30th Annual INCOSE international symposium

Virtual Event
July 20 - 22, 2020

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Employing Model Based Conceptual Design to Identify Test Range Resources Required to Validate the Delivered Solution

Outline

- Introduction / Motivation
- Background from INCOSE IS 2019 Work
- Literature Review
- Modeling Approach
- Analysis Results
- Conclusions and Next Steps

Introduction / Motivation

- During system concept development, engineers will look at the problem space to satisfy the stakeholder capabilities
- We extend our MBCD concepts developed during IS 2019 and apply to a firefighting and emergency response problem
- We will evaluate a larger solution space and utilize modeling and simulation techniques to assess the testing
- Also consider the test range resources as part of the solution set

Background from IS 2019 Work

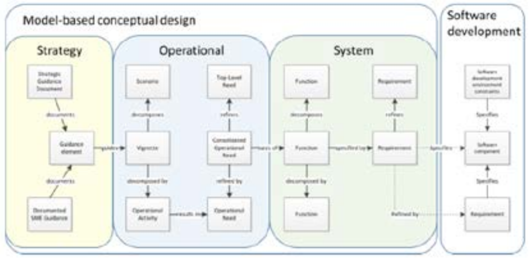
- Initial work presented in IS 2019
- During the initial concept development phase, Model Based Conceptual Design (MBCD) techniques may be used to assist the customer and other stakeholders develop a greater understanding of the system concept
- This approach does not provide significant focus on the Test and Evaluation (T&E) space, or identify where the T&E space is would be affected with a change in requirements
- Our hypothesis is that decision makers would equally gain insight into the T&E considerations as well as system space considerations using MBCD techniques

5 Segment Approach from IS 2019

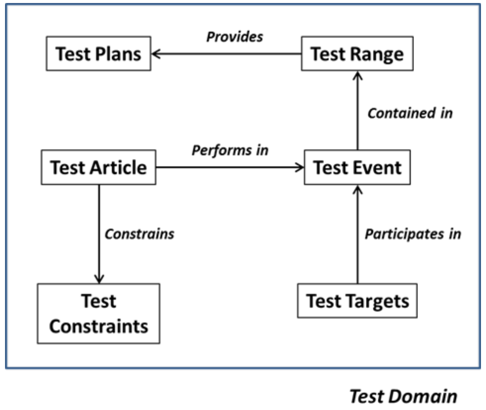
- The first defines how MBCD is used for system concept development and discusses the relevant artifacts, actors, and information
- The second describes the proposed T&E extension to the MBCD technique
- The third segment describes the linkage between the test domain and the other MBCD domains
- The fourth segment offers additional considerations to evaluate the entire system model
- The last segment offers an approach to evaluate the new linkages and to visualize the insight gained when one domain causes changes to the other domains

5 Segment Approach from IS 2019

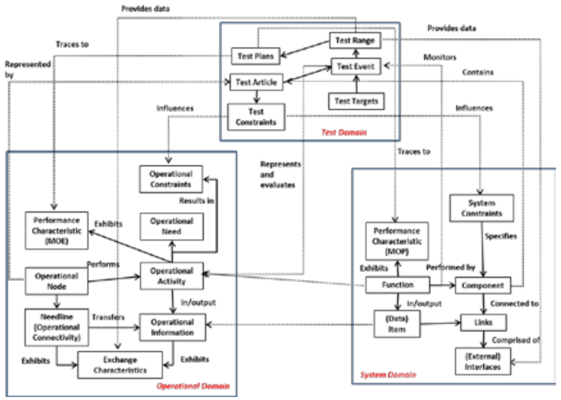
Segment 1: MBCD Usage

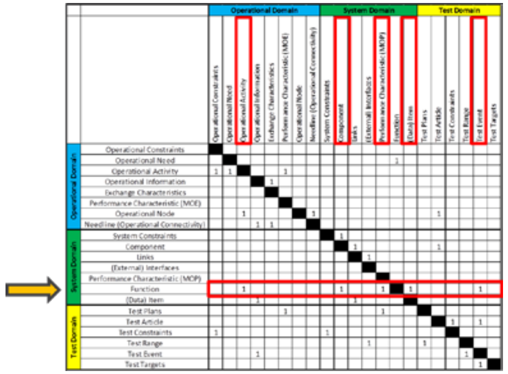


Segment 2: T&E Extension

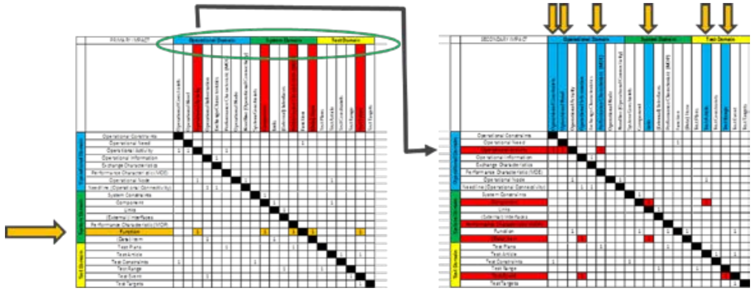


Segment 3: Test Domain Linkage

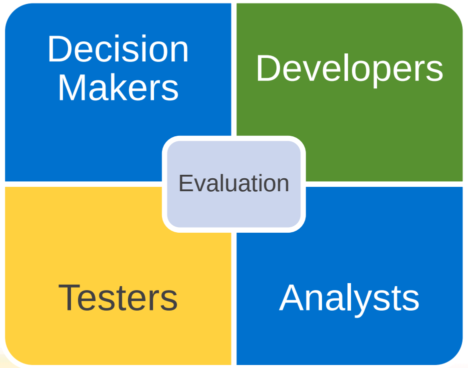




Segment 5: Impacts of the Changes



Segment 4: Evaluation of the Linkage

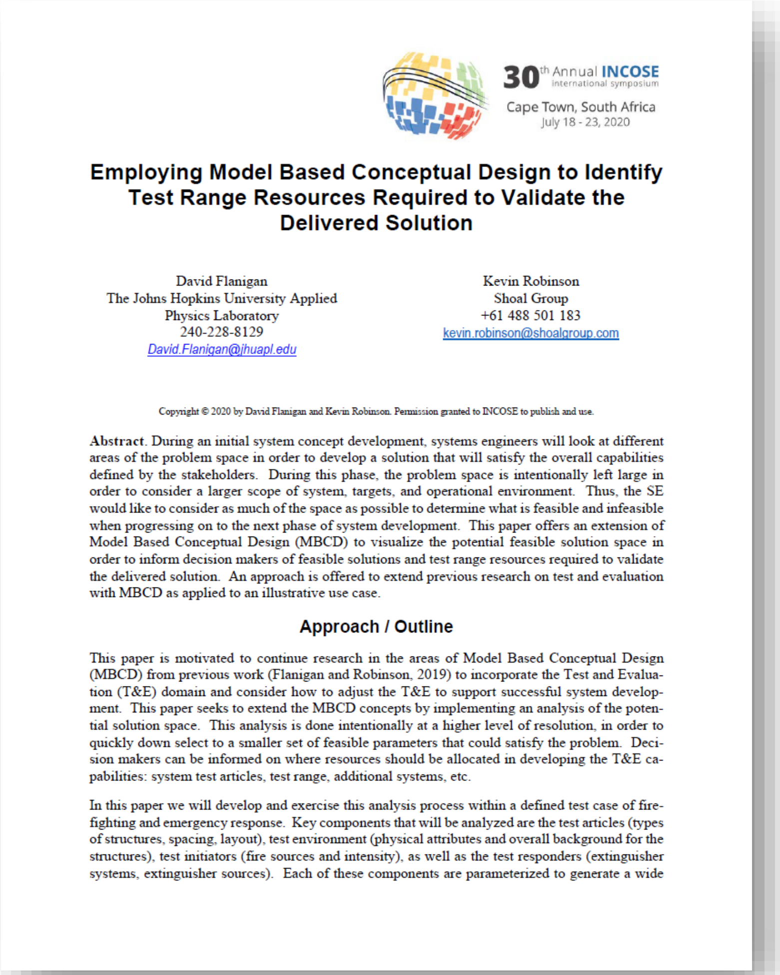


Literature Review

- For this paper, we investigated three main topics
- MBCD
  - Spencer and Harvey's (2014) capability framework model to show traceability between capability requirements and integrated systems model
  - Leverage this concept to extend to the T&E domain
- Applications to test and evaluation
  - Mattsson and Juas (1997) analyze fire and rescue services that develop metrics and building types
  - Taylor and Freeman (2010) analyze other firefighting testing metrics
- Modeling and simulation
  - Raz, Kenley, DeLaurentis characterize the proposed design space for decision makers
  - Fanfarova and Maris (2017) simulate fire and rescue activities

Paper and Analysis Outline

- “Employing Model Based Conceptual Design to Identify Test Range Resources Required to Validate the Delivered Solution”
- Further extend the MBCD concept and apply to an initial problem
- Focus on the firefighting and emergency response test articles, as well as the test range
- Evaluate a larger solution space and utilize modeling and simulation in order to assess the testing
- Also consider the test range resources as part of the solution set



30th Annual INCOSE international symposium
Cape Town, South Africa
July 18 - 23, 2020

Employing Model Based Conceptual Design to Identify Test Range Resources Required to Validate the Delivered Solution

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Abstract. During an initial system concept development, systems engineers will look at different areas of the problem space in order to develop a solution that will satisfy the overall capabilities defined by the stakeholders. During this phase, the problem space is intentionally left large in order to consider a larger scope of system, targets, and operational environment. Thus, the SE would like to consider as much of the space as possible to determine what is feasible and infeasible when progressing on to the next phase of system development. This paper offers an extension of Model Based Conceptual Design (MBCD) to visualize the potential feasible solution space in order to inform decision makers of feasible solutions and test range resources required to validate the delivered solution. An approach is offered to extend previous research on test and evaluation with MBCD as applied to an illustrative use case.

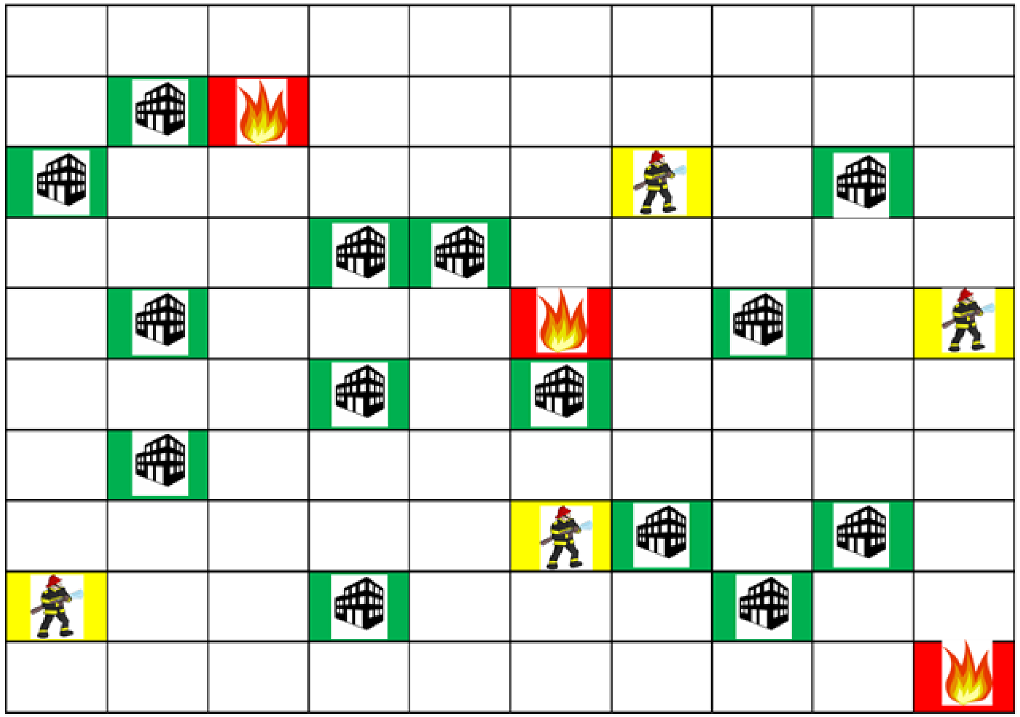
Approach / Outline

This paper is motivated to continue research in the areas of Model Based Conceptual Design (MBCD) from previous work (Flanigan and Robinson, 2019) to incorporate the Test and Evaluation (T&E) domain and consider how to adjust the T&E to support successful system development. This paper seeks to extend the MBCD concepts by implementing an analysis of the potential solution space. This analysis is done intentionally at a higher level of resolution, in order to quickly down select to a smaller set of feasible parameters that could satisfy the problem. Decision makers can be informed on where resources should be allocated in developing the T&E capabilities: system test articles, test range, additional systems, etc.

In this paper we will develop and exercise this analysis process within a defined test case of firefighting and emergency response. Key components that will be analyzed are the test articles (types of structures, spacing, layout), test environment (physical attributes and overall background for the structures), test initiators (fire sources and intensity), as well as the test responders (extinguisher systems, extinguisher sources). Each of these components are parameterized to generate a wide

Model Approach

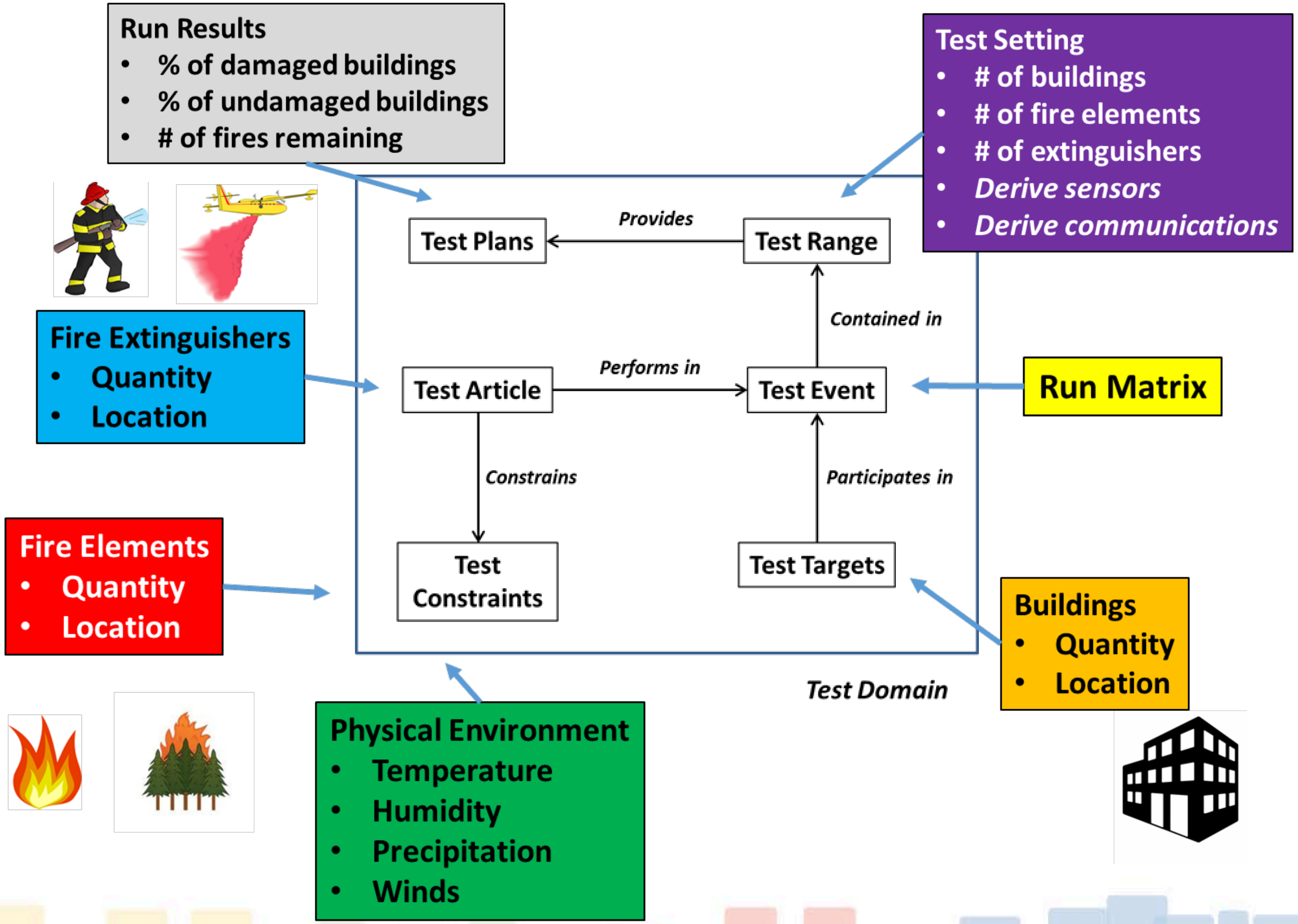
- Create the test range within an MBCD construct
  - Buildings that are still intact are denoted in green
  - Extinguisher locations are in yellow
  - Fire elements are in red



Representation of test range

Linkage of Test Domain Model

- Leverage the 2019 MBCD test domain model
- Describe the dependencies of different elements that interact within a test event
- Transform the elements into an analysis task
- Start with the test domain model and overlay the analysis to be conducted on these elements



Full Factorial Development

- Develop the solution space which is a full factorial of all combinations of:
  - Test articles (closeness of articles within 3 environments)
  - Physical environment (2 types), fire elements (2 quantities)
  - Extinguishers (2 types)
- The entire run matrix consists of 3*2*2*2=24 unique combinations

Run	Buildings	Weather	Fire	Extinguishers
1	Rural	Low	Low	Low
2	Rural	Low	Low	High
3	Rural	Low	High	Low
4	Rural	Low	High	High
5	Rural	High	Low	Low
6	Rural	High	Low	High
7	Rural	High	High	Low
8	Rural	High	High	High
9	Urban	Low	Low	Low
10	Urban	Low	Low	High
11	Urban	Low	High	Low
12	Urban	Low	High	High

Run	Buildings	Weather	Fire	Extinguishers
13	Urban	High	Low	Low
14	Urban	High	Low	High
15	Urban	High	High	Low
16	Urban	High	High	High
17	Suburban	Low	Low	Low
18	Suburban	Low	Low	High
19	Suburban	Low	High	Low
20	Suburban	Low	High	High
21	Suburban	High	Low	Low
22	Suburban	High	Low	High
23	Suburban	High	High	Low
24	Suburban	High	High	High

Develop Rulesets for Simulation Analysis

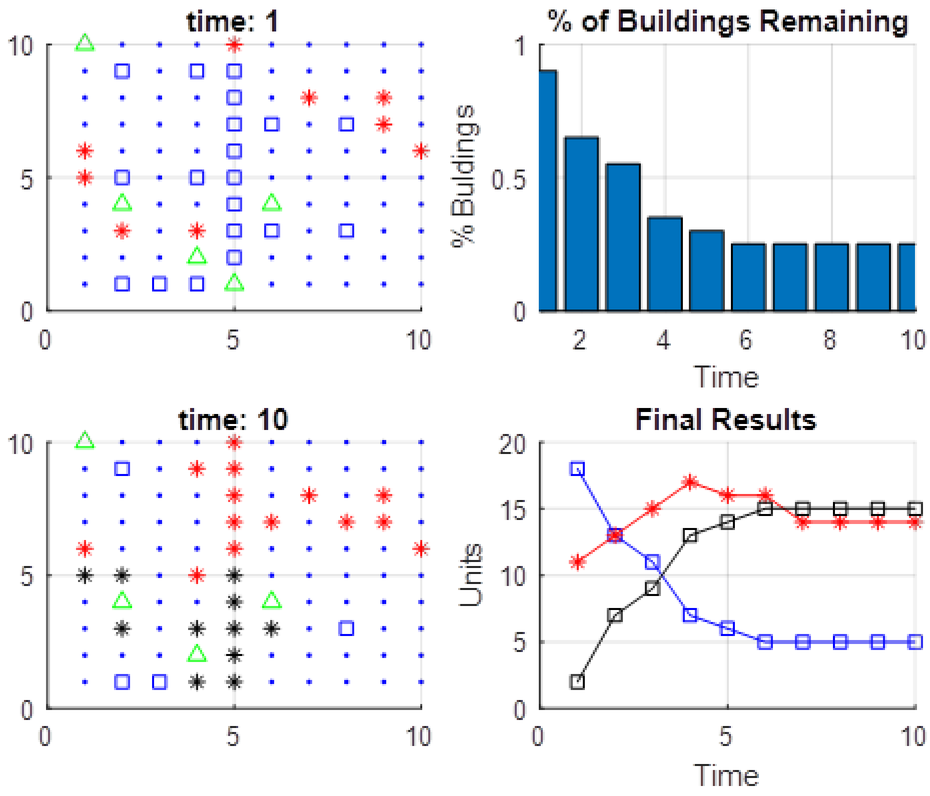
- Start with fire element and check for adjacent spots:
  - If it is a building: expand the fire element and continue
  - If it is a fire extinguisher: extinguish the fire element
- Modify performance based on environmental performance
  - Increased fire performance as a result of higher temperatures, lower humidity, and higher winds
- Continue the simulation until all fire elements are extinguished or fire cannot spread anymore
- Note this is a first-order approximation, more realistic performance would be performed by higher fidelity physics-based simulations

Example Output

1. Buildings remaining (blue square) and burned (red asterisk) and fire extinguishers (green triangle) before (top left) and after the simulation run (bottom left)

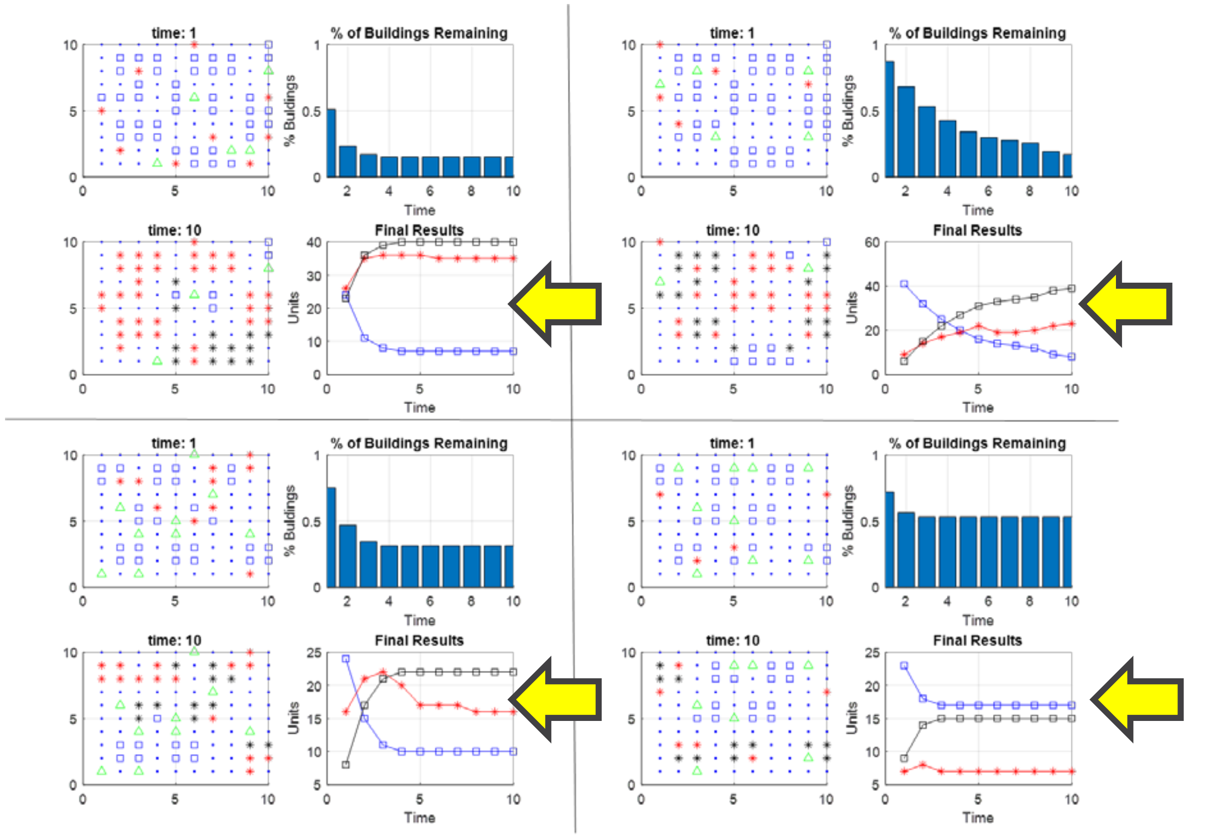
2. Count the percentage of still standing buildings (top right) throughout the simulation

3. Count the number of buildings and fires that are active throughout the simulation (bottom right)



24 Run Simulation Results

- The full factorial is a 24 run design that incorporates three building settings for numbers of buildings and density (urban, suburban, and rural)
- Weather effects that decrease or increase the effectiveness of both fire and extinguishers (low / high)
- # Fire elements at the start of the simulation (low / high)
- # Extinguisher elements at the start of the simulation (low / high)
- Note the wide variety of time-ordered performance dependent on the run

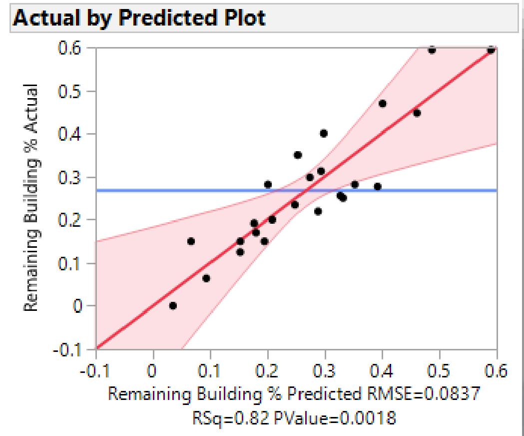


Blue: intact building; **Red**: fires; **Black**: burned building

Statistical Analysis

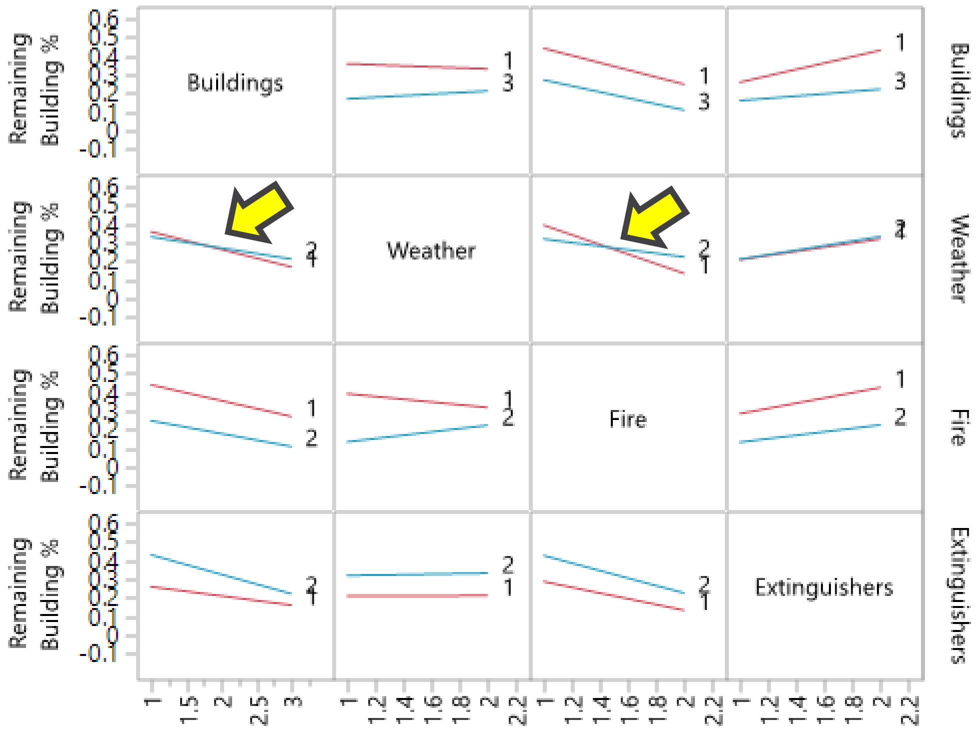
- Utilize SAS JMP 13, a statistical tool to evaluate the data generated by the simulation
- Shows the statistically significant factor(s)
- Can show how much of the data and errors can be explained by the linear regression model (R-squared value)
- In this case, $R^2 = 0.82$, which indicates a good fit of the data

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Buildings	1	1	0.09378906	13.4033	0.0029*
Weather(1,2)	1	1	0.00032878	0.0470	0.8318
Fire(1,2)	1	1	0.18627189	26.6198	0.0002*
Extinguishers(1,2)	1	1	0.07984625	11.4107	0.0049*
Buildings*Weather	1	1	0.00472656	0.6755	0.4260
Buildings*Fire	1	1	0.00097656	0.1396	0.7147
Weather*Fire	1	1	0.03935049	5.6235	0.0338*
Buildings*Extinguishers	1	1	0.01196289	1.7096	0.2137
Weather*Extinguishers	1	1	0.00016835	0.0241	0.8791
Fire*Extinguishers	1	1	0.00335538	0.4795	0.5008



Statistical Analysis

- SAS JMP can also identify the factor(s) that have a significant effect on the remaining building %, which is how we measure the goodness of the extinguisher systems
- Interaction profiler can show which factors have an interaction with each other to influence the outcome



Can also analyze cross factors that affect each other, in this case weather and fire

Application of MBCD to Narrow Solution Space

- Utilize this quick-turn approach to highlight the runs that provide improved performance (% unburned buildings)
- In this case, 9 of 24 were evaluated to have better performance, which could be examined in more detail

Original Run Matrix

Run	% unburned buildings
1	0.500
2	0.500
3	0.313
4	0.375
5	0.438
6	0.531
7	0.000
8	0.500
9	0.170
10	0.681
11	0.106
12	0.447
13	0.085
14	0.404
15	0.085
16	0.170
17	0.150
18	0.250
19	0.300
20	0.250
21	0.150
22	0.200
23	0.650
24	0.100

Revised Run Matrix

Run	% unburned buildings
1	0.500
2	0.500
5	0.438
6	0.531
8	0.500
10	0.681
12	0.447
14	0.404
23	0.650

Summary and Next Steps

- Demonstrate the viability of utilizing MBCD artifacts
  - Supported by mathematical analysis
  - Better define and prioritize Test and Evaluation resources
- Next steps
  - Incorporate higher fidelity simulations as the viable solution set narrows
  - Consider other simulations to aid in modeling and analysis
    - Agent-based models
    - System dynamics
    - Discrete event simulations

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