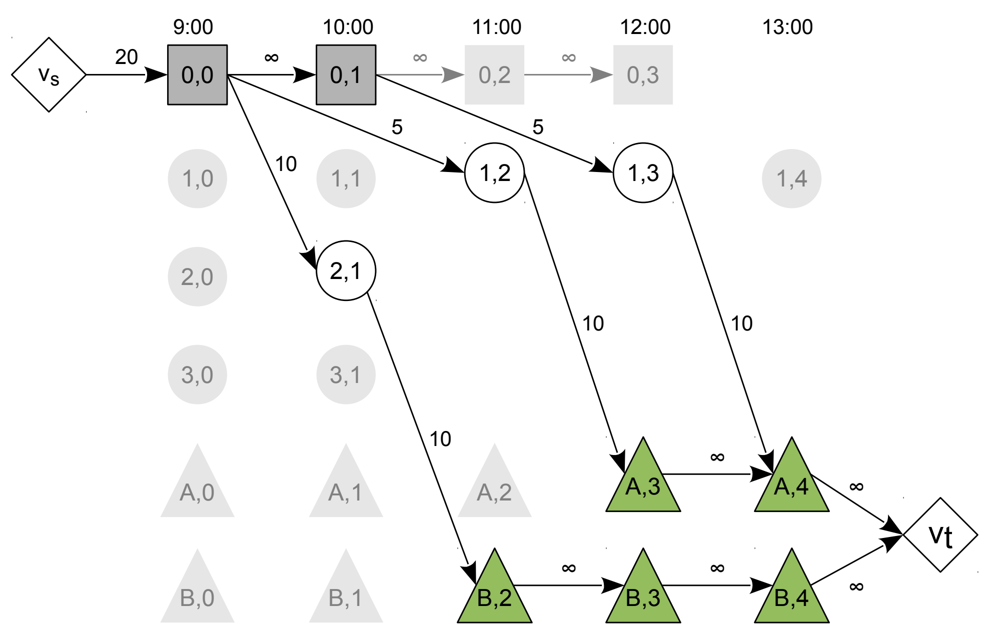


Evacuation route **Evacuation schedule**

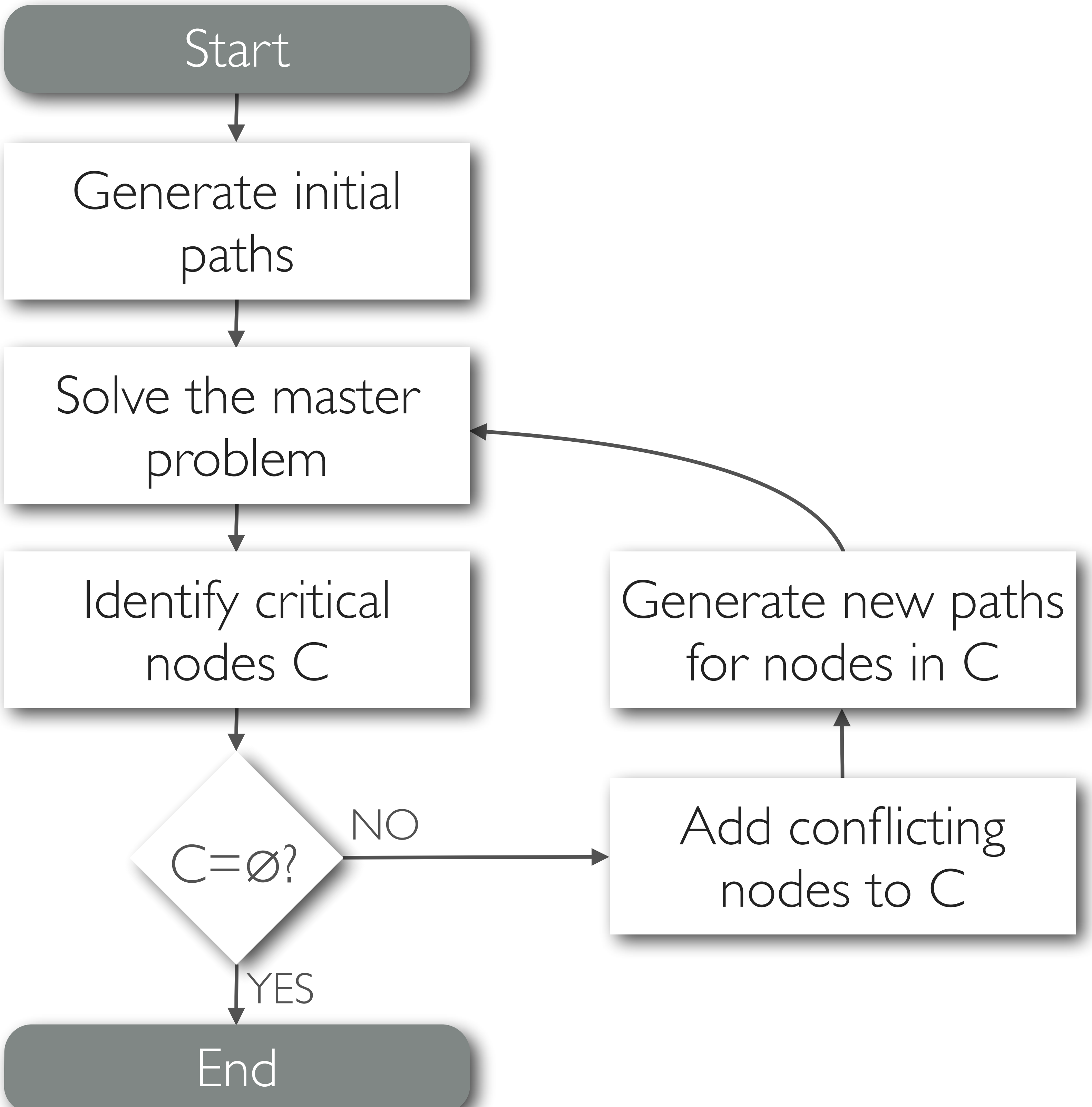
State Of The Art

- Most approaches rely on free flow models
  - Solve a max flow problem on the time-expanded graph



- Limitations
  - No detailed instructions to evacuees (no evacuation route)
  - Underestimate the time required for evacuation

Conflict Path Generation (CPG)



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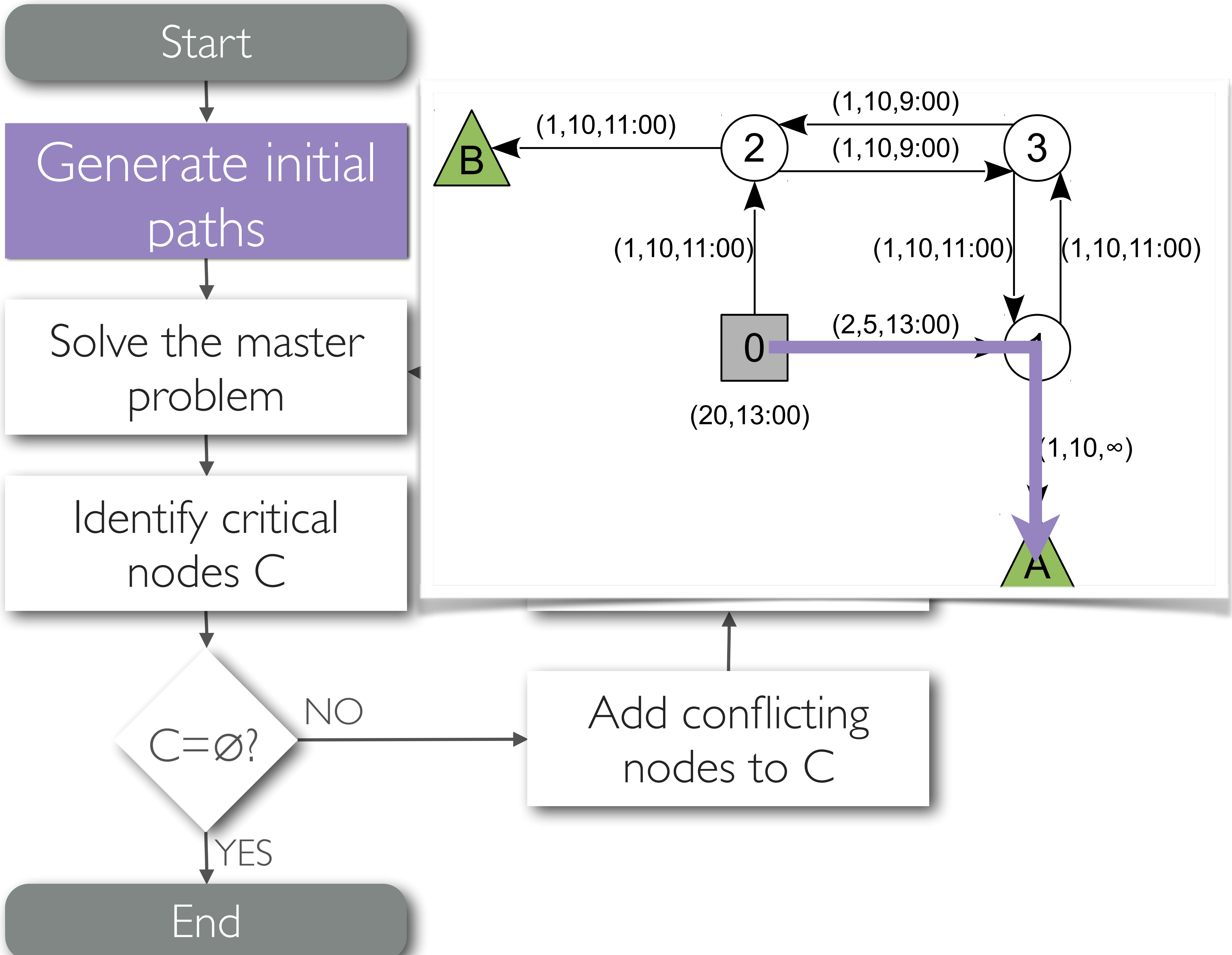
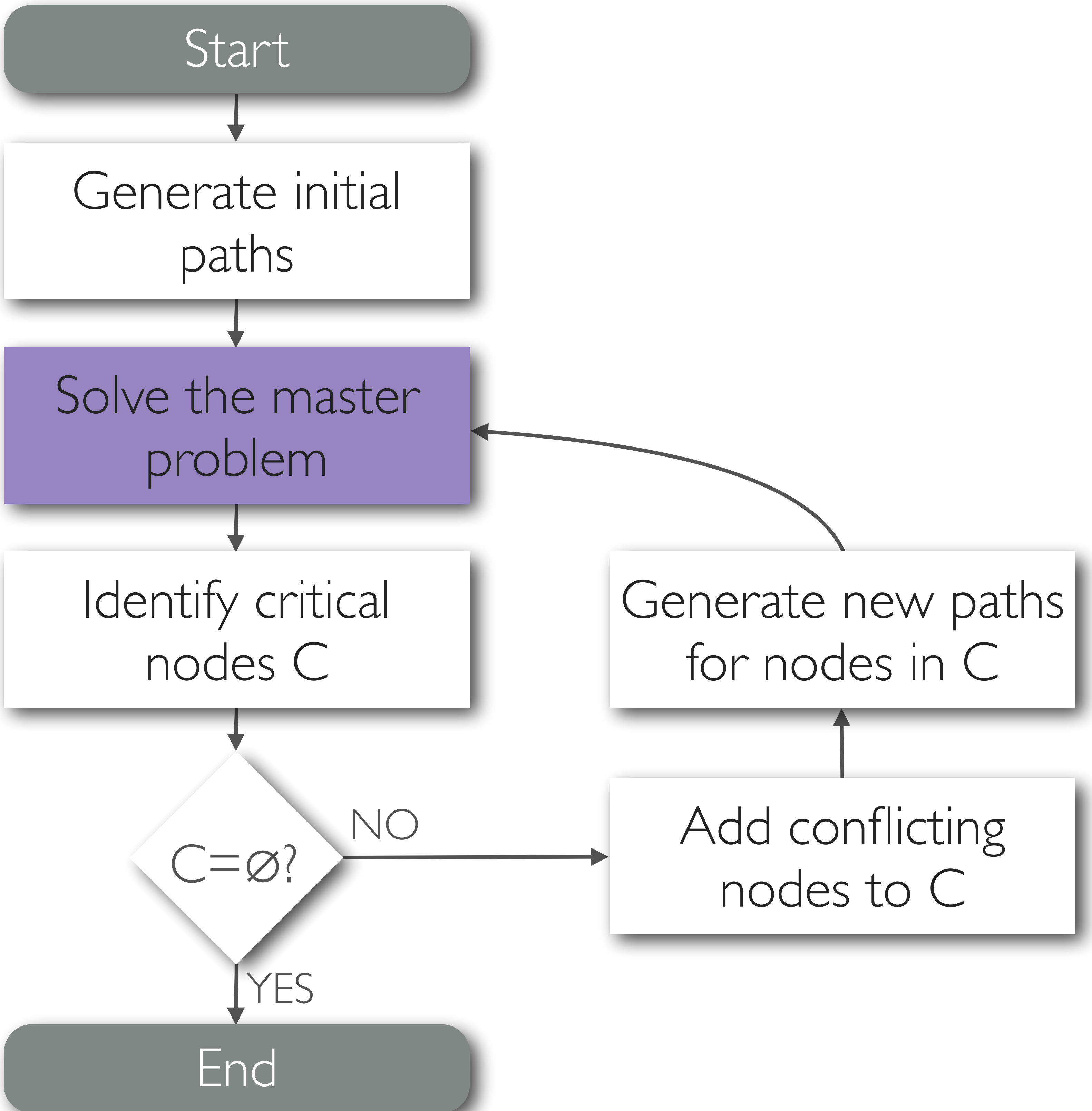


Approach Overview



Reduced Master Problem I

$$
\begin{aligned}
\max \quad & \sum_{p\in\Omega}\sum_{t\in\mathcal{H}_p} \varphi_t^p && \\
\text{s.t.} \quad & \sum_{p\in\Omega_k} x_p = 1 && \forall k \in \mathcal{E} \\
& \sum_{p\in\Omega_k}\sum_{t\in\mathcal{H}_p} \varphi_p^t + \varphi_k = d_k && \forall k \in \mathcal{E} \\
& \sum_{\substack{p\in\omega(e) \\ t-\tau_p^e\in\mathcal{H}_p}} \varphi_p^{t-\tau_p^e} \leq u_e && \forall e \in \mathcal{A}\setminus\mathcal{A}_c, t \in \mathcal{H} \\
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Reduced Master Problem I

Max. number of evacuees reaching safety

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Max. number of evacuees reaching safety

Select one path per evacuated area

Reduced Master Problem I

$$\max \sum_{p\in\Omega}\sum_{t\in\mathcal{H}_p} \varphi_t^p$$

Max. number of evacuees reaching safety

$$\text{s.t.} \sum_{p\in\Omega_k} x_p = 1$$

Select one path per evacuated area

$$\sum_{p\in\Omega_k}\sum_{t\in\mathcal{H}_p} \varphi_p^t + \varphi_k = d_k$$

Account for non evacuated vehicles

$$\sum_{\substack{p\in\omega(e)\\ t-\tau_p^e\in\mathcal{H}_p}} \varphi_p^{t-\tau_p^e} \leq u_e \qquad \forall e\in\mathcal{A}\setminus\mathcal{A}_c, t\in\mathcal{H}$$

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Max. number of evacuees reaching safety

Select one path per evacuated area

Account for non evacuated vehicles

Edge capacity
&
Contraflow decisions

Reduced Master Problem I

$$\max \sum_{p\in\Omega}\sum_{t\in\mathcal{H}_p} \varphi_t^p$$

Max. number of evacuees reaching safety

$$\text{s.t.} \quad \sum_{p\in\Omega_k} x_p = 1$$

Select one path per evacuated area

$$\sum_{p\in\Omega_k}\sum_{t\in\mathcal{H}_p} \varphi_p^t + \varphi_k = d_k$$

Account for non evacuated vehicles

$$\sum_{\substack{p\in\omega(e)\\ t-\tau_p^e\in\mathcal{H}_p}} \varphi_p^{t-\tau_p^e} \leq u_e$$

$$\sum_{\substack{p\in\omega(e)\\ t-\tau_p^e\in\mathcal{H}_p}} \varphi_p^{t-\tau_p^e} \leq y_e u_e + (1-y_{\bar{e}})u_{\bar{e}}$$

Edge capacity
&
Contraflow decisions

$$y_e + y_{\bar{e}} \geq 1$$

$$y_e \geq x_p \qquad \forall e\in\mathcal{A}_c, \forall p\in\omega(e)$$

$$\sum_{t\in\mathcal{H}_p} \varphi_p^t \leq |\mathcal{H}_p| x_p u_p$$

Link flow and path selection variables

$$\varphi_p^t \geq 0 \qquad \forall p\in\Omega, t\in\mathcal{H}_p$$

$$\varphi_k \geq 0 \qquad \forall k\in\mathcal{E}$$

$$y_e \in \{0,1\} \qquad \forall e\in\mathcal{A}_c$$

$$x_p \in \{0,1\} \qquad \forall p\in\Omega$$

Reduced Master Problem I

$$\max \sum_{p \in \Omega} \sum_{t \in \mathcal{H}_p} \varphi_t^p$$

$$\text{s.t.} \quad \sum_{p \in \Omega_k} x_p = 1$$

$$\sum_{p \in \Omega_k} \sum_{t \in \mathcal{H}_p} \varphi_p^t + \varphi_k \ldots$$

$$\sum_{\substack{p \in \omega(e) \\ t-\tau_p^e \in \mathcal{H}_p}} \varphi_p^{t-\tau_p^e} \leq \ldots$$

$$\sum_{\substack{p \in \omega(e) \\ t-\tau_p^e \in \mathcal{H}_p}} \varphi_p^{t-\tau_p^e} \leq \ldots$$

$$y_e + y_{\bar{e}} \geq 1$$

$$y_e \geq x_p \qquad \forall e \in \mathcal{A}_c, \forall p \in \omega(e)$$

$$\sum_{t \in \mathcal{H}_p} \varphi_p^t \leq |\mathcal{H}_p| x_p u_p$$

$$\varphi_p^t \geq 0 \qquad \forall p \in \Omega, t \in \mathcal{H}_p$$

$$\varphi_k \geq 0 \qquad \forall k \in \mathcal{E}$$

$$y_e \in \{0,1\} \qquad \forall e \in \mathcal{A}_c$$

$$x_p \in \{0,1\} \qquad \forall p \in \Omega$$

Max. number of evacuees reaching safety

Select one path per evacuated area

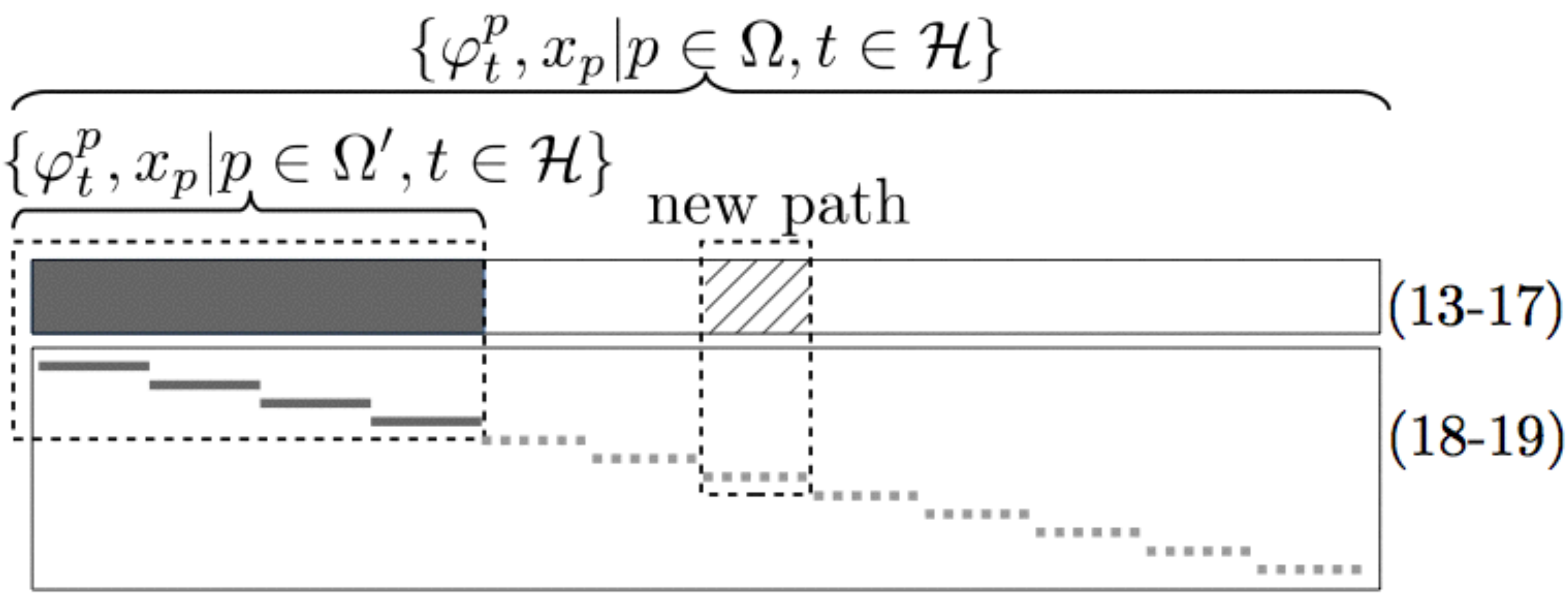
Link flow and path selection variables

Advantages:

- Adds variables and constraints only when needed
- Factor 100 reduction in number of variables and constraints

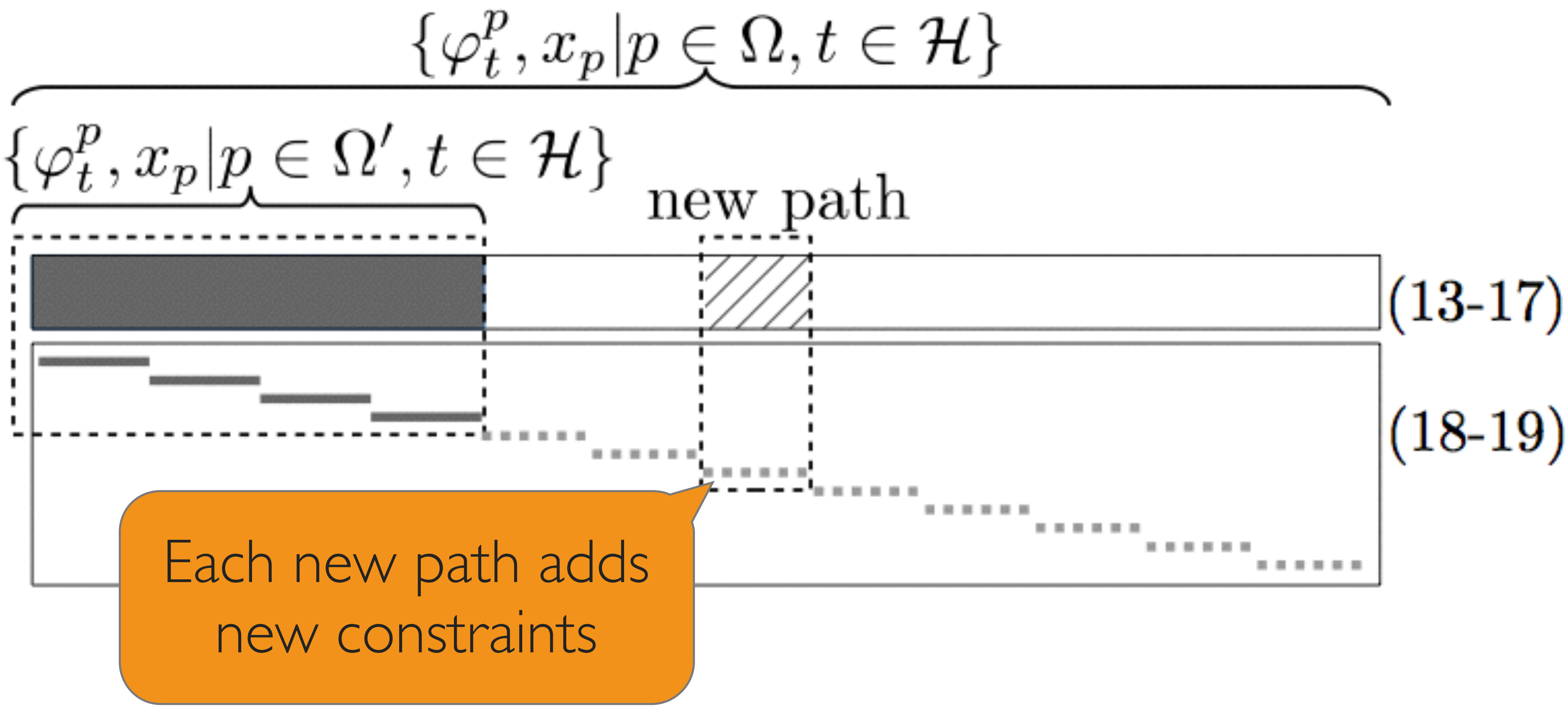
Reduced Master Problem 2

- Structure of the master problem:

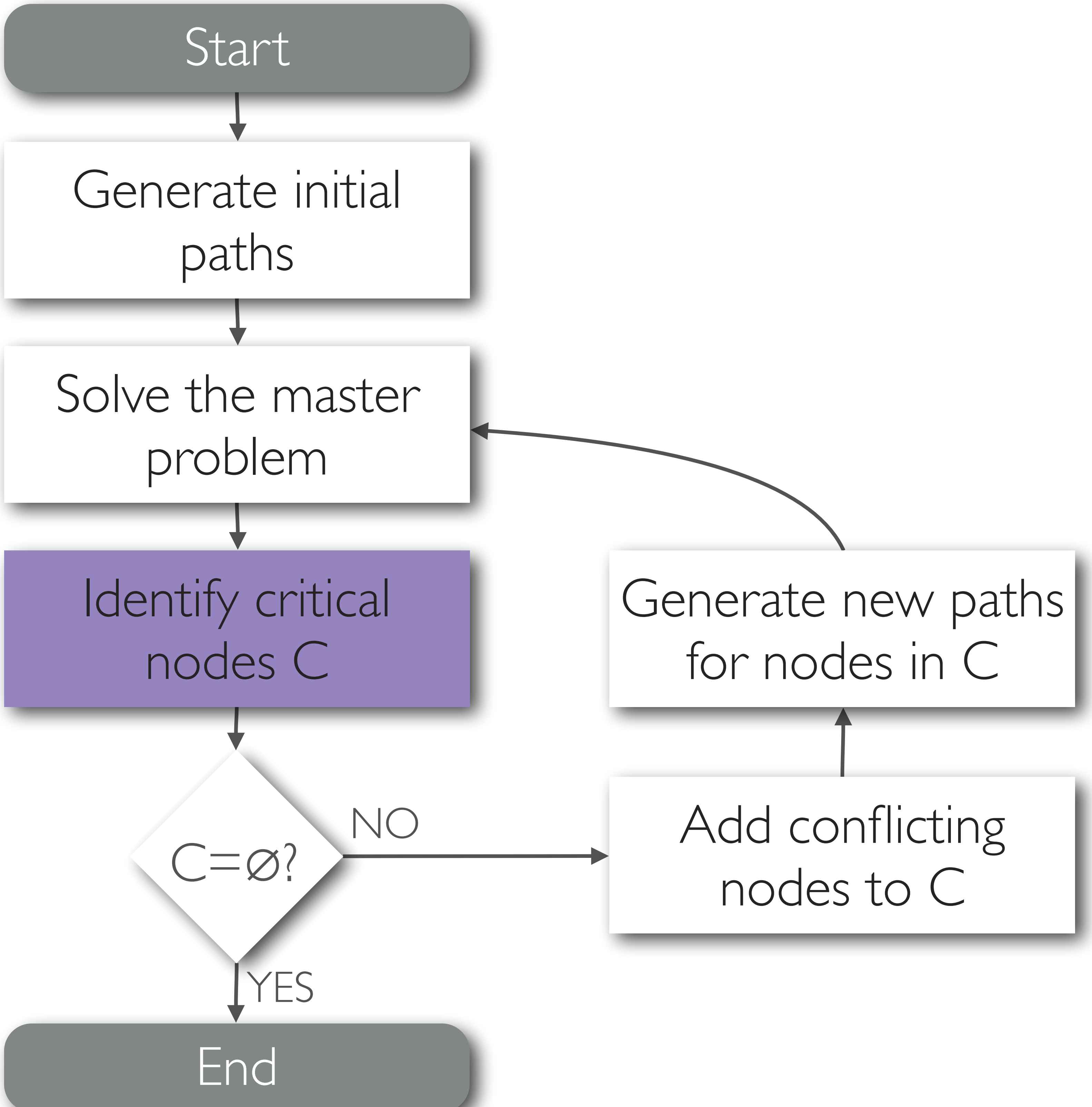


Reduced Master Problem 2

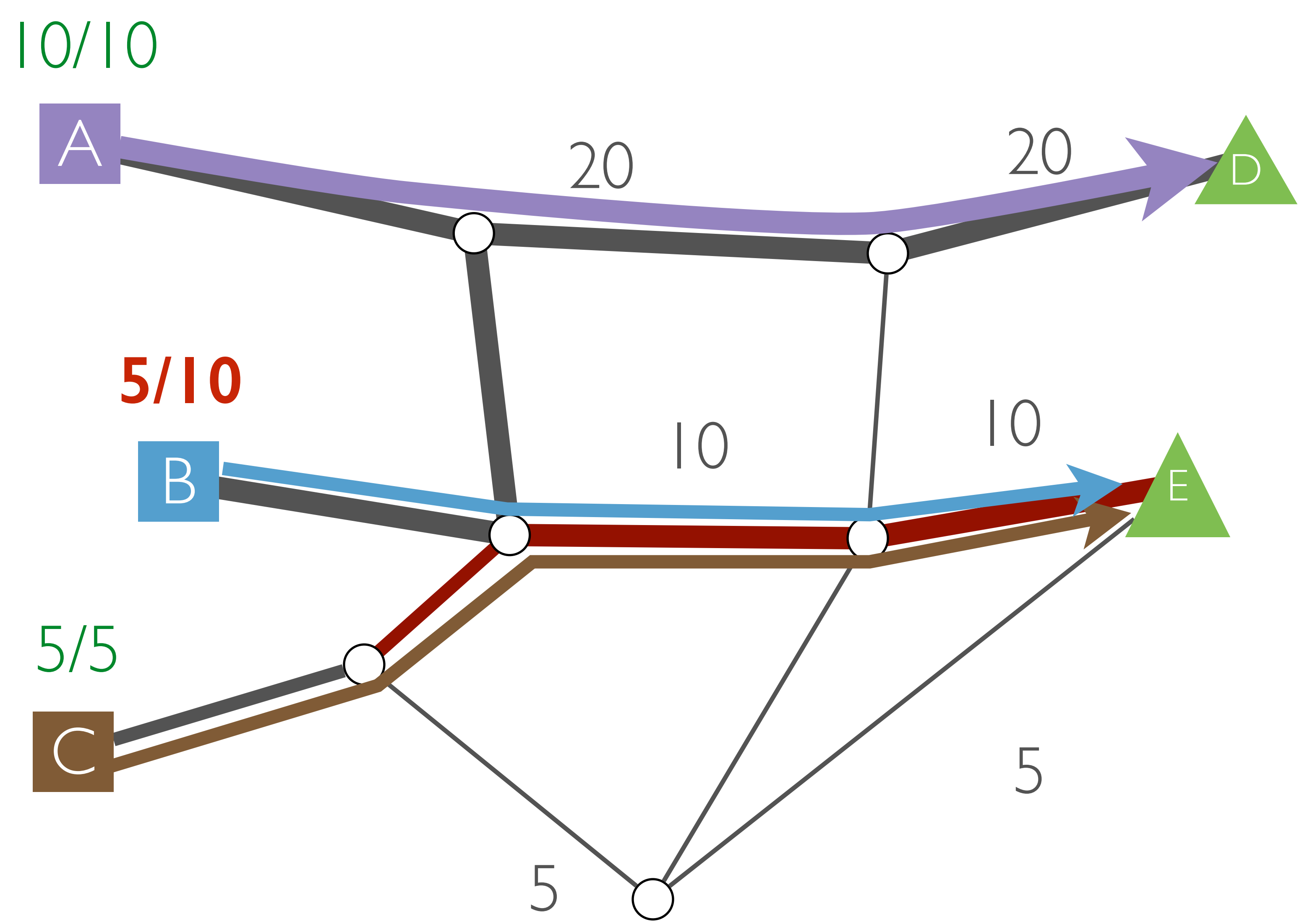
- Structure of the master problem:



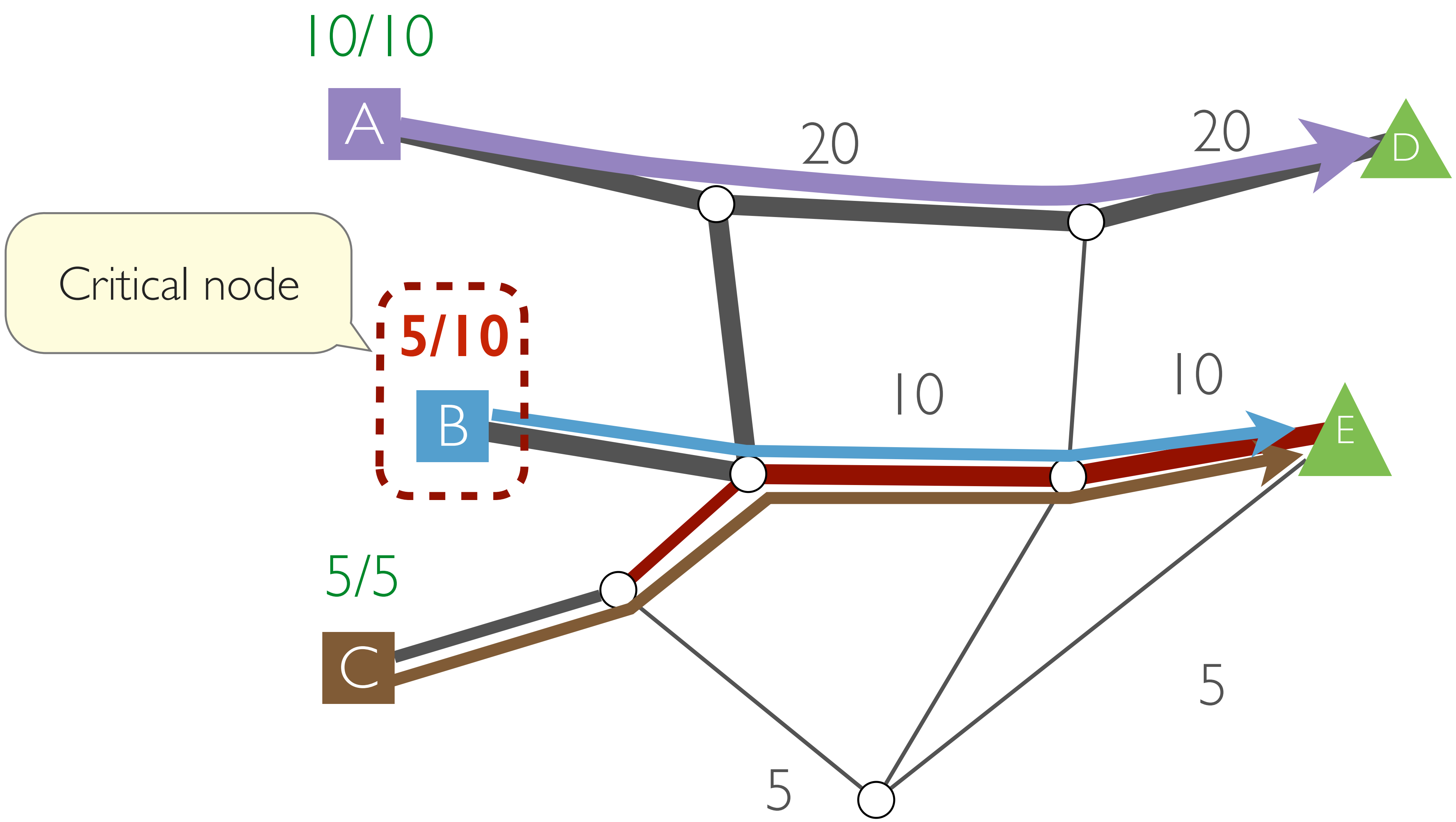
Approach Overview



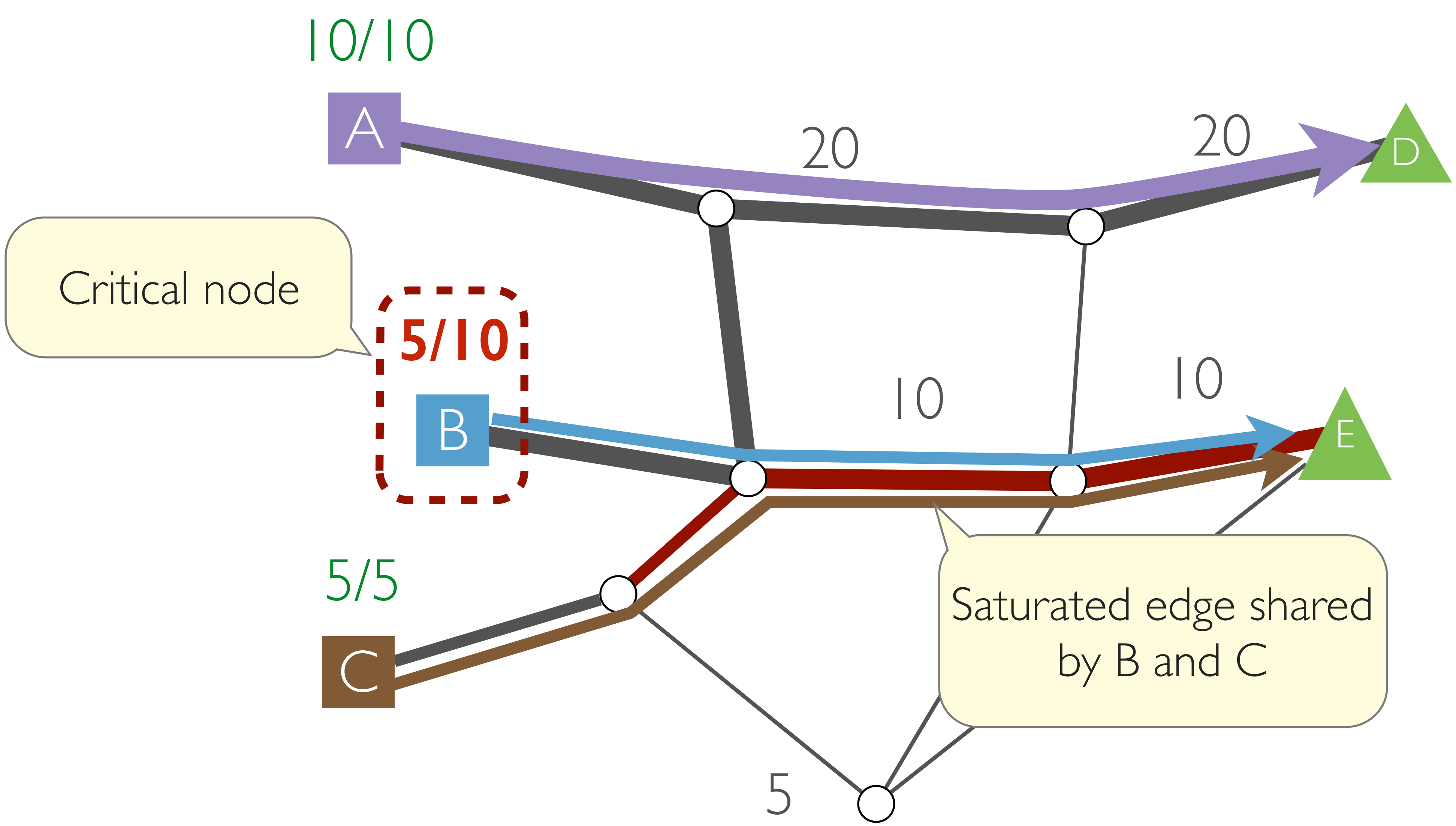
Critical Evacuated Nodes



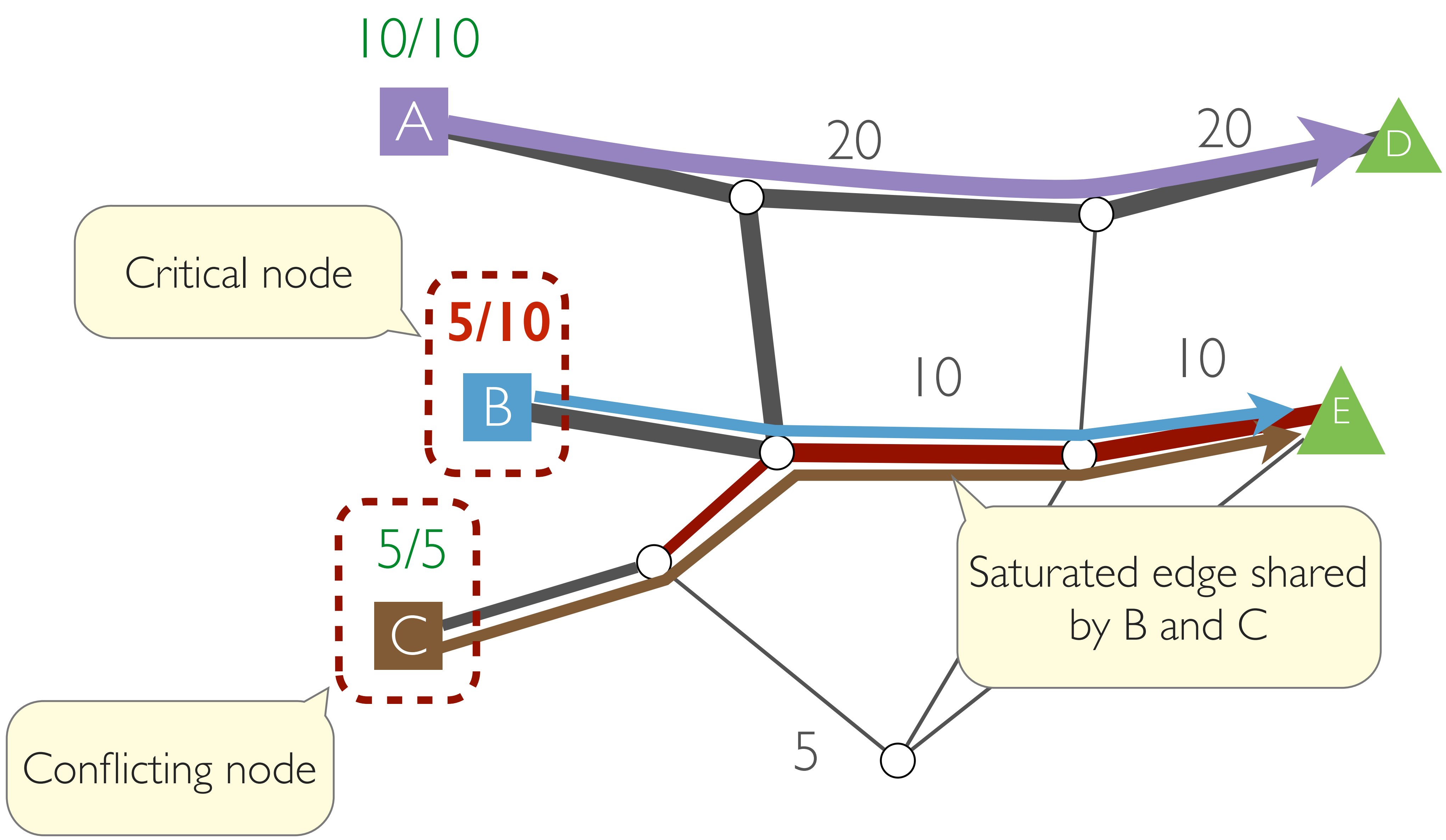
Critical Evacuated Nodes



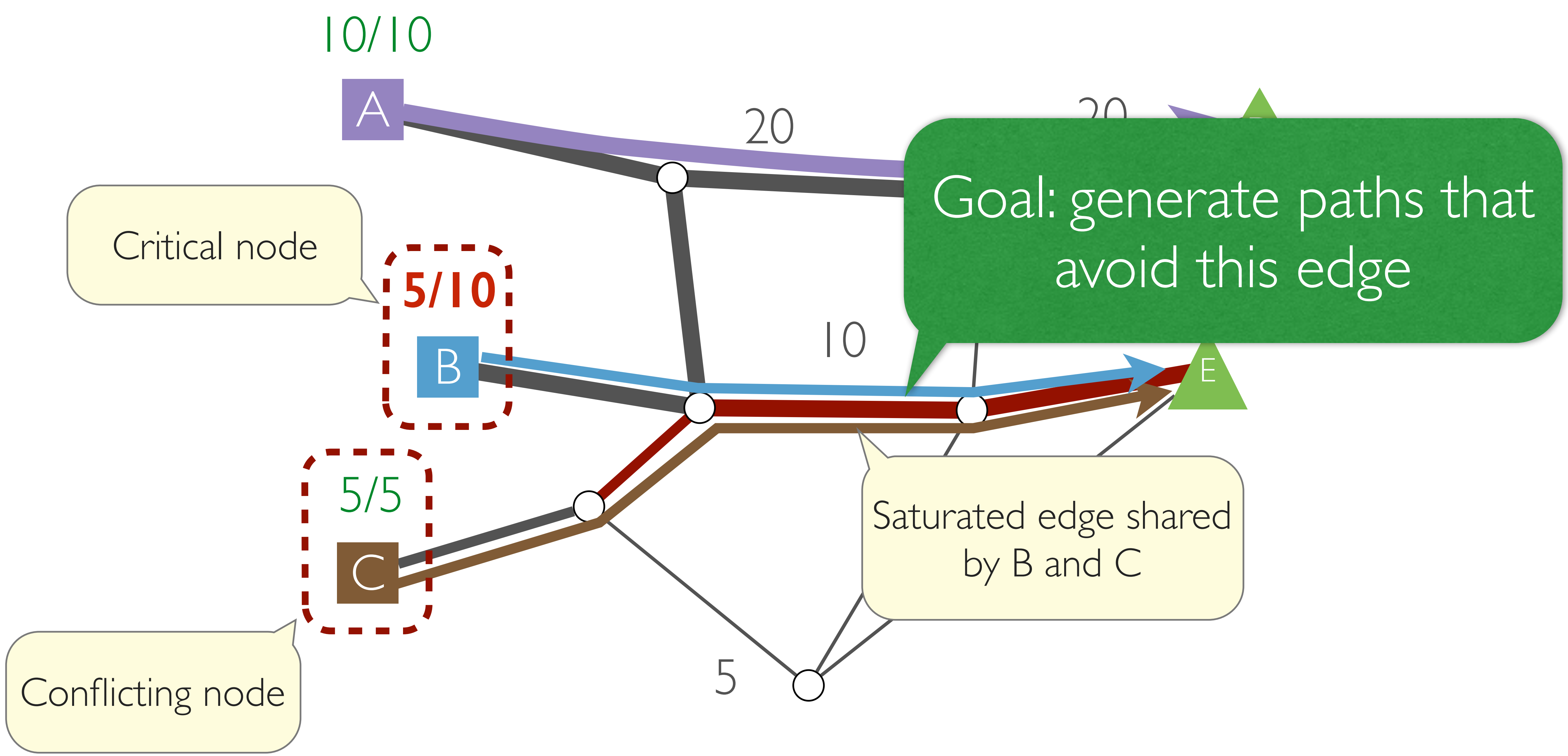
Critical Evacuated Nodes



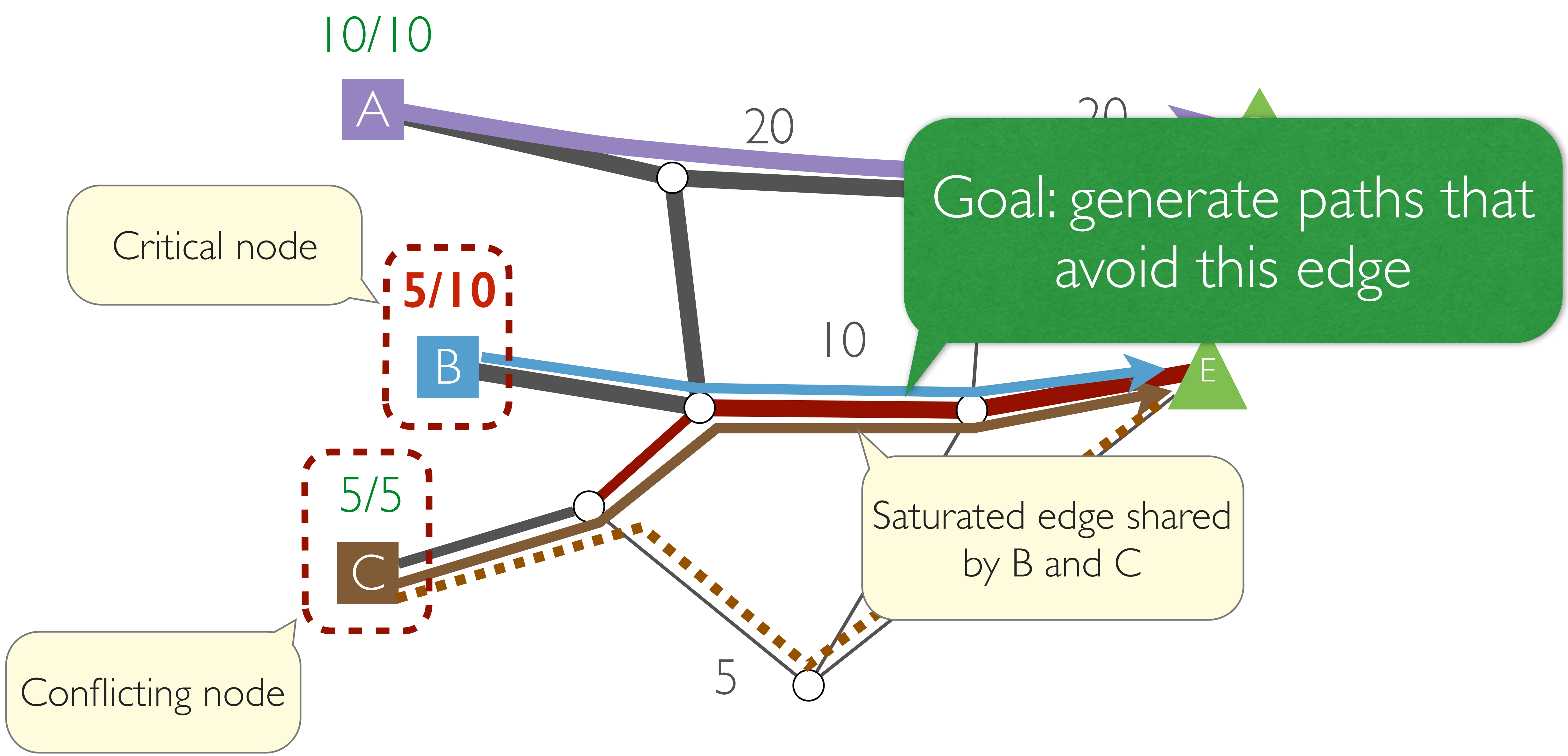
Critical Evacuated Nodes



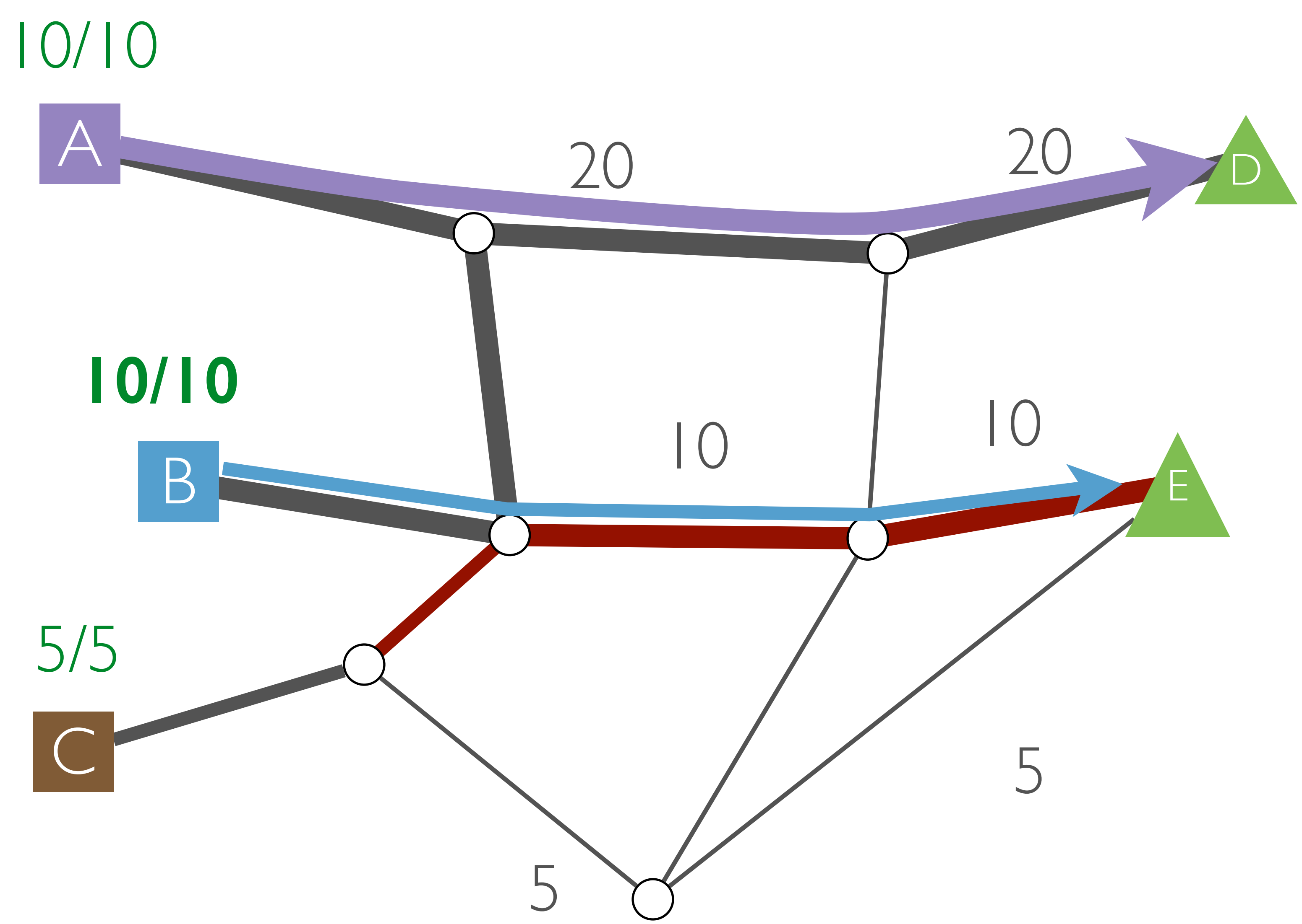
Critical Evacuated Nodes



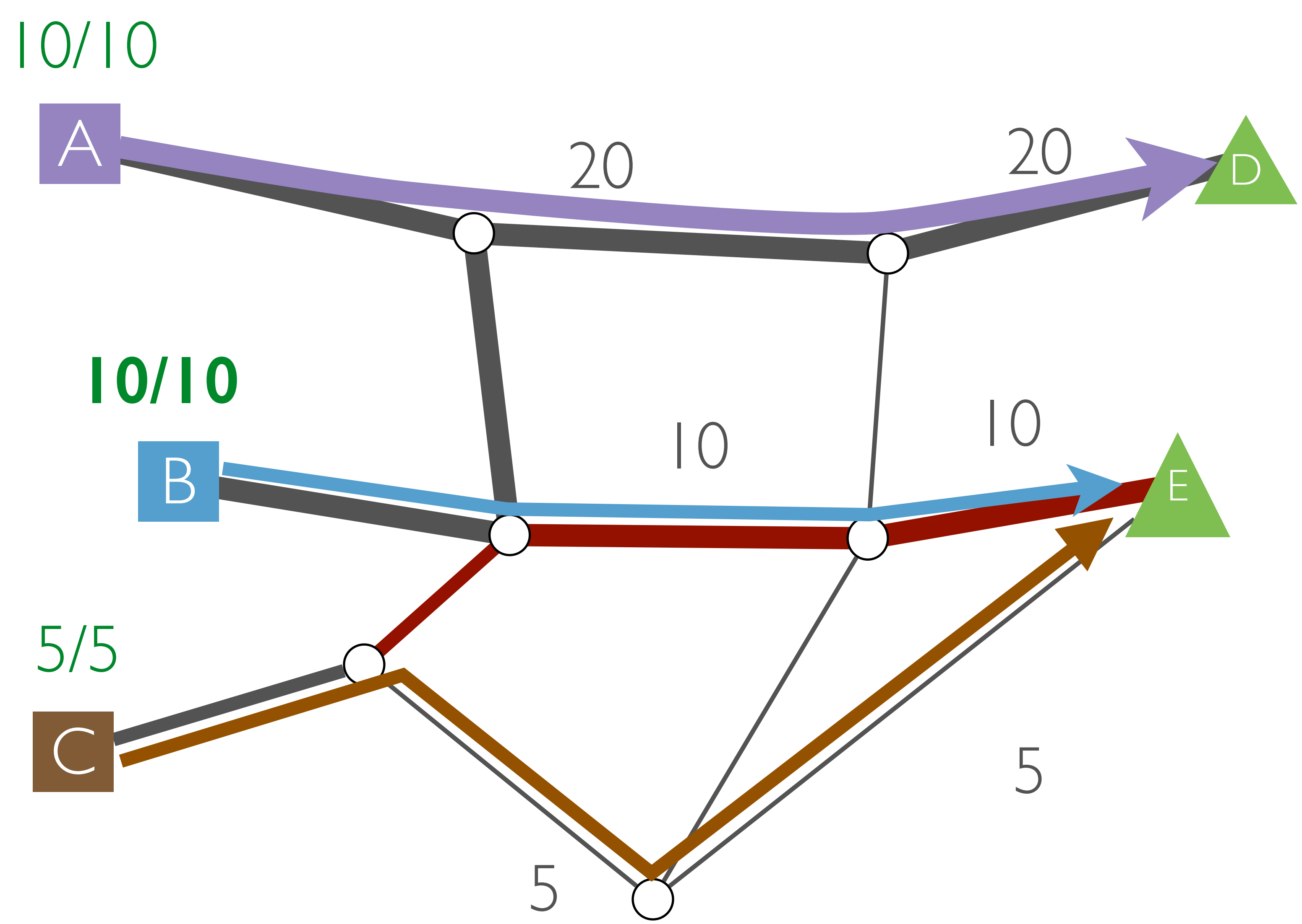
Critical Evacuated Nodes



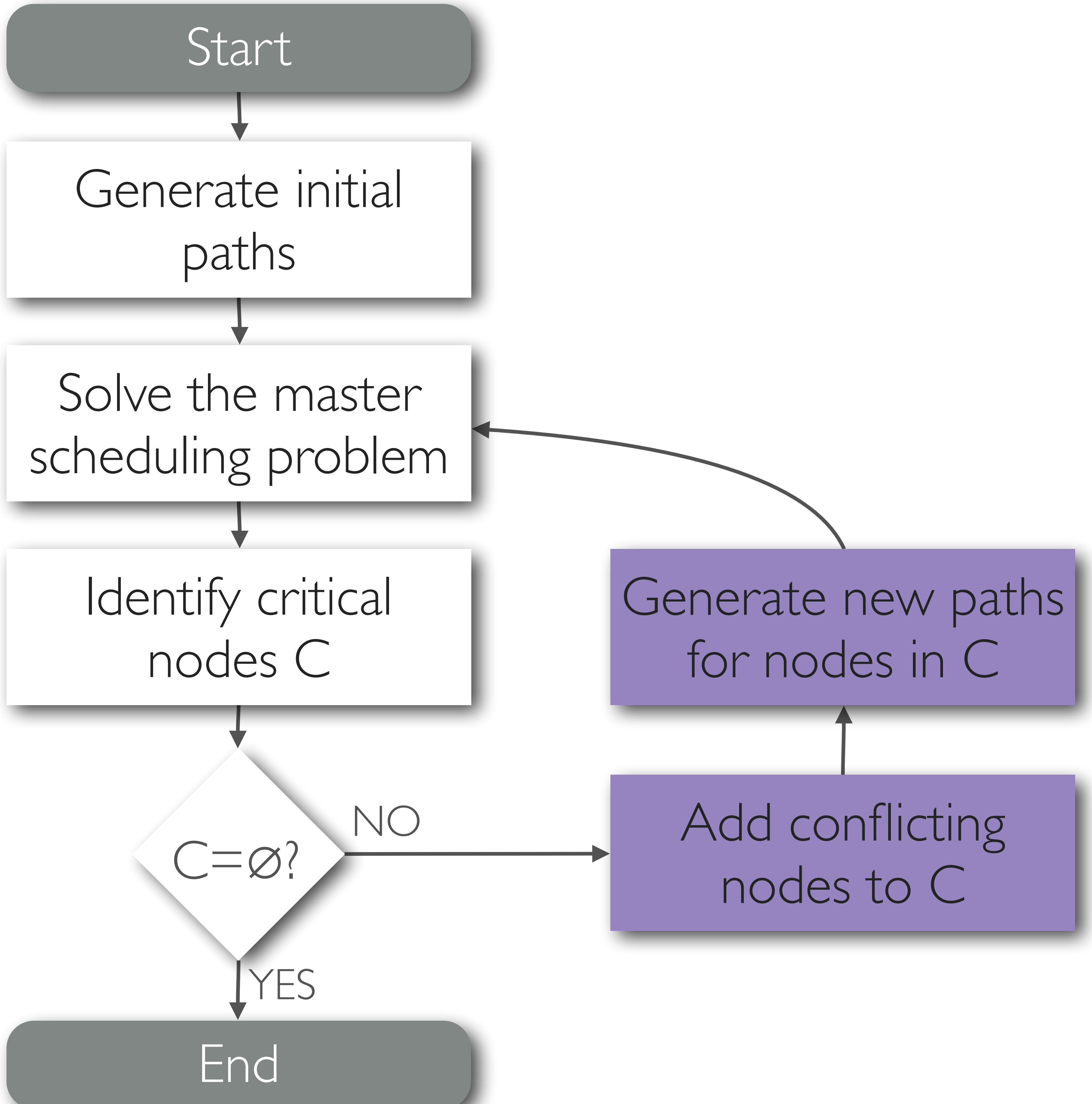
Critical Evacuated Nodes



Critical Evacuated Nodes



Approach Overview



Heuristic Path Generation (HPG)

NICTA

- Generate paths without considering the evacuation schedule
- Shortest path in the evacuation graph
- Penalize edges depending on current solution

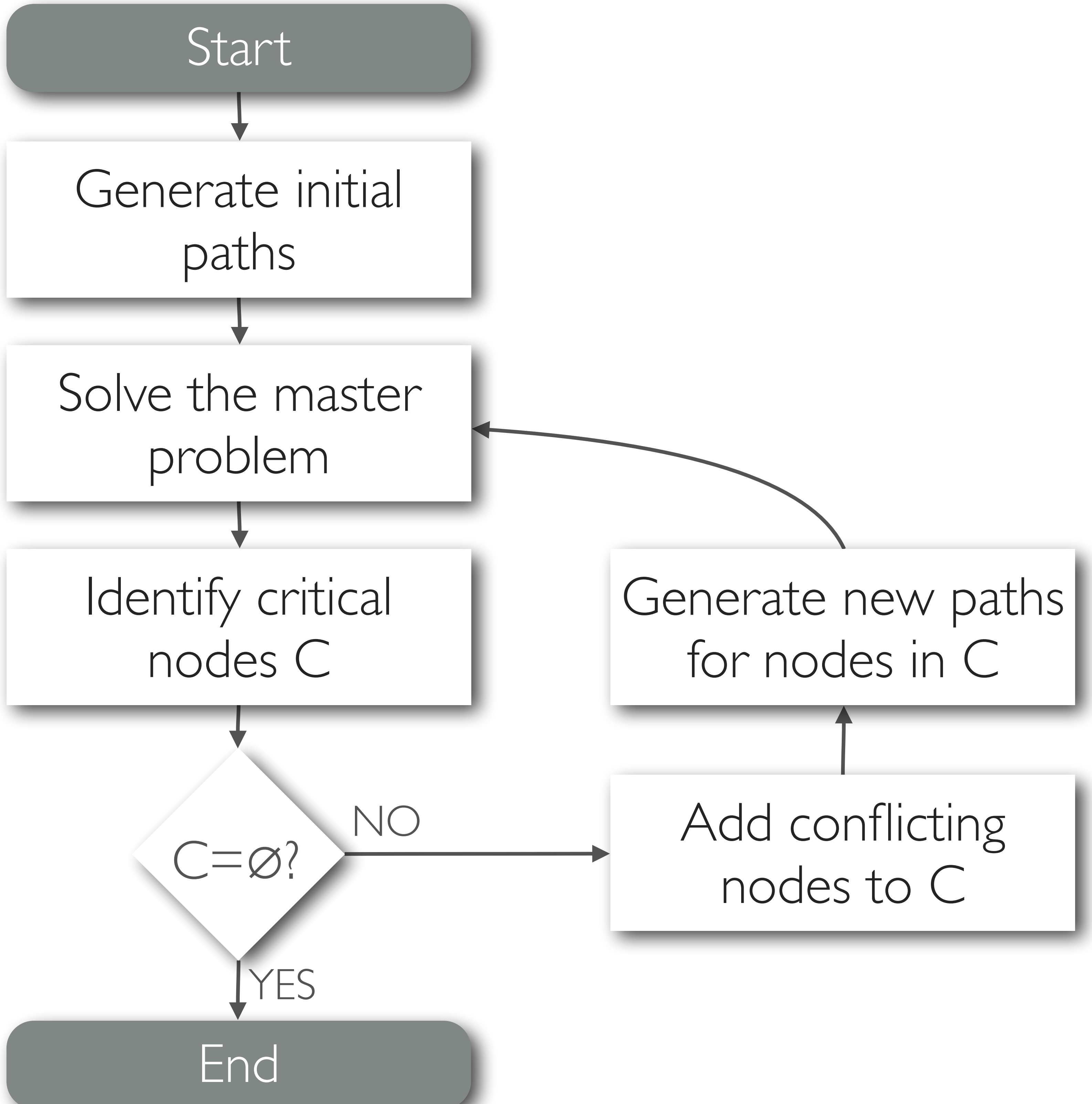
Edge travel time

\+ Number of time the edge was used

\+ Average utilization in current solution

\+ Random noise

Conflict Path Generation (CPG)

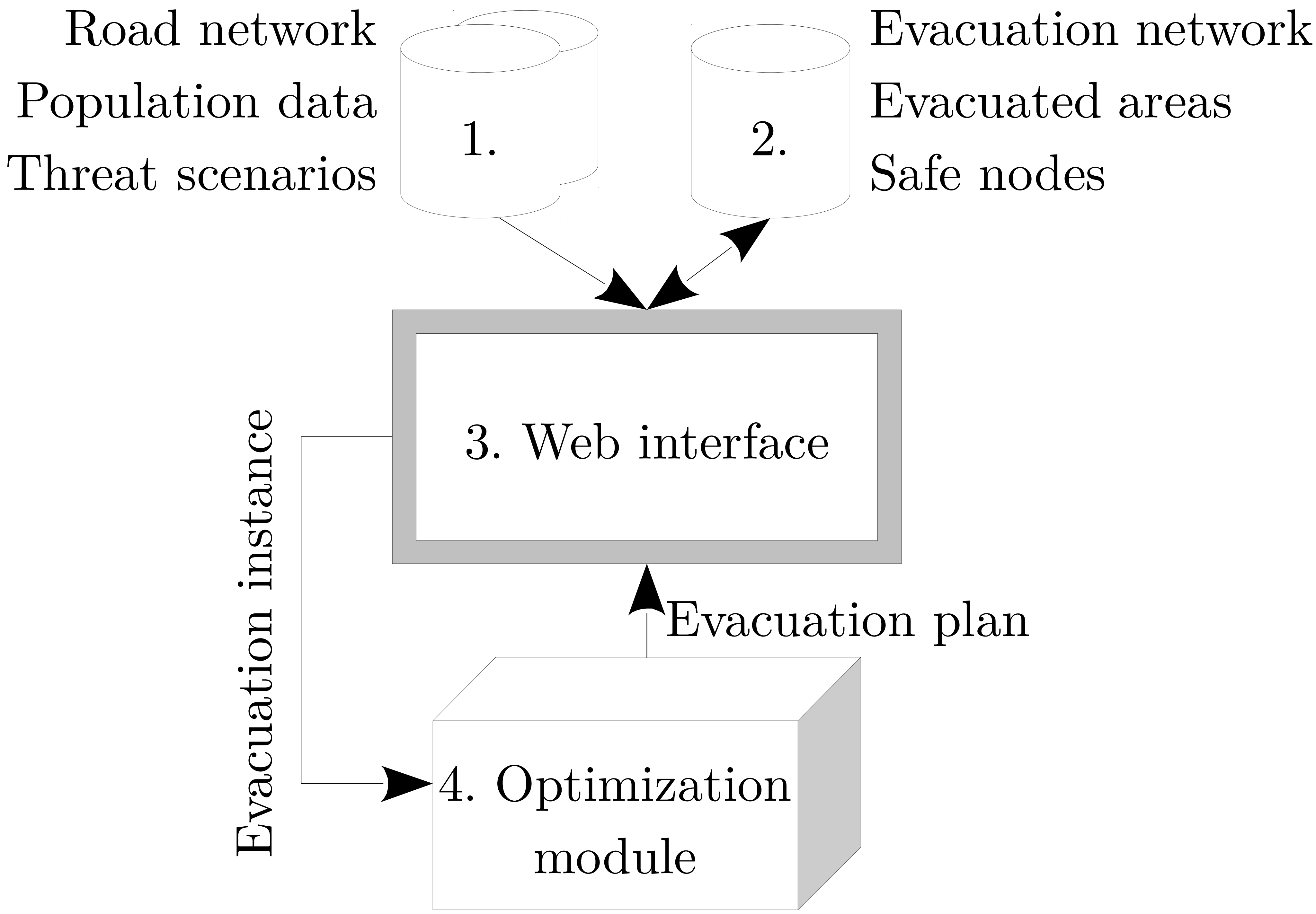


Computational experiments

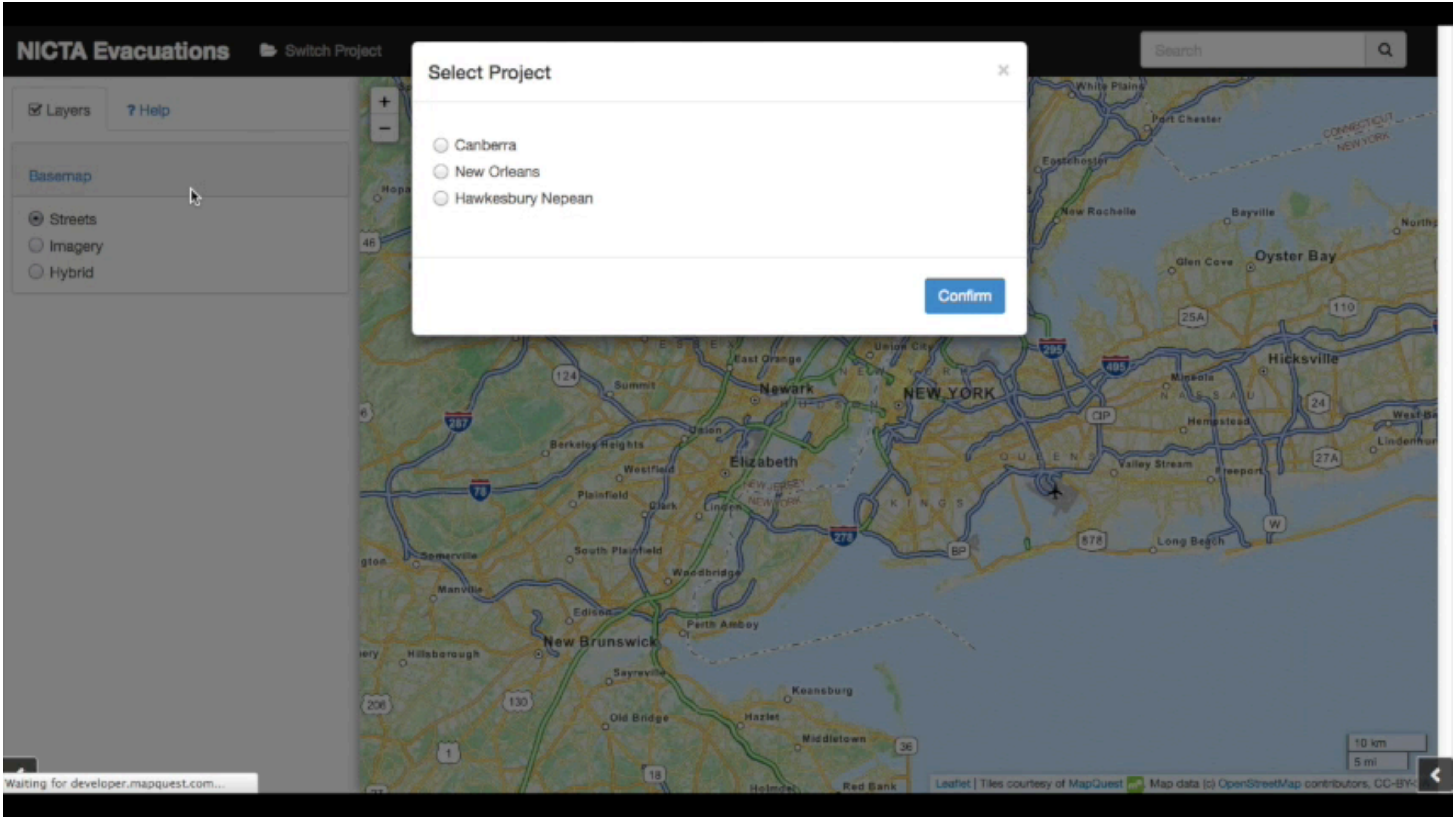
NICTA

Instance	Contraflow	Num. evac.	Num. nodes	Num. paths	CPU (min)	Perc. Evac.	Evac. Time
Hawkesbury Nepean	No	70k	170	1014	15	100%	8h05
	Yes	70k	170	1125	6	100%	5h34
New Orleans	No	1m	2000	3741	131	100%	60h48
	Yes	1m	2000	3818	152	100%	39h53

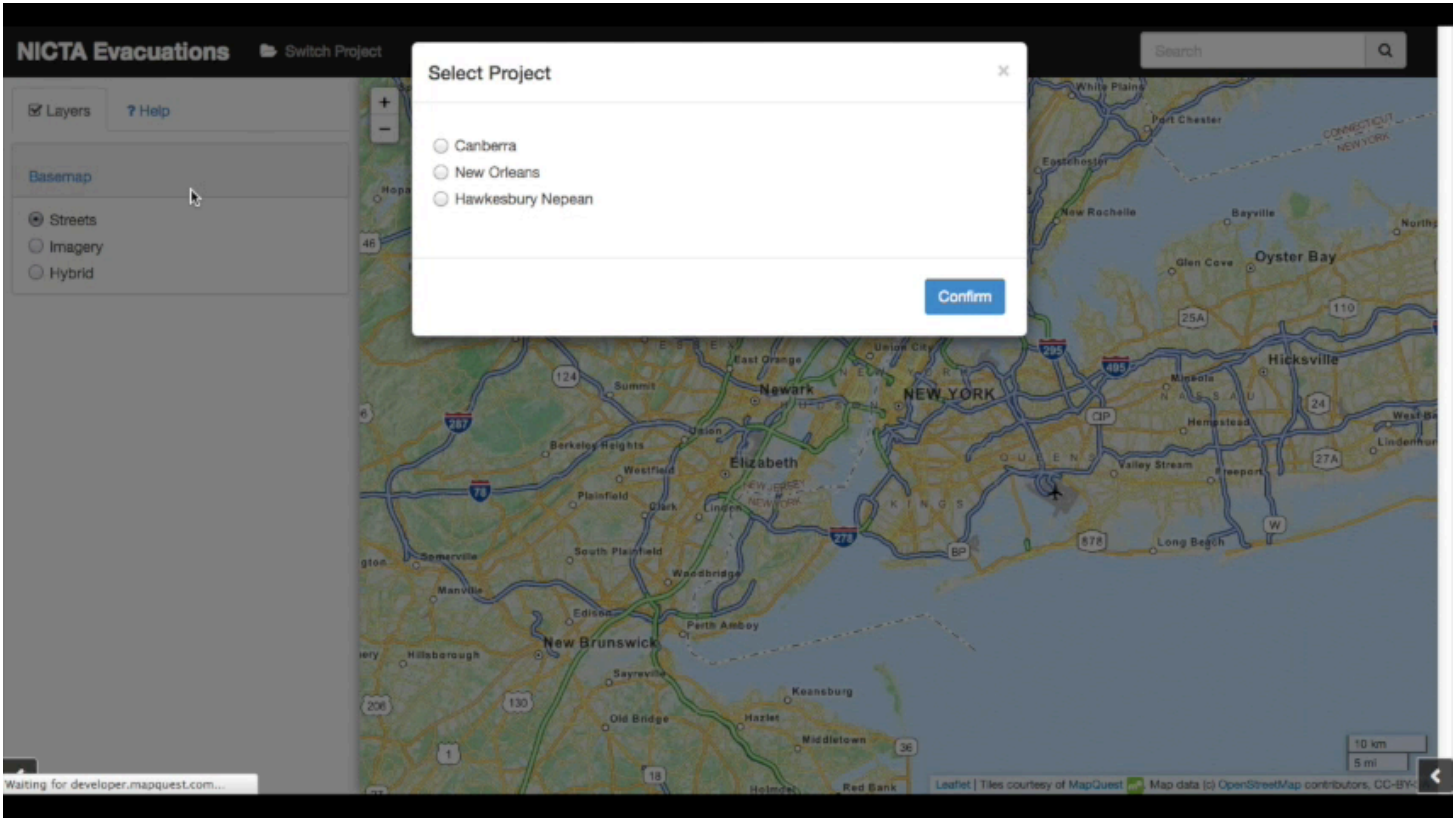
NICTA Evacuation Planner



NICTA Evacuation Planner



NICTA Evacuation Planner



Take away

- Evacuations are a critical aspect of disaster management
  - Evacuation planners heavily rely on expert knowledge
  - Decision support systems are needed!

- Conflict based path generation
  - General decomposition approach
  - Leverage domain knowledge to generate new columns
  - Useful when the Master Problem is a MIP

Perspectives

- Current work
  - Include evacuees behavior in optimization
  - Traditional column generation approach
  - Refine modeling of the road network
  - Deploy with an emergency service partner
- Extensions
  - Model operational cost of contraflow
  - Agent based simulation including behaviors