Recent Advances in Post-Earthquake Fire Modeling:

An Urban Fire Simulation Model (UFS)

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Background

Post-earthquake fires can cause great damage

Tohoku earthquake induced tsunami fire, March, 2011

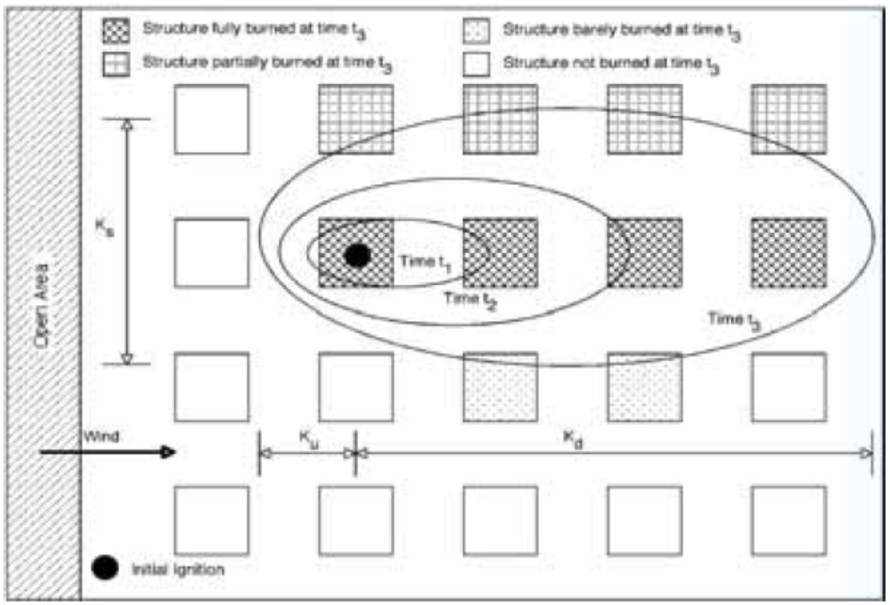
Fire at the Cosmo Oil refinery in Ichihara, March, 2011

Tohoku (2011) – 345 fires
Kobe (1995) – 110 fires
Northridge (1994) – 110 fires
Loma Prieta (1989) – 36 fires

Background

Hamada-based models

Macro, empirical



- Scawthorn et al. 1981
- HAZUS-MH (FEMA 1999)

Physics-based models

Micro, physics-based

Various spread modes

- Himoto/Tanaka (2008)
- Cousins et al. (2002)
- Iwami et al. (2004)
- ResQ Firesimulator (2004)

Urban Fire Simulation (UFS) Model

Applicability

- Involves many buildings
- Possibly many ignitions
- Post-eq and WUI

Components

- Ignition
- Spread
- *Suppression*

Anticipated uses

- Improve understanding, contributing factors, how they interact
- Estimate risk under different circumstances
- Identify, evaluate effectiveness of risk reduction measures
- Identify areas for further study

Presentation Outline

- Introduction
  - Background
  - Uses and applicability of model
- UFS model description
  - Inputs and GIS pre-processing
  - Ignition module
  - Spread modules
  - Fire suppression module
- Applications/Validation
  - Grass valley fire case study
  - Results and remarks
- San Bruno gas explosion project
- Final remarks

Model Inputs

Building

- Num. stories
- Occupancy type (e.g., single-family, school)
- % exterior wall that's windows
- Cladding, roof type
- Home ignition zone (HIZ) level
- Geometric attributes from building footprint

Region

- NFDRS Ignition Component (IC), Spread Component (SC)

Ignition

- Deterministic. User-specified.
- Probabilistic. Simulate exact location based on ground motion.

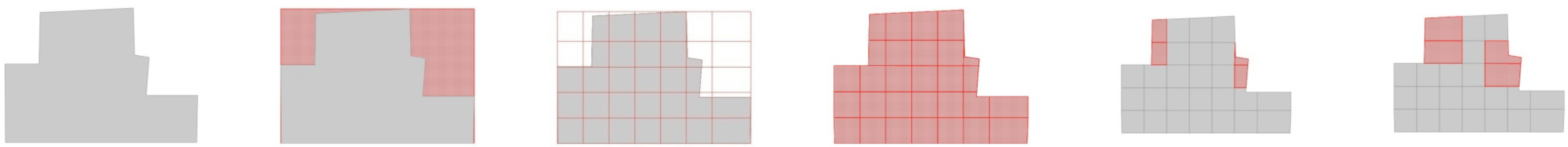
Wind

- Deterministic. User-specified.
- Probabilistic. Sample time series from historical data.

GIS Pre-processing (Customized and automated)

Divide building footprints into rooms

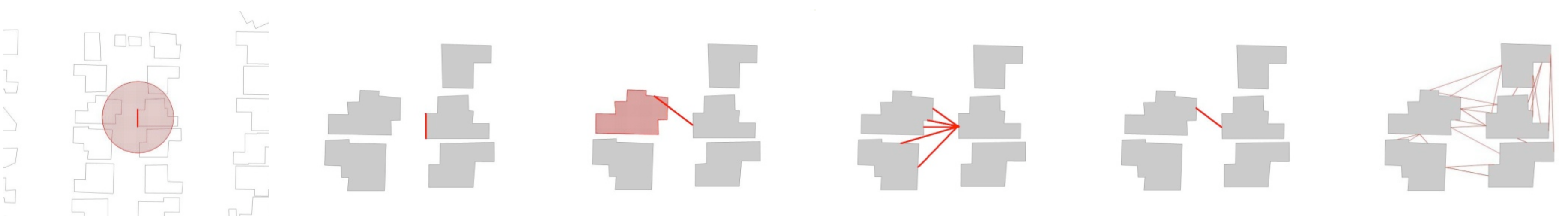
Assume min. room wall length, min. room area



1. Building footprint
2. Enclosing rectangle
3. Grid lines
4. Divide rooms
5. Sliver areas
6. Dissolve slivers

Find “facing wall” for each building wall

Nearest wall of another building s.t. line connecting them doesn’t intersect any buildings



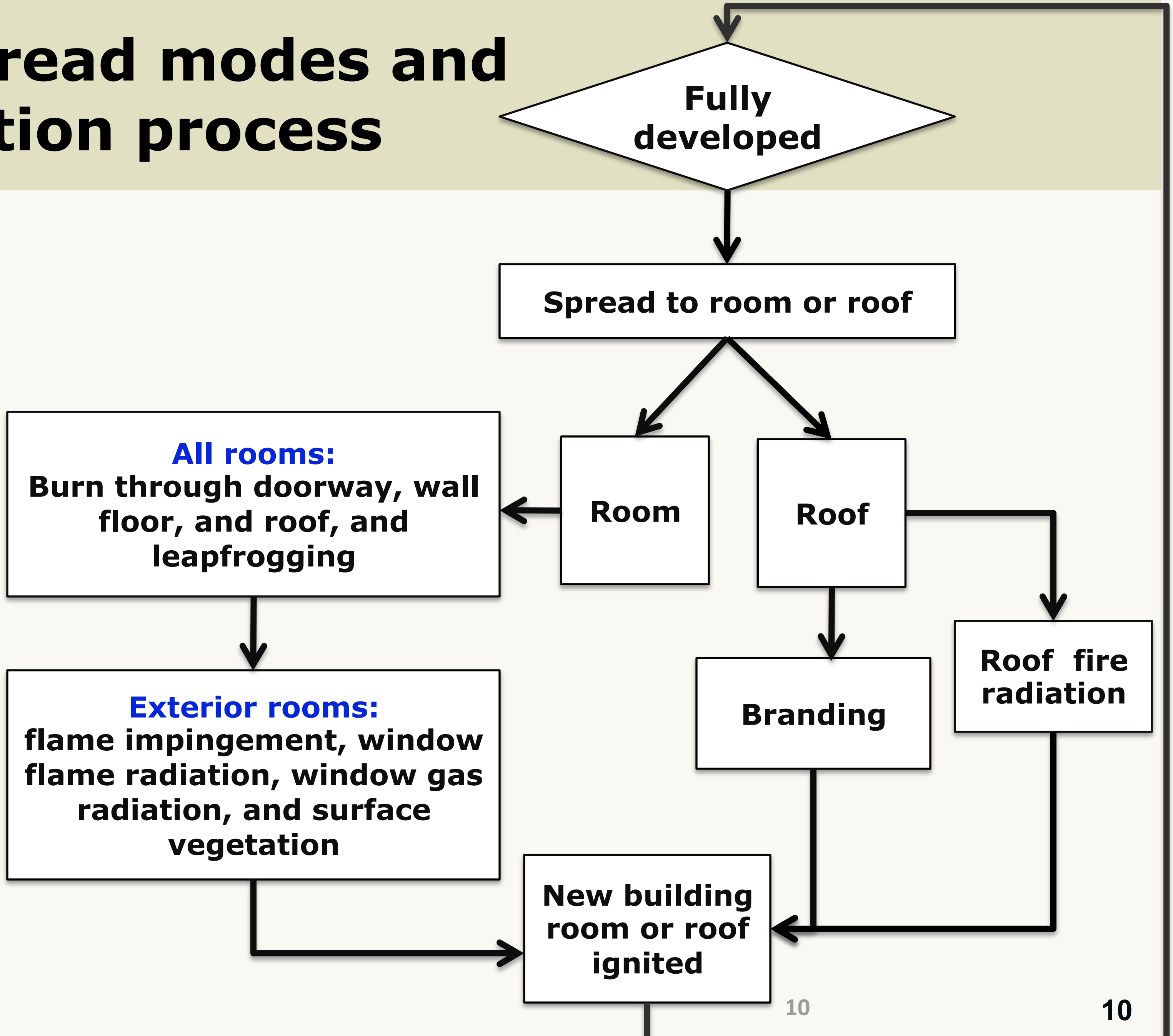
1. Threshold area
2. Select bldgs
3. Line intersects building area
4. All possible lines
5. Choose shortest
6. Shortest facing building wall pairs

Ignition module

- Statistical modeling – To regress ignition rate and earthquake intensity
- Generalized linear and generalized linear mixed models (Davidson 2009)
  - Recognizes that ignition counts are discrete
  - Examines many possible covariates
  - Uses a small unit of study to ensure homogeneity in variable values for each area unit.
- RAPID project: Fires following the March 2011 Japan earthquake and tsunami (Co-PI: Prof. Scawthorn)
  - Apply Davidson approach to earthquake ignition data

Fire spread module

Fire spread modes and simulation process



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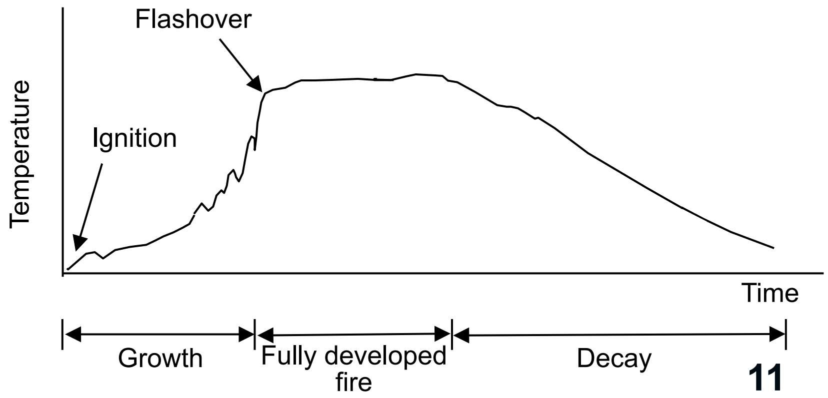
Evolution within a Room or Roof

Temperature-time curves (Law and O'Brien 1981)

- Reasonable results
- Requires only room dimensions, window area, fire load
- Includes other modules → ensures consistency

Rate of burning

- Draft conditions (thru or no)
- Occupancy-dependent fuel load
- Room, window dimensions



Room-to-Room Spread within a Building

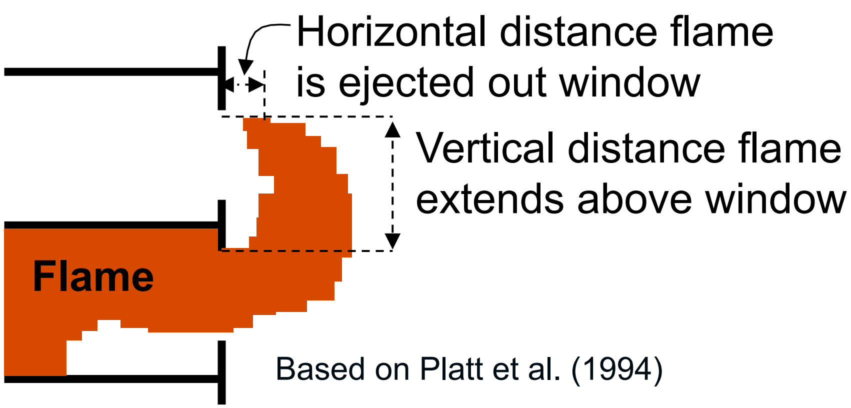
Through doorways (1 door/interior wall)

- P (door is open) = 0.5

Burn through walls, ceilings, floors

(based on IBC 2006)	Mean time to burnthrough in hours		
	Fire-resisitive	Protected	Unprotected
Interior beaing walls	2	1	0.25
Interior non-bearing walls	0.25	0.25	0.25
Floor-ceiling assemblies	2	1	0.25
Roof-ceiling assemblies	1.5	1	0.25

Leapfrogging



Based on Platt et al. (1994)

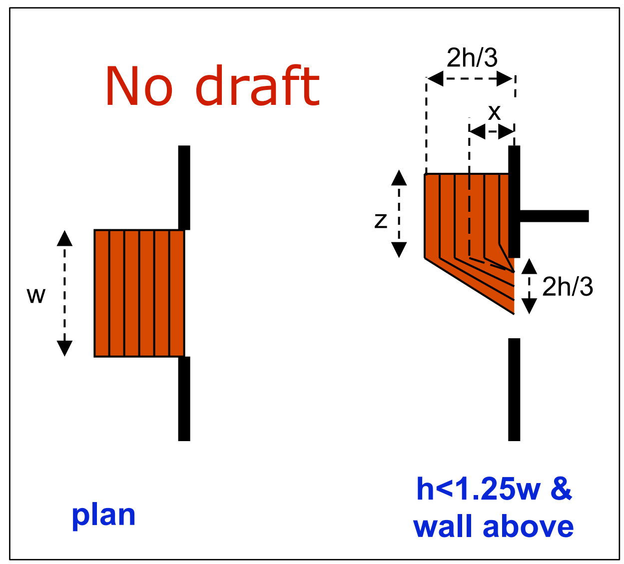
External wall spread

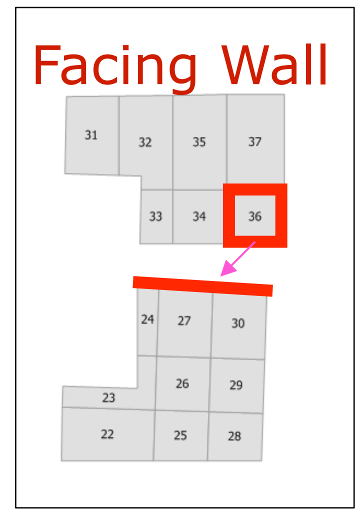
If cladding flammable

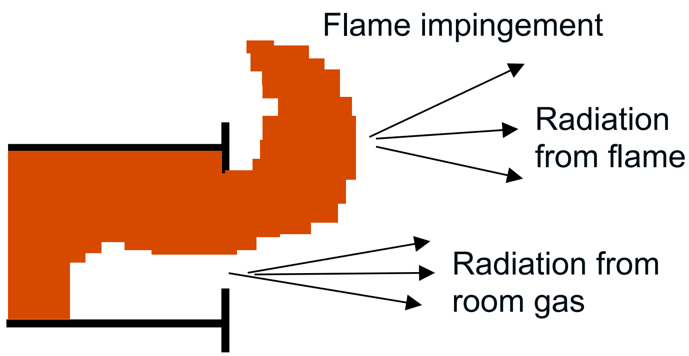
→ t_{spread}~U(2, 10 min)

Building-to-Building Spread: Flame Impingement & Window Flame & Room Gas Radiation

1. Window flame geometry (Law and O'Brien 1981)
2. Configuration factor
3. Radiation received



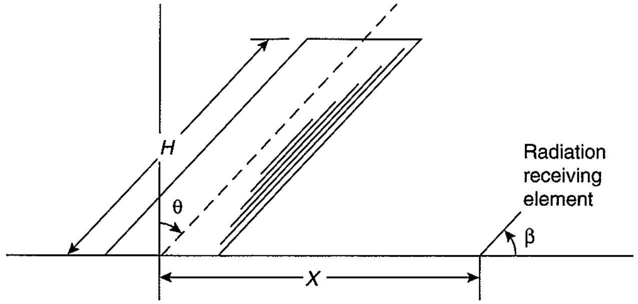


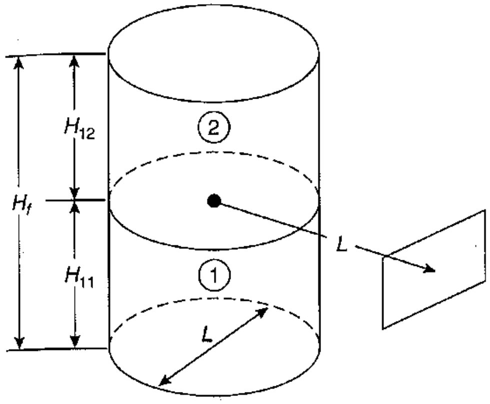


Building-to-Building Spread: Radiation from Roof Flame

Assume roof flame is large, open pool fire (Mudan 1984)

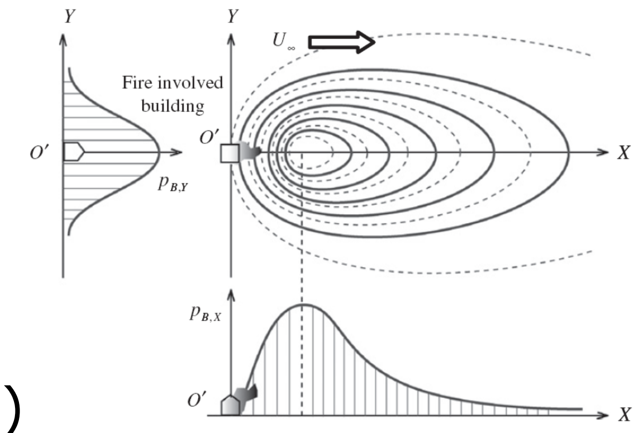
1. Burning rate
2. Roof flame geometry
3. Configuration factor, F
4. Radiation received



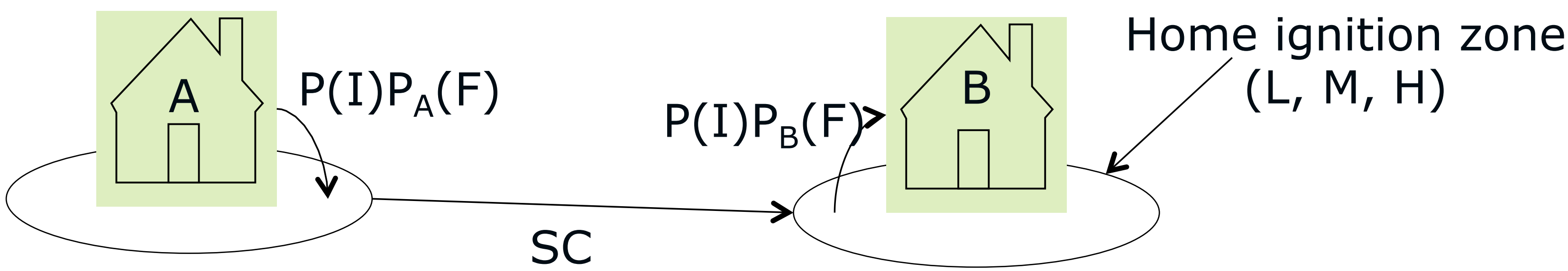


Building-to-Building Spread: Branding

1. Generation
   - Empirical (e.g., Waterman 1969)
   - Depends on wind speed, roof area
   - Size: Fine, medium, coarse
2. Transport (Himoto and Tanaka 2008)
3. Host ignition
   - Empirical (e.g., Waterman and Takata 1969)
   - Depends on roof type



Bldg-to-bldg spread: Surface vegetation (WUI)



P(I) **Probability fuel will ignite**
f(air temp, moisture content)
(from NFDRS ignition component)

P(F) **Probability there is fuel to ignite near home**
Based on home ignition zone level (L, M, H)

SC **Speed of spread**
f(wind speed, slope, moisture content, fuel characteristics)
Spread component NFDRS

Fire suppression module

(being developed)

Fire suppression module features

Focus on post-earthquake fire suppression

Priority-based resource allocation
- Current involvement
- Threat to neighbors
- High priority for high occupancy buildings
- Water availability
- Distance/Travel time

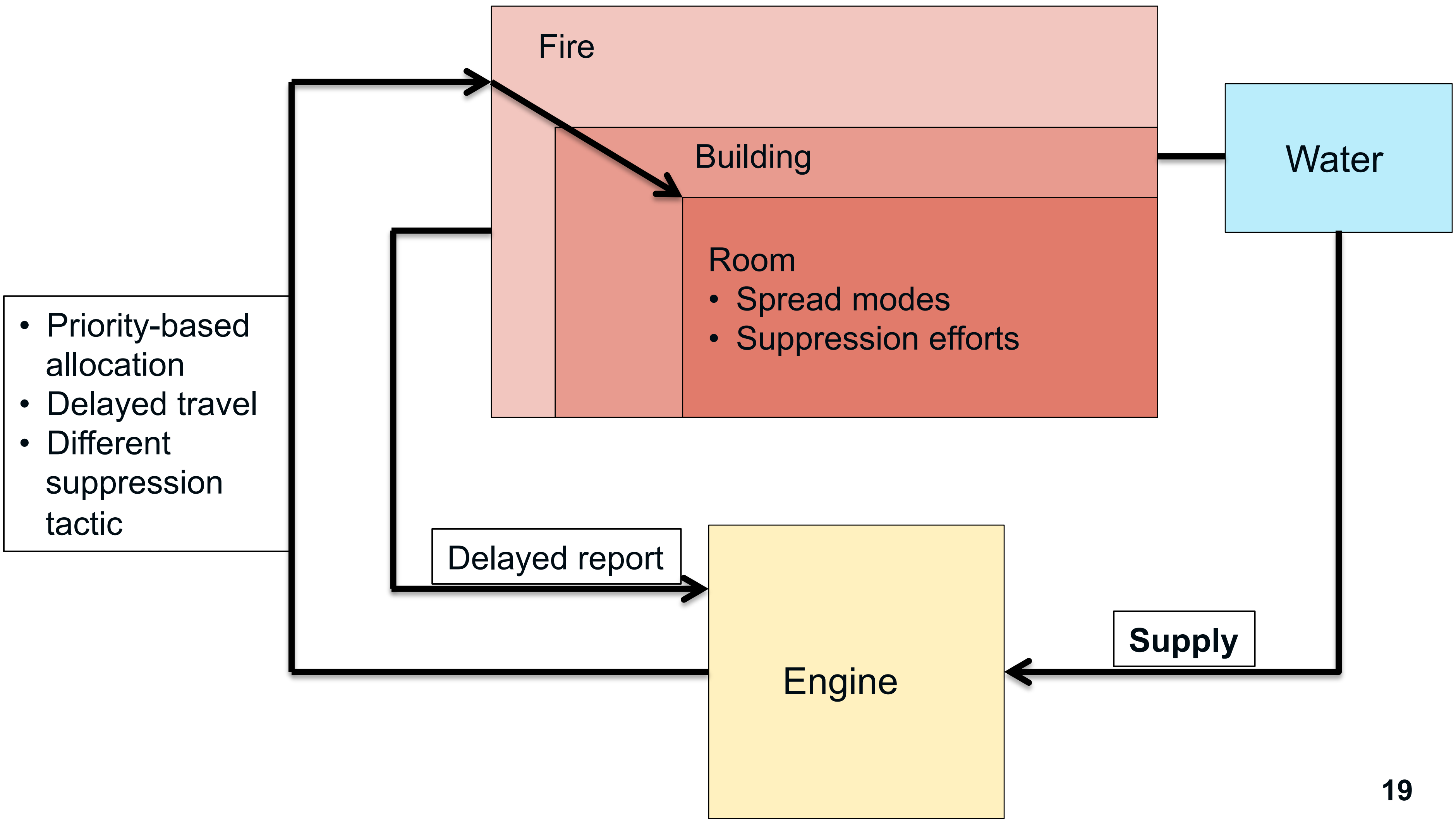
Delayed fire report
Delayed engine travel

Water supply changing over time
- Fire suppression usage
- Loss due to earthquake

Major fire fighting tactics included
- Defensive attack for multi-buildings fire
- Offensive attack when necessary

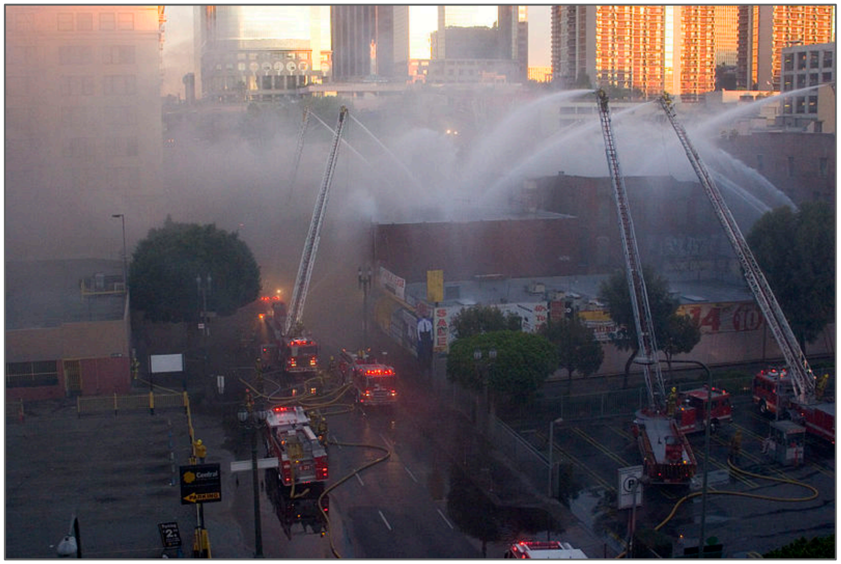
Interaction with fire spread module

Fire suppression simulation process



Fire suppression

- Sensitivity analysis
  - Number of ignitions
  - Water availability
  - Wind speed and direction
  - Priority rules
- Case study
  - Various scenarios



Key features of UFS

- Physics-based with simplified rules
- Ignition model
- Room-to-room spread
- Quantify uncertainty
- Suppression to be incorporated

Application/Validation of UFS

Case studies

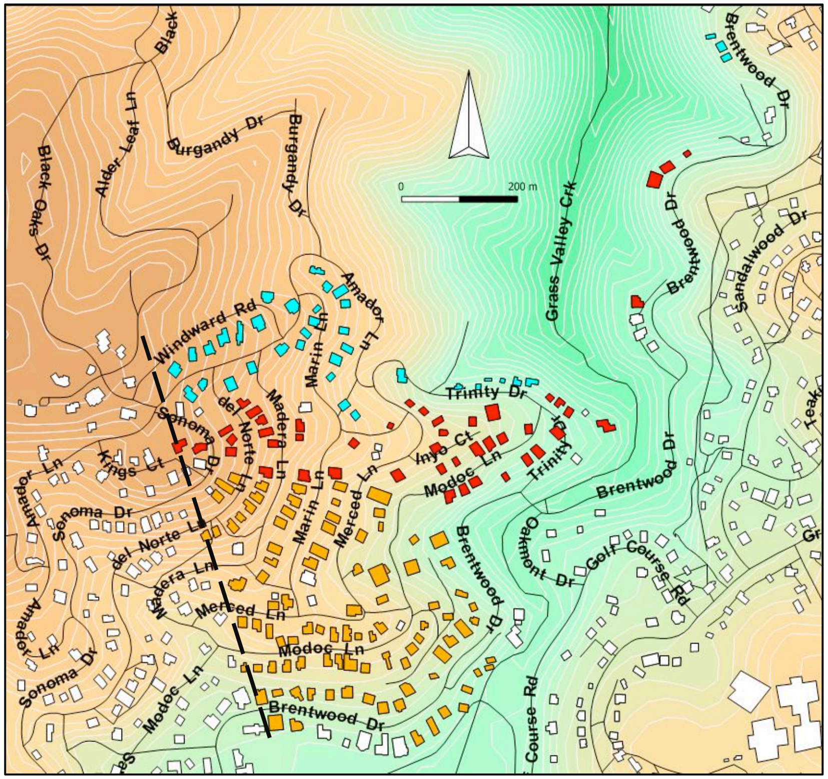
1. Los Angeles (Lee 2009)
   - Model application
   - Sensitivity analysis
2. UFS vs. Hamada (Li et al. 2010)
   - Similar spread rate and shape
   - Differences
3. Grass Valley fire (Li and Davidson 2011)
   - Comparison with observations
   - More fire spread modes

Grass Valley, CA fire

- October 22, 2007
- Part of 23-fire outbreak in So. Calif.
- Burned 1250 acres, destroyed 174 homes, damaged 25
- Steep terrain
- Lots of vegetation (Pine/oak overstory, brush understory, needle/leave/branch surface litter)
- Large 2- to 3-story woodframe SFDs with clapboard siding, wood or asphalt shingle roofs
- Drought, Santa Ana winds
- Suppression. $5.7M, 109 engines, 3 helicopters, up to 1051 firefighters

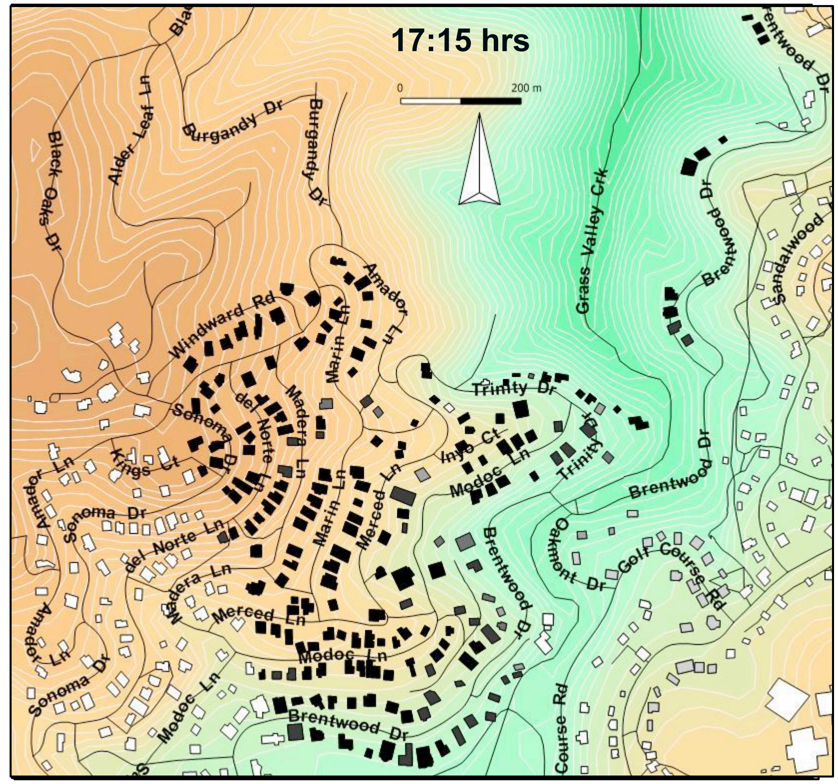
Cohen and Stratton (2008)

Grass Valley fire spread



Undamaged
By 1000 hrs
By 1030 hrs
By 1130 hrs

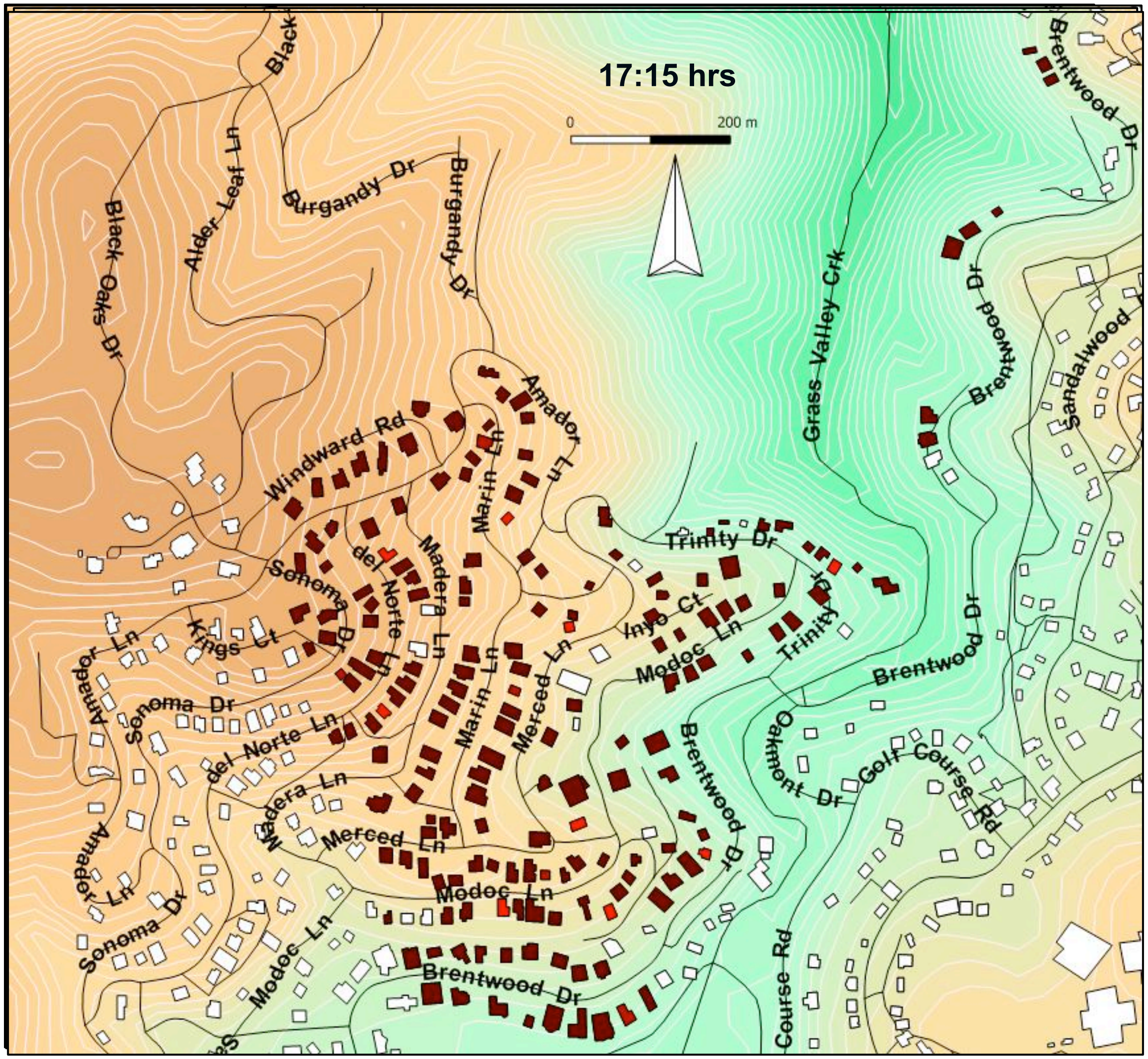
Spread Boundary



Percentage of times burned
0
1 – 10
10 -30
30 – 50
50 -80
> 80
Ignition

100 iterations
(so CI half-length of mean total burned area=3.6%)

Nature of fire spread



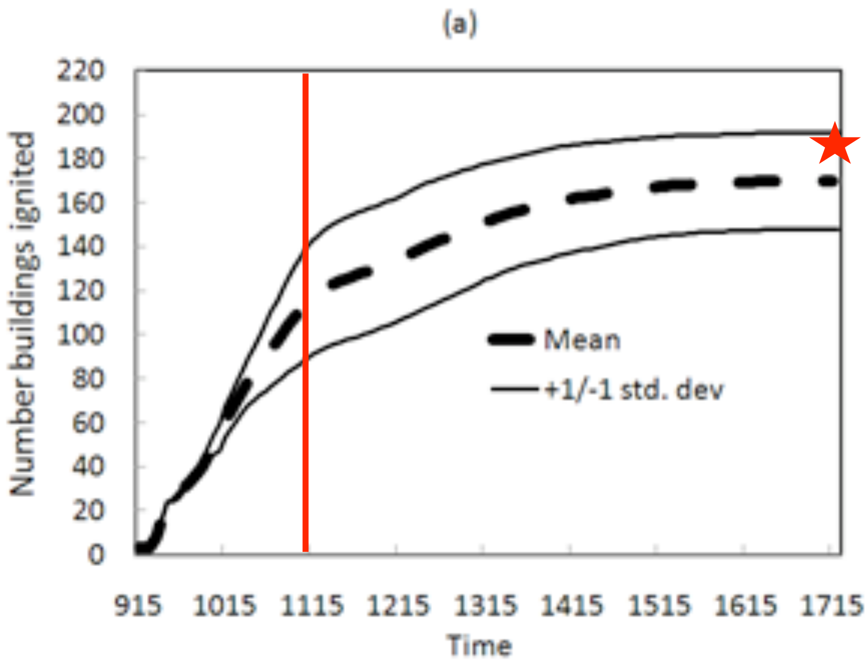
1 iteration from 100 iterations

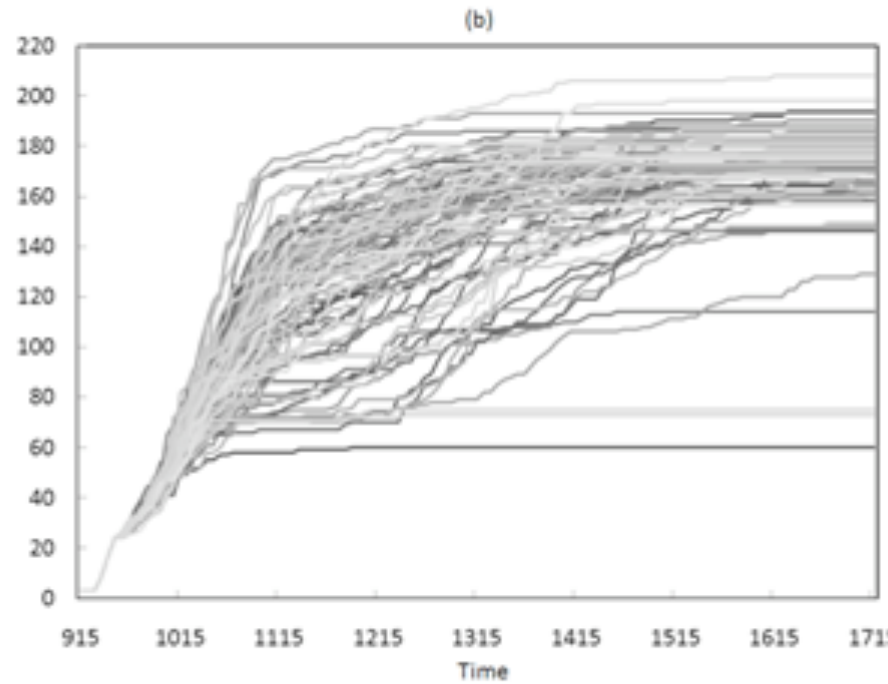
- >95% simulations spread stopped at actual Eastern border
- Spotty, not a uniform front, as observed.

Percentage of building area burned

- 0
- 1 – 25
- 25 – 50
- 50 -75
- > 75

Speed of spread thru neighborhood

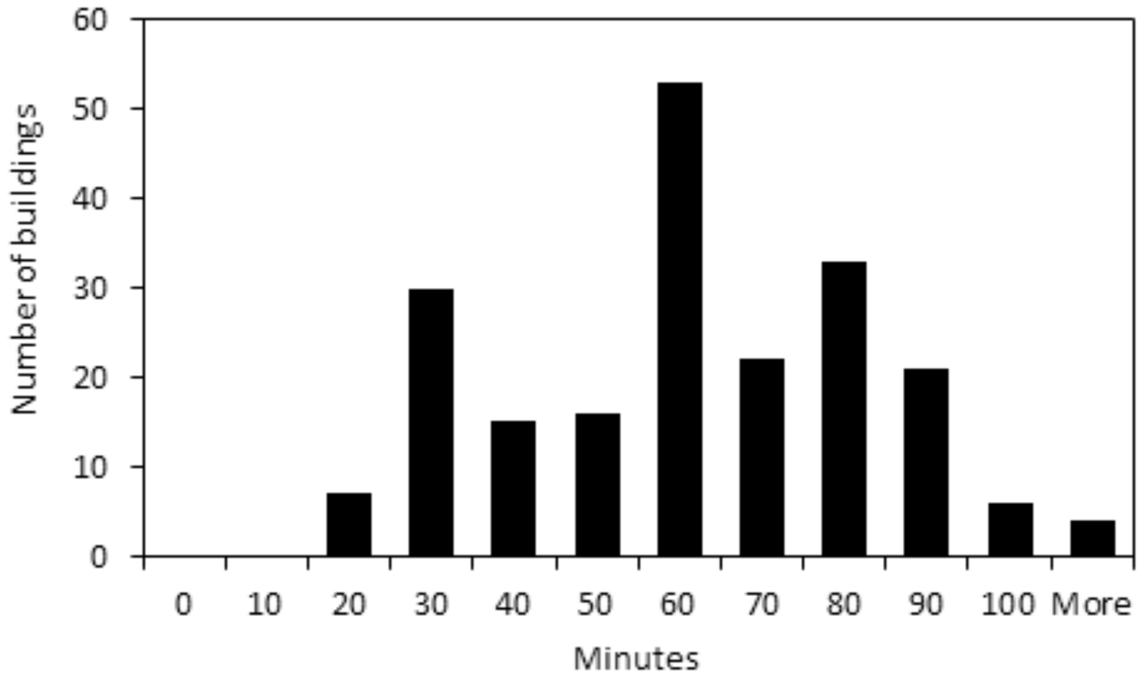




- On avg. 170 bldgs ignited vs. 180 in real life
- At 11:41a, on avg. 125 ignited and 85 >50% burned. vs. 75 to 100 reported destroyed

- High variability as in real life

Speed of spread thru a bldg.

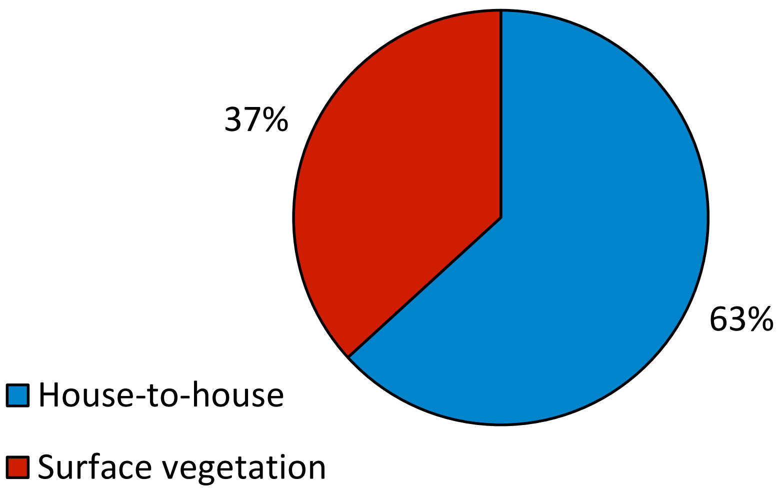


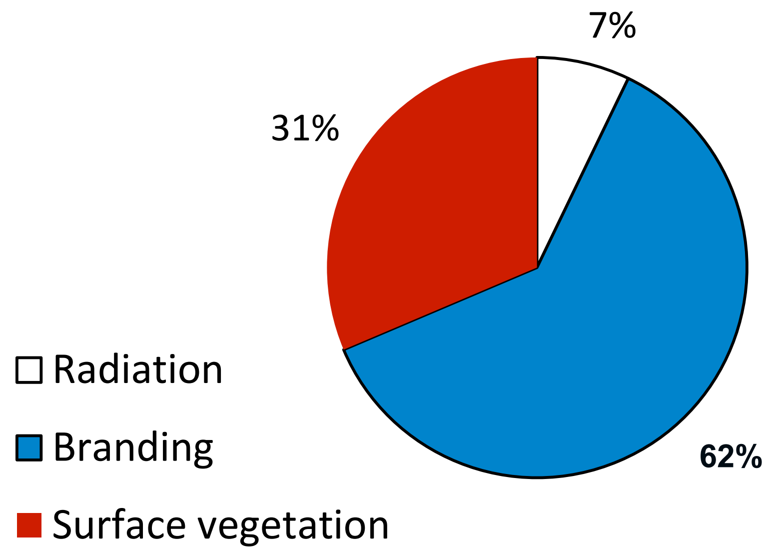
Time
from ignition
to 100% burned

- Mean=57 min
- Consistent with common belief
- Possibly fast because of external wall spread

Modes of fire spread

Observed





- Similar modes of spread
- In reality, difficult to determine mode & may be multiple modes

Remarks

- UFS results match Grass Valley observations well w.r.t. timing, spatial pattern, modes of spread
- Validation is difficult (e.g., Oreskes et al. 1994)
  - Match between observations and model results doesn't prove model is correct
  - Variability and few events to observe
  - Observations incomplete

San Bruno gas pipe explosion

(independent project)

PIs:

- Prof. R. Davidson, University of Delaware
- Prof. J. Kendra, University of Delaware
- Prof. D. McEntire, University of North Texas
- Prof. C. Scawthorn, PEER

RAPID: San Bruno gas explosion project

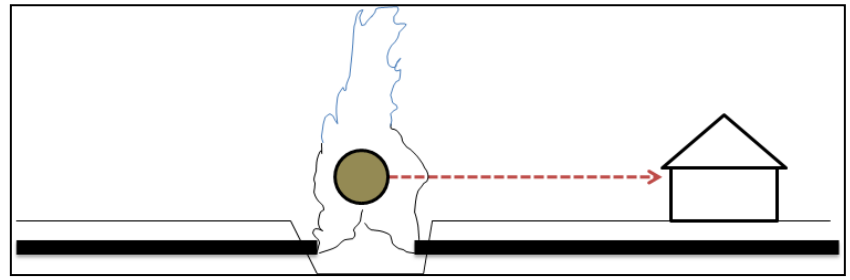
- Sept. 9, 2010, San Bruno, California
- 30 inch natural gas pipe explosion
- 38 homes destroyed and 63 homes damaged
- Investigation
  - Interview with fire departments, emergency managements, etc.
  - Field trips
  - Event documentation
  - Analysis
    - Gas fire radiation
    - Emergency management

Damage area
(NTSB)

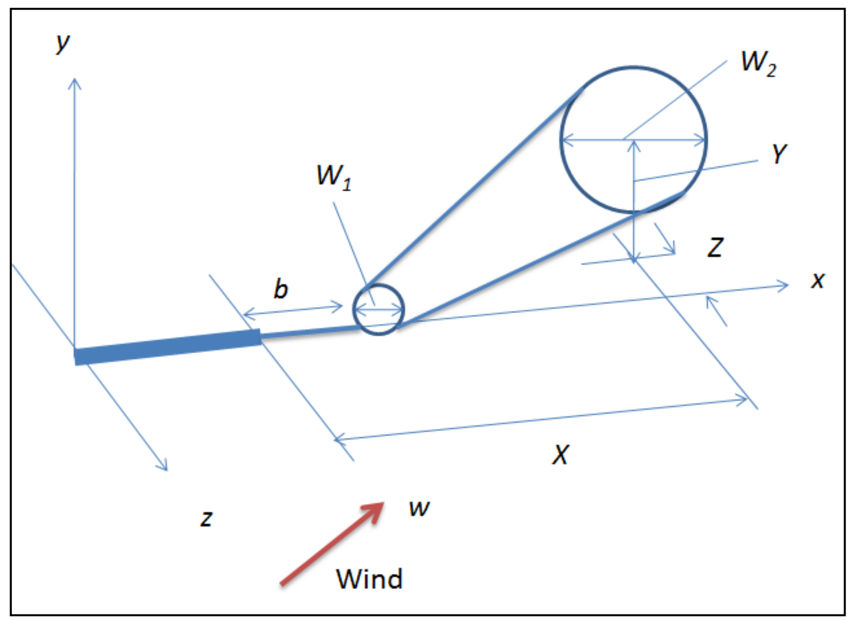
Damage scene
(Prof. Charles Scawthorn)

Preliminary results

- Effective gas release rate
- Gas fire model
  - Point source
  - Cone
- Damage area



Point source model



Cone model

Final remarks

- UFS is applicable for fire risk estimation and comparison of risk reduction measures
- Fire models can be integrated with lifeline risk estimation
- Next step:
  - Finish the suppression module and case study
  - Do case studies on the Tohoku earthquake for ignition and fire spread/suppression module

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RAPID

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- Charles Scawthorn, SPA

San Bruno Project PIs

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- Prof. J. Kendra
- Prof. D. McEntire
- Prof. C. Scawthorn

Japan Project PIs

- Prof. R. Davidson
- Prof. C. Scawthorn

For more information

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