# Operational Resilience in Maintenance Decision Support Systems

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# Outline

- Introduction
- Forecast Errors
- Developing System Resilience
  - In the time domain
  - In the weather domain
- Conclusions

# Introduction - Economics

- Economic benefits of winter maintenance are clear
- Costs of one-day shutdowns of a transportation system have been modeled and/or measured
  - Michigan – direct $115M, derived $144M
  - Iowa – direct $27.9M, derived $34.8M
  - I-90 in Washington State – Snoqualmie Pass closed for five days, total economic loss $27.9M, total state tax revenue loss $1.42M – loss rate per hour $230,000

# Introduction - Safety

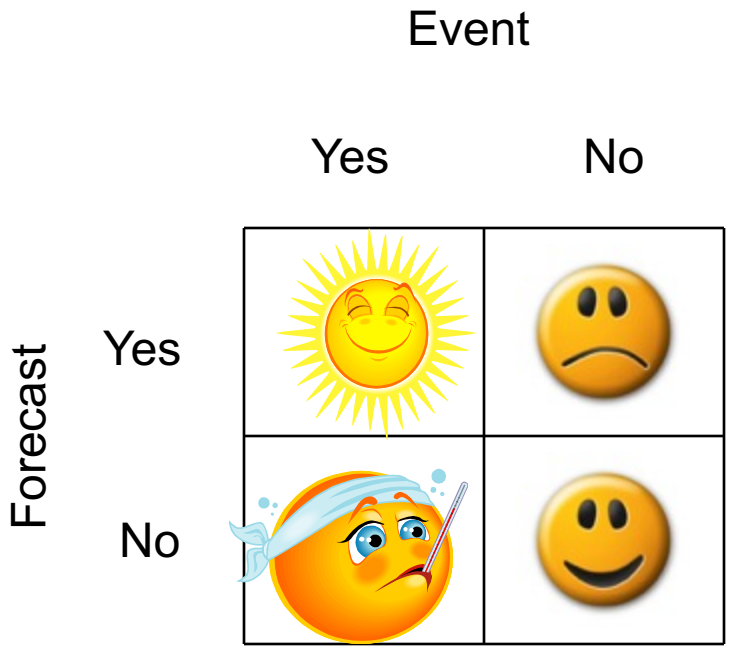
- Meta-analysis shows that snow on the road strongly negatively impacts safety
  - On a per kilometer traveled basis, fatalities increase by 9%, crashes by 84%
  - US FHWA estimates 2,200 fatalities and 192,500 crashes each year due to winter weather
- Crash rate in winter is improving over time
- Appropriate winter maintenance can bring excellent improvements (e.g. Breem – 83% reduction)

# Introduction - Decisions

- Anti-icing gives excellent results
- BUT, must be done pro-actively (i.e. before a storm starts)
- Hence anti-icing actions may be impacted by forecasting errors
- Errors happen!
- So, how do we make decision support systems resilient in the context of the inevitable forecast errors?

# Forecast Errors

- Happen!
- But, an error for a meteorologist may not be an error for a winter service provider
- Notion of operational accuracy might need to be explored
- What are key aspects of operational significance?

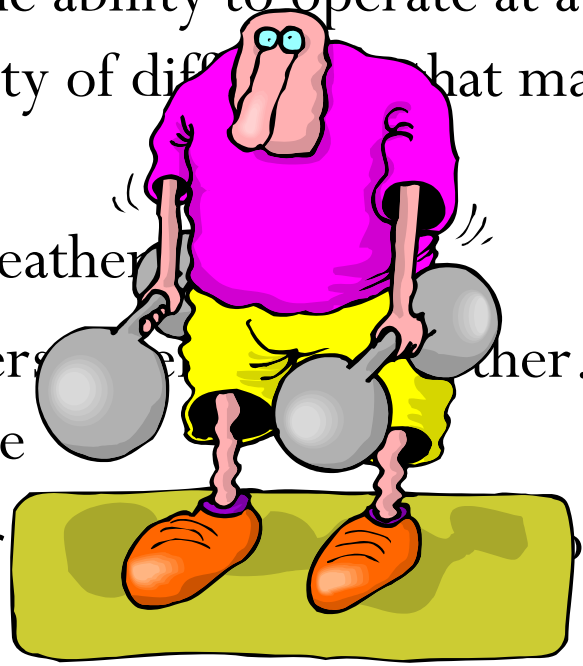


# Operationally Critical Aspects of Winter Storms

| Winter Storm Aspects of Operational Significance | Factors Impacted by an Incorrect Forecast |
|---|---|
| **Storm start time** | Scheduling of personnel, timing of applications, especially with respect to rush hours |
| **Storm duration** | Scheduling of personnel |
| **Precipitation type** | Appropriate chemical treatment, and in particular, appropriate pre-storm treatment |
| **Wind speed, during and after storm** | The use of liquids, either directly or as pre-wetting, especially at the end of storms if drifting is possible |
| **Pavement temperature** | Application rates, and selection of materials |
| **Pavement temperature trends at the end of a storm** | The use of pre-wet chemicals towards the end of a storm |

# Developing Resilience

- Resilience – the ability to operate at a near-optimal level in spite of a variety of di[illegible]hat may arise (during a storm)
- Not just the weathe[illegible]
- Equipment, pers[illegible]ther… BUT weather is an important issue
- Two particular [illegible]r domains) require resilience
  - The time domain
  - The weather domain



# Resilience in the Time Domain

- Impacts in three areas
  - Rush hour applications
  - Shift starting times
  - Shift switch over and scheduling (for longer storms)
- Three approaches to building resilience

# Flagging Long Storms

- If a storm will last more than 8 hours then flag it as a multi-shift storm (assumes 12 hour shifts)
  - Allows time before for pre-treatment
  - Errors in start time can be accommodated (somewhat)
  - Preparation in terms of multi-shift planning can begin earlier and thus be more successful

# Providing a Time Window

- Instead of "the storm will start at 3 a.m." better to have "the storm will start between 3 a.m. and 9 a.m."
- Want to have a level of probability associated with the time window, and level should be high
  - E.g. "95% chance that storm will start between…"
- Want the window to be as narrow as possible

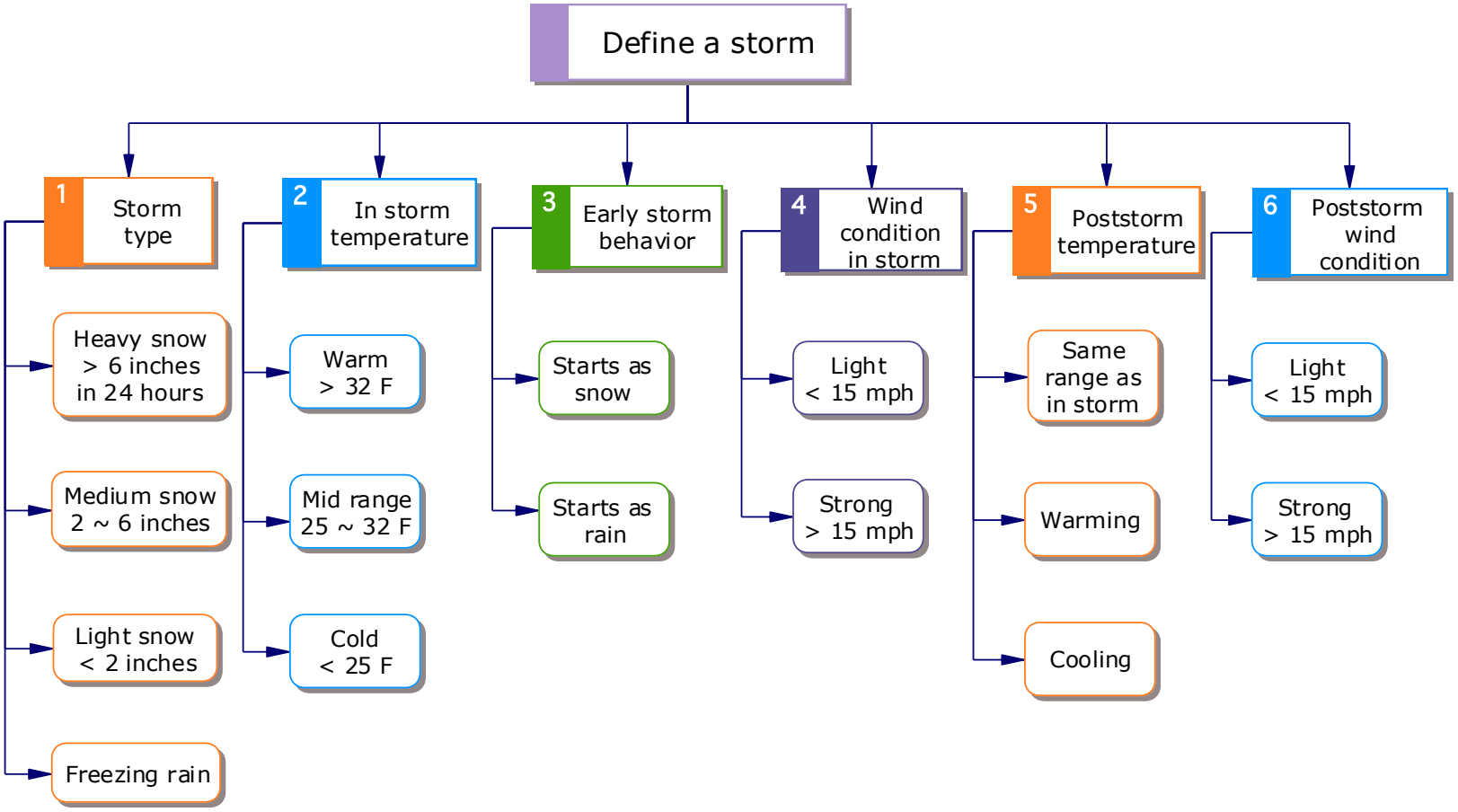
# Flag "Rush Hour Impacting" Storms

- Indicate when a storm will start at such a time that it will impact pre-storm and early-storm treatments
- Clearly will vary from location to location (e.g. in US afternoon rush hour starts at about 3 p.m.)
- Want to be able to pre-treat before rush hour begins (if at all possible) and so early application may be required
- Length and intensity of rush hours are also highly variable

# Resilience in the Weather Domain

- Describe storms by determining a series of descriptive boundaries between weather conditions
- Assign different treatments to the weather conditions found on differing sides of the boundaries
- If treatment shifts significantly across any boundary, then that boundary must be carefully considered in any forecasts, since errors in that regard can have profound operational consequences

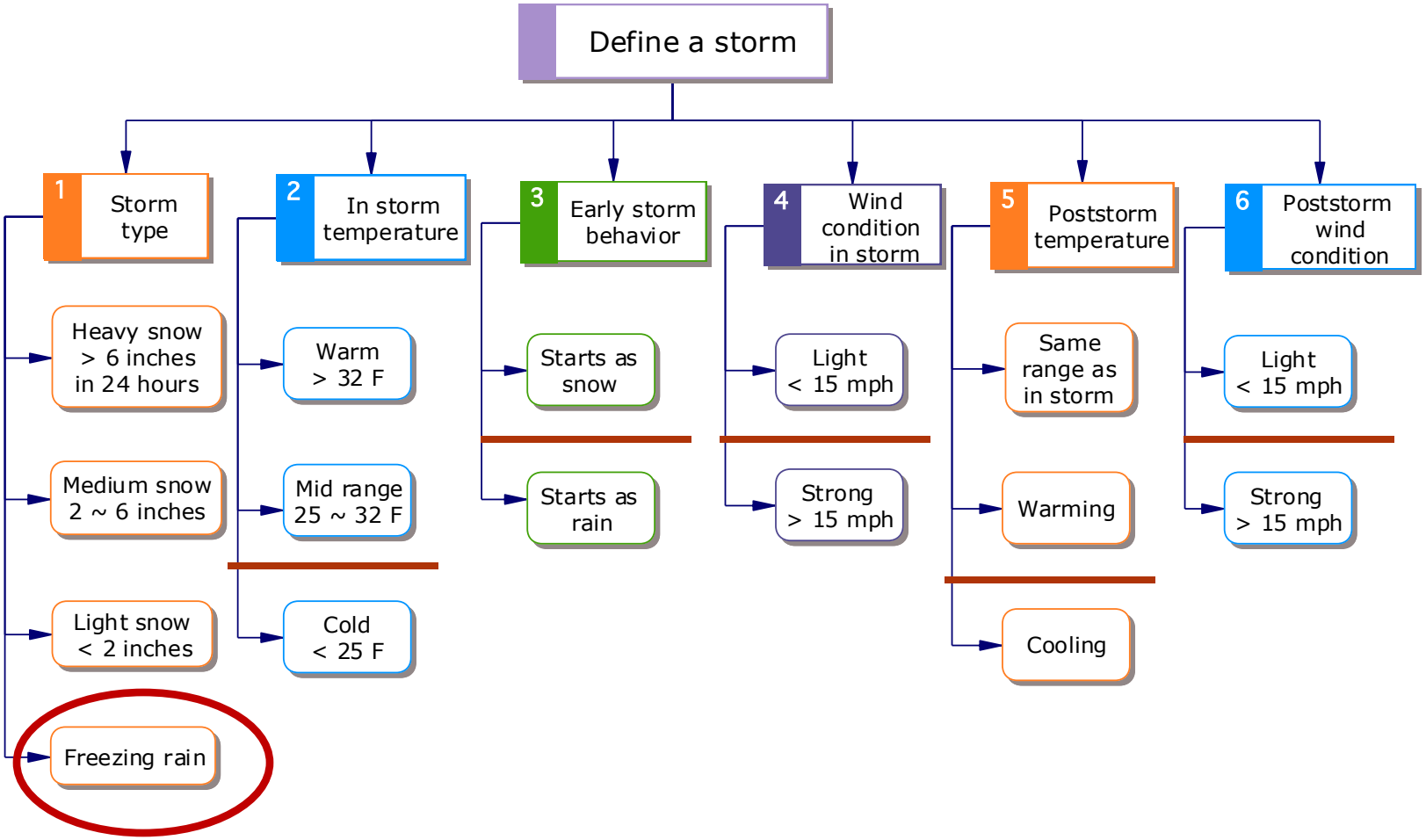
# Descriptive Boundaries by Matrix



# Storm Description

- Select one choice from each of the six categories
- For example: "medium snow (2 to 6 inches or 5 to 15 cm) with pavement temperatures between 25° and 32° F (-4° to 0° C) starting as snow with light winds (less than 15 mph or 25 kph) during and after the storm and the post-storm pavement temperature is cooling."
- A treatment can be assigned to each possible storm description
- Identify those "boundaries" which are operationally critical

# Critical Boundaries



# Conclusions

- By identifying situations where operational risks are greater, the resiliency of winter service activities can be improved
- Thinking of the forecast in terms of a time domain and a weather domain can help operationally
- Only a first step for now …