The Dilemma of Early Warning Against Debris Caused by Successful Ballistic Missile Interception

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General

- Since the year 2001 Israel has sustained more than ~~16,000~~ 18,000 rockets
- Iron Dome is an Anti-Missile Air Defence System which is operational since April 2010 and has shot down more than ~~500~~ 1,000 rockets with a success rate of over ~~86%~~ 90%

Background

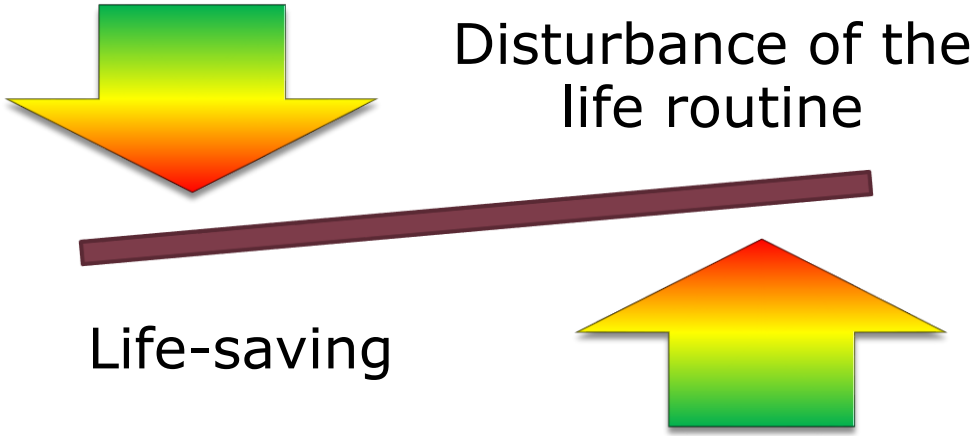
- The role of Anti-Missiles Air Defence Systems in military operations is steadily increasing
- Every successful interception is followed by falling debris
- Some of the debris might endanger people below the interception point


Netania
Nab
Petah-Tikva
Tel Aviv-Yafo
TAV
Jerusale
JER
Ashdod
SOP
Beit-Leh
Ashkelon
Qiriat-Gat
Gaza
Beer-Sheva

Main Dilemma

- This (new) situation evokes the question:

Is early warning against interception debris essential?



Goals

①Estimate the risk to the population on the ground:

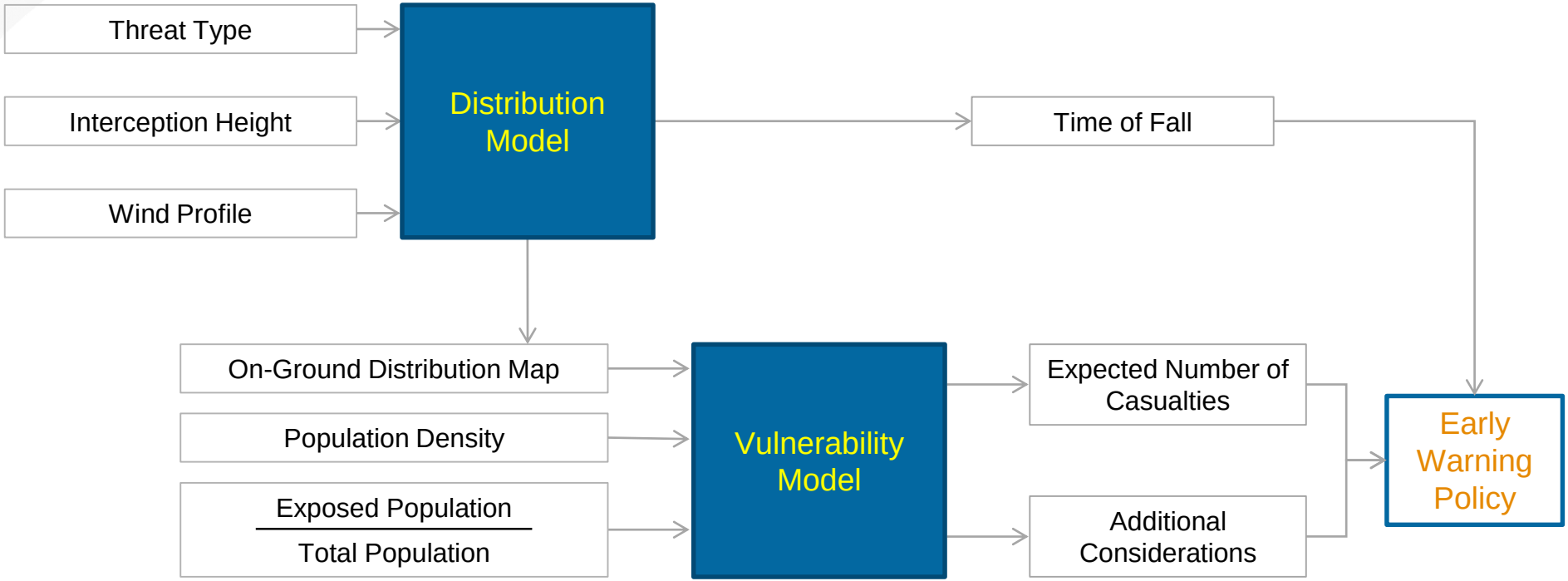
- *Calculate the limits of debris' danger area*
- *Calculate the time during which the danger persists*
- *Estimate of casualty numbers in case no early warning is given*

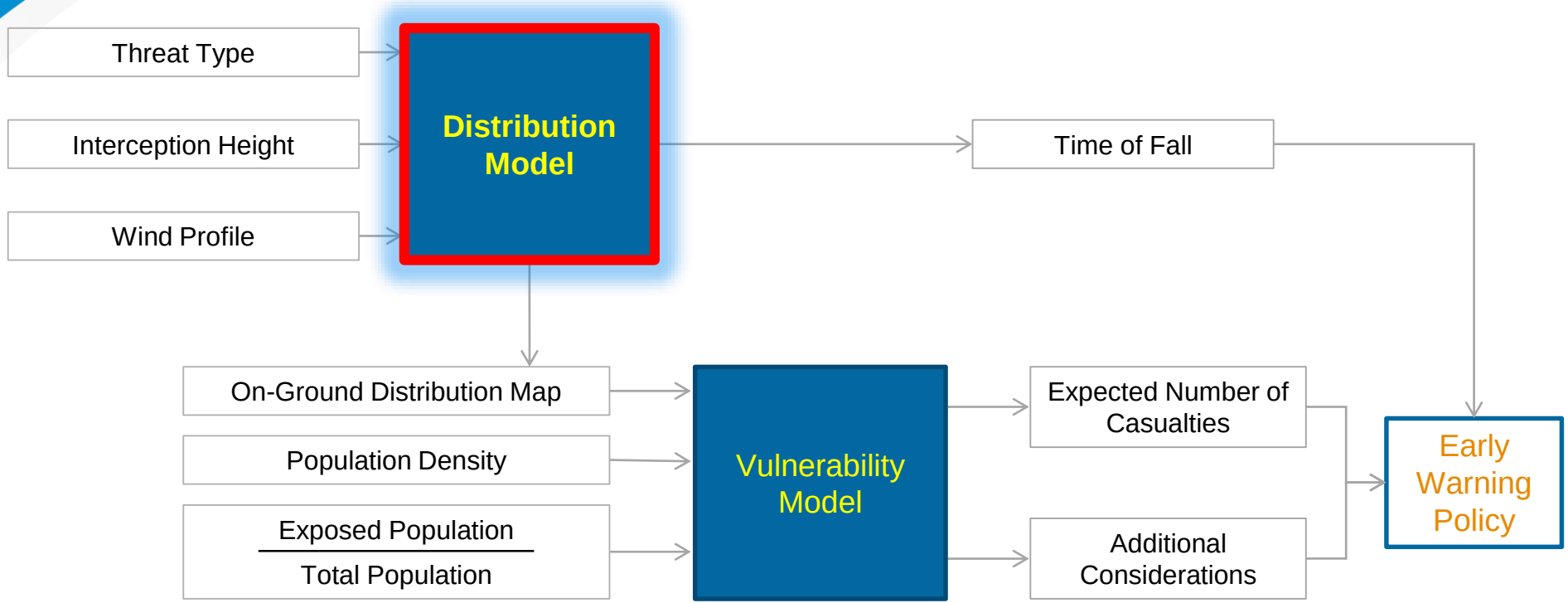
②Recommend ways to update the early warning policy based on research results

- *Is early warning against interception debris essential?*
- *If so, where should this warning be given?*
- *How should people be warned?*
- *What instructions should be given to the population?*

This paper discusses lower tier intercepts only (up to 15-20 km)

Method


Threat Type
Interception Height
Wind Profile
Distribution Model
Time of Fall
On-Ground Distribution Map
Population Density
Exposed Population
Total Population
Vulnerability Model
Expected Number of Casualties
Additional Considerations
Early Warning Policy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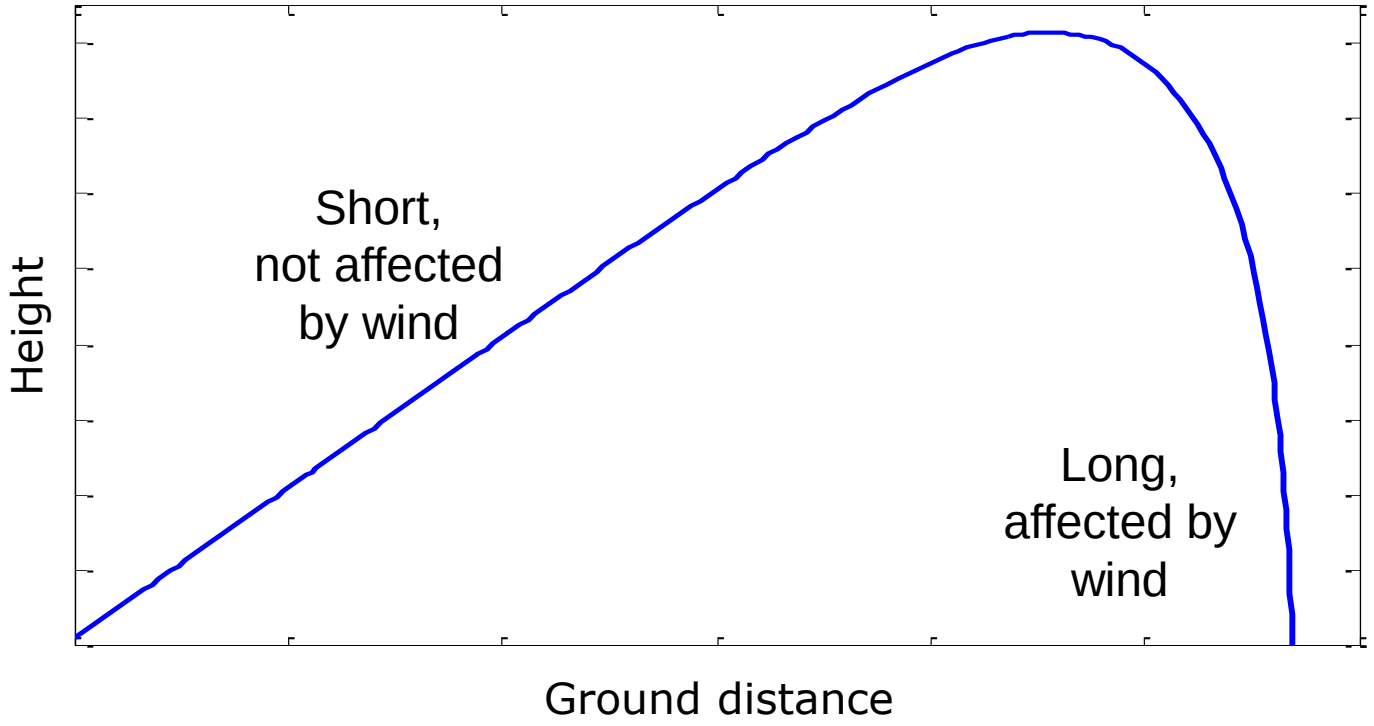
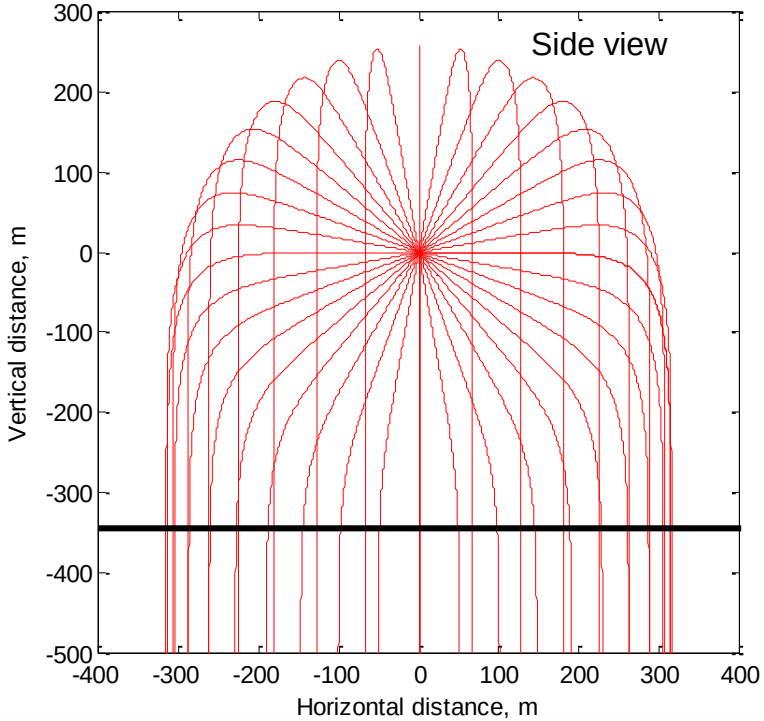
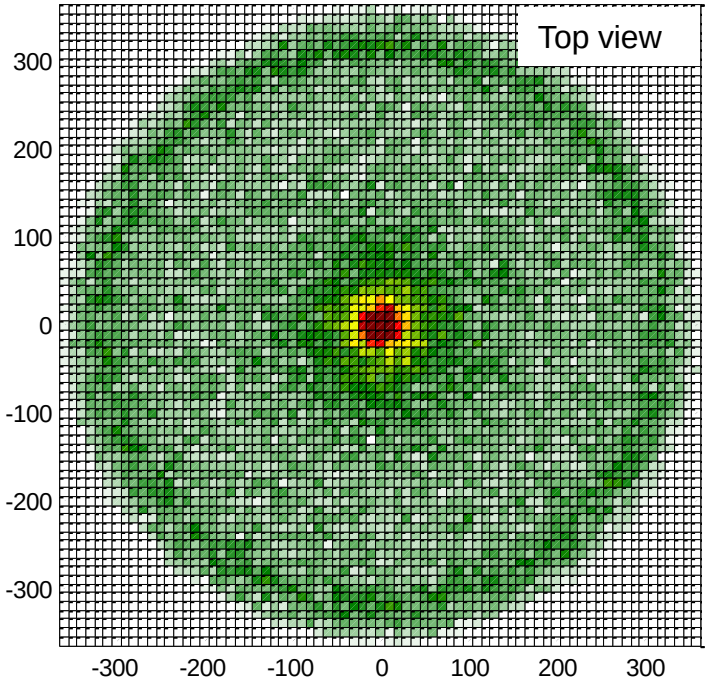
Single Fragment Trajectory

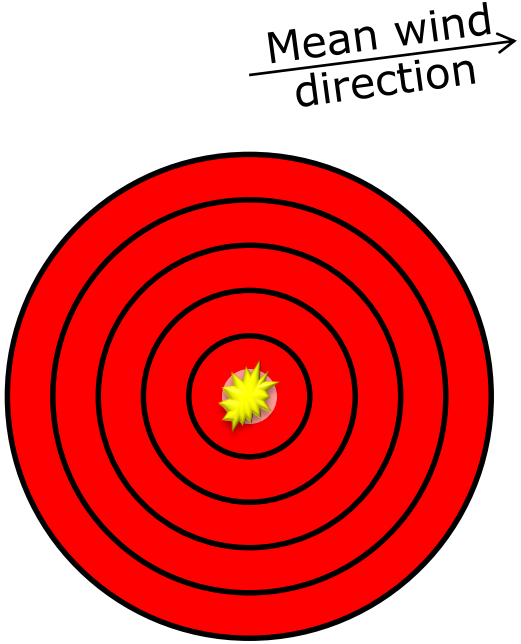


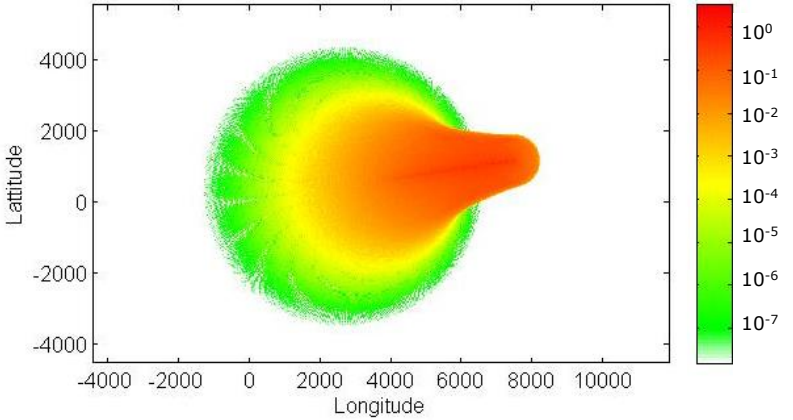
Homogeneous Fragmentation Cloud





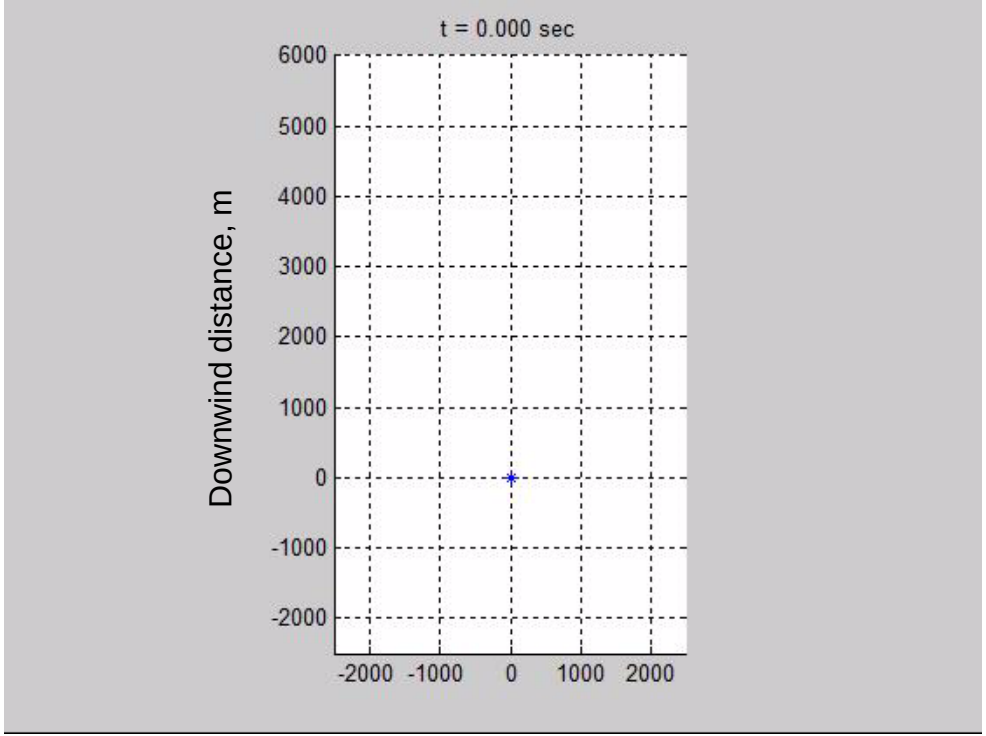
Drifting

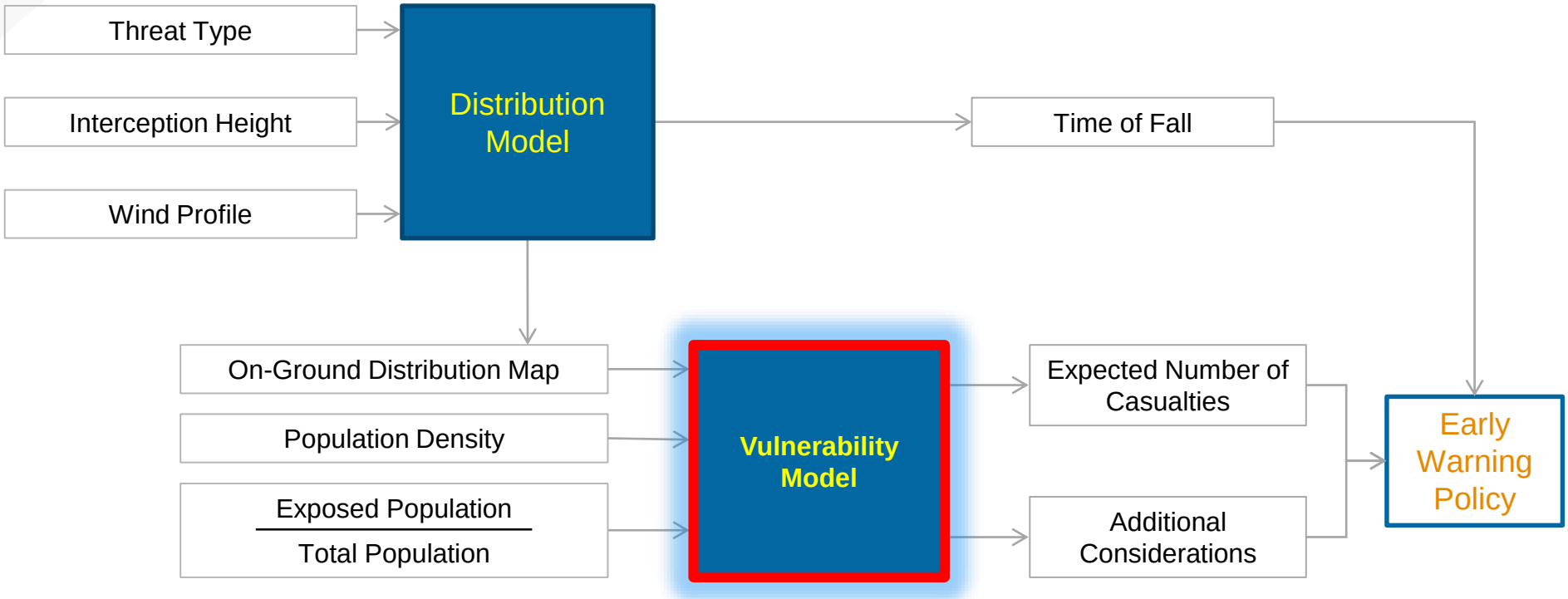




Falling time – up to several minutes

Simplified Approach Validation

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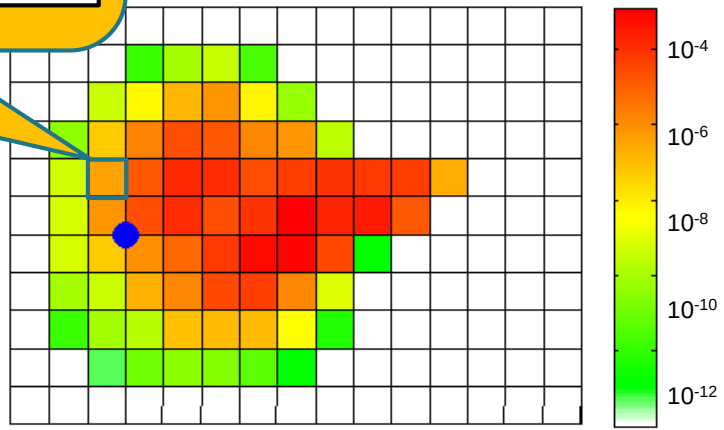
Vulnerability Model

Probability of Casualty = Fragments Density * Person Presented Area * Population Density * Ratio of Exposed Population

Expected Number of Casualties $= \iint$ Probability of Casualty dx dy

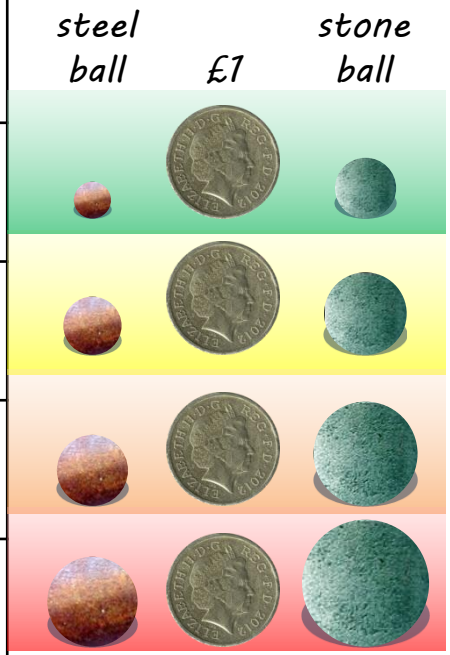


Criterion for Dangerous Fragment

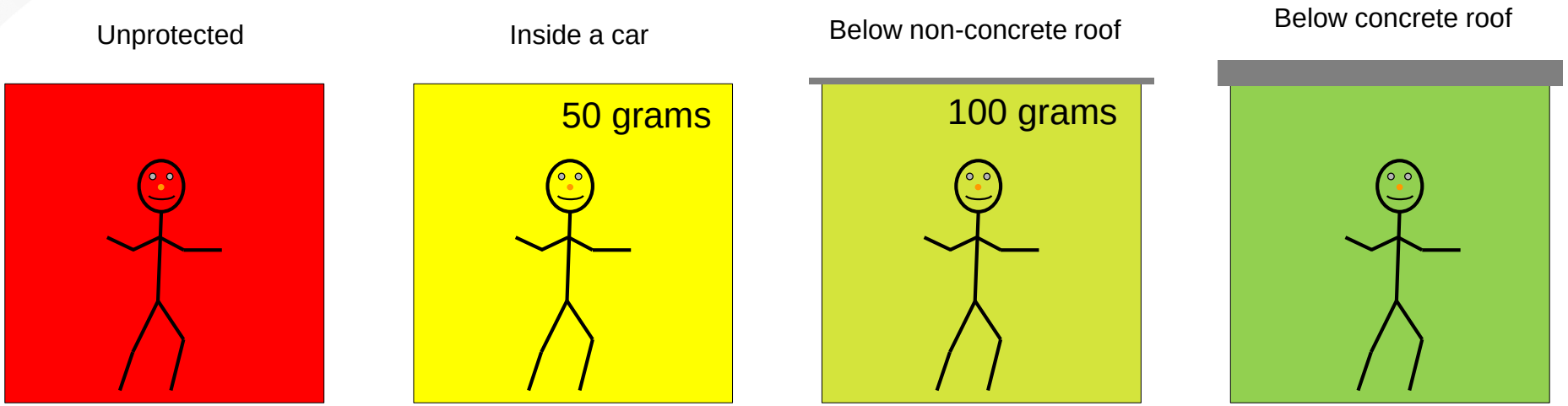
- Currently measured by amount of kinetic energy or kinetic energy per cross-section area
- A fragment approaches the ground with a constant (terminal) velocity, which is a function of its mass
- Hence the criterion can be formulated in terms of fragment's mass

Risk Estimation

Fragment Mass (Terminal Velocity)	Expected Impact	Risk Level
0-2 grams (40 miles/h)	Minor Injury – scratch, limited bleeding	No risk
2-5 grams (50-100 miles/h)	Minor to Moderate Injury	Low
5-10 grams (55-110 miles/h)	Moderate to Serious Injury	Medium
above 10 grams (60-120 miles/h)	Serious to Severe Injury	High



Who Needs to be Warned?

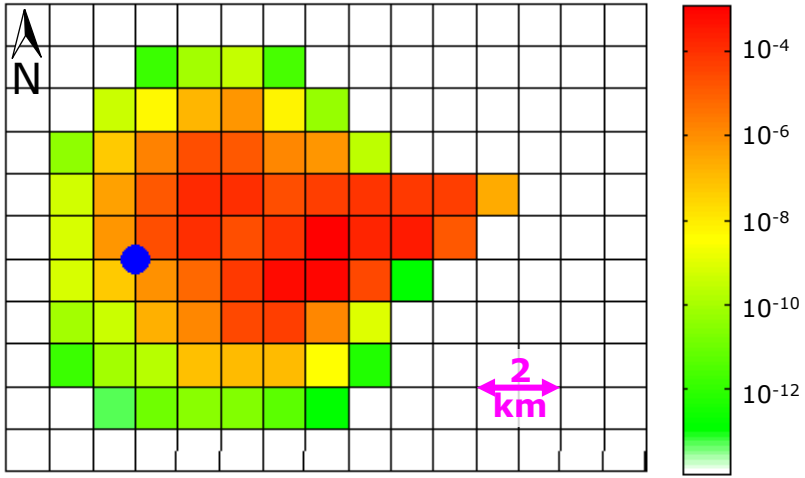


- Unprotected persons should find the nearest shelter (concrete roof)
- Persons in a car should stop and remain inside
- Persons inside a building should do nothing

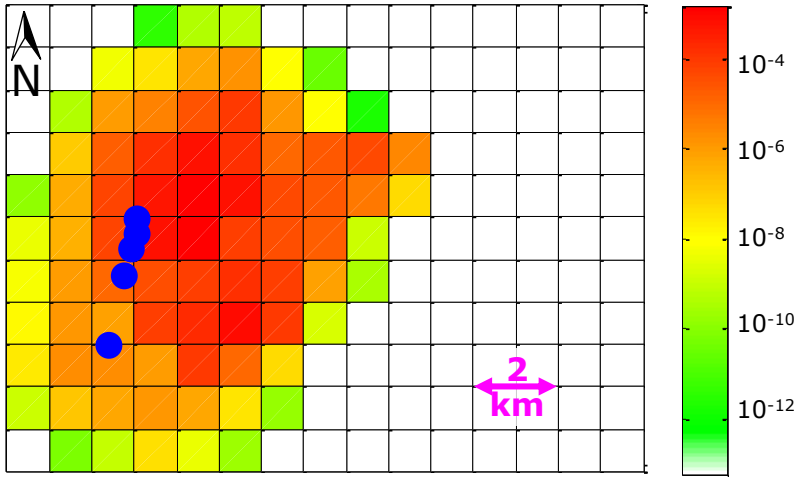
Expected Number of Casualties

(real-time calculation)

Medium-sized warhead,
Total expected number of casualties – $5 \cdot 10^{-3}$



Salvo of 5 small warheads,
Total expected number of casualties – $3 \cdot 10^{-2}$



Conclusions

- Dangerous free falling fragments weigh 2 grams and more
- The expected number of casualties is about 1/100 per intercept
- The dangerous area might be very large
- Early warning is not always essential (night, wartime)