Advances in Hybrid Simulation: Challenges and Research Opportunities from Philosophical, Conceptual and Technological Perspectives

SIMULTECH 2020 – keynote lecture

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Hybrid Simulation

A Complexity Perspective

What is Hybrid Simulation?

- Proposed definition
  - Mixing and/or linking of two or more simulation approaches (namely, Discrete Event Simulation, Agent Based Simulation, and System Dynamics) for the purpose of developing an overarching all-encompassing simulation model to tackle complex problems.

Why Hybrid Simulation?

Historically systems were complex because of their structure or behaviour.

Today's complexity is caused by multiple information points with more and more stakeholders involved.

Whilst intricate models fail to cope with complexity, the world is moving towards mixing more simpler models.

Hybrid simulation seems to be a viable way forward.

3 Dimensions of Complexity

Structural Complexity

- high volume of interconnected heterogenous components;
- process oriented with input➔process➔ output frame;
- e.g. patients flow management.

Dynamic Complexity

- relationships and feedback loops components;
- system is viewed holistically as a set of causes and effects;
- e.g. impact of price rise on willingness to buy.

Evolving Complexity

- emerging phenomena and untended consequences;
- autonomous components and goal seeking behaviour;
- e.g. social contagion

Three Simulation Approaches

Discrete Event Simulation (DES)	System Dynamics (SD)	Agent Based Simulation (ABS)
• Models queue networks and processes • Model individual entities (non-autonomous) • Top-down approach	• Models the fluidity of system behaviour • Dynamic feedback behaviour • Top-down approach	• Model individual autonomous entities • Used to identify the interaction behaviour • Bottom-up approach
Why use it		
• More intuitive in modelling • More straightforward to develop once the problem is agreed	• Helps in understanding complex systems • Able to identify the relevant factors that exist in complex systems	• Able to capture an emergence phenomena • Good for mobile interactive behaviour
Challenges		
• Not amenable for analysing model that is related to human behaviour • Time consuming when modelling complex systems	• Becomes quite complex very quickly • Does not approach individual behaviour kindly	• Involve high skills in computation for the use in large systems • Not does capture processes visually

3 dimensions of complexity

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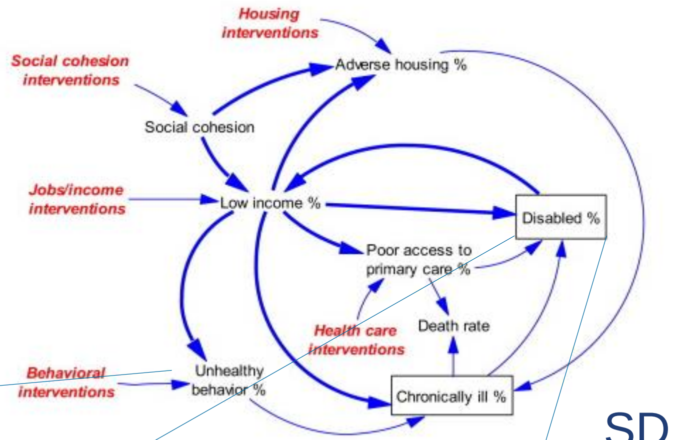
DES | SD | ABS

Wicked Problems Taming Methods

As proposed by Rosenhead (1996)

- Facilitate a visual representation for the systematic, group exploration of a solution space.
- Accommodate multiple alternative perspectives rather than prescribe single solutions.
- Focus on relationships between discrete alternatives with continuous variables.
- Concentrate on possibility rather than probability.
- Function through group interactions rather than back office calculations.
- Generate ownership of the problem formulation through transparency.

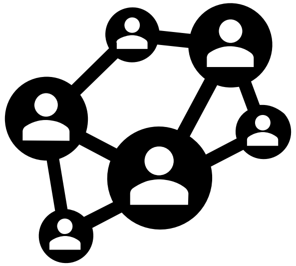
e.g. Hybrid Simulation for Health and Social Care



Mahamoud, A., Roche, B., & Homer, J. (2013). Modelling the social determinants of health and simulating short-term and long-term intervention impacts for the city of Toronto, Canada. *Social science & medicine*, *93*, 247-255.

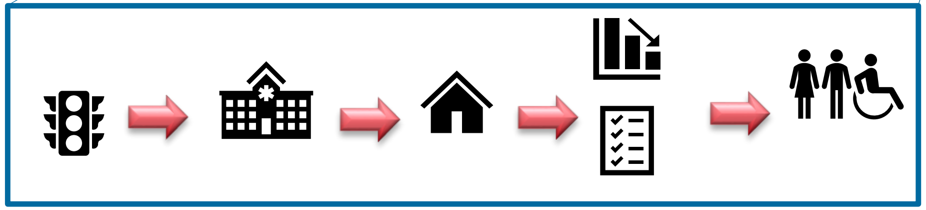
SD

Strategic analytics
Fluid analytics



ABS

Behavioural analytics
Transactional analytics



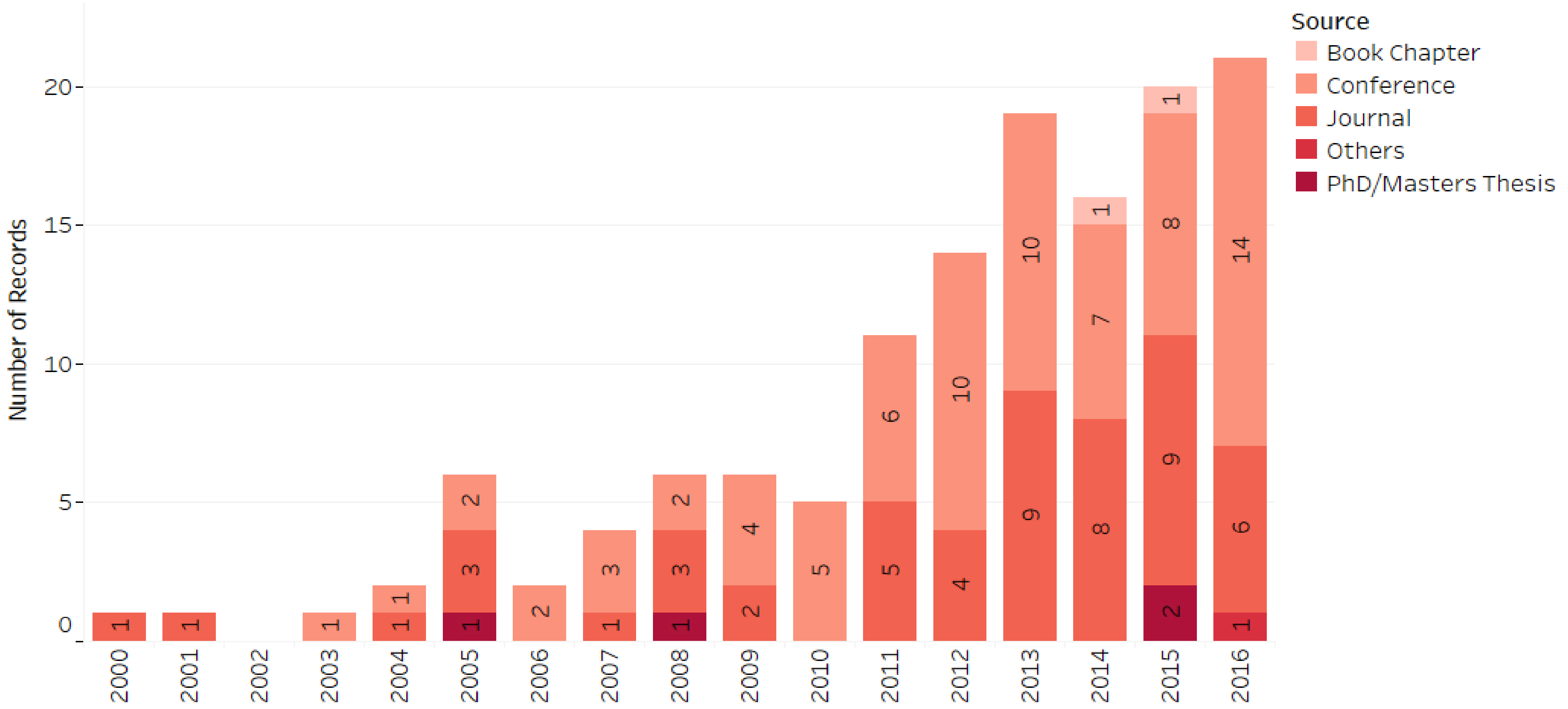
DES

Operational analytics
Quantitative analytics

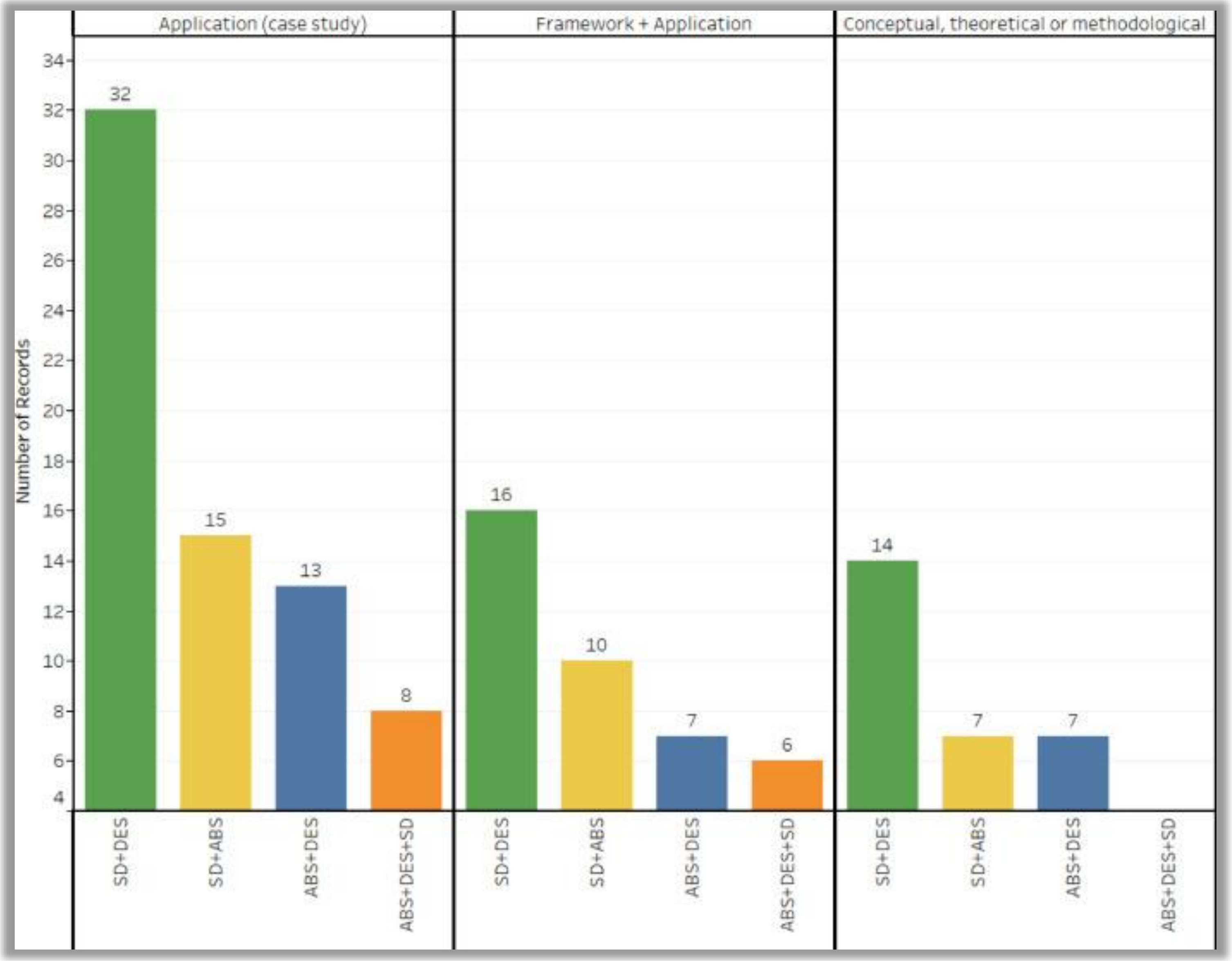
EJOR Review of Hybrid Simulation

Brailsford, S.C., Eldabi, T., Kunc, M., Mustafee, N. and Osorio, A.F., 2019. Hybrid simulation modelling in operational research: A state-of-the-art review. *European Journal of Operational Research*, *278*(3), pp.721-737.

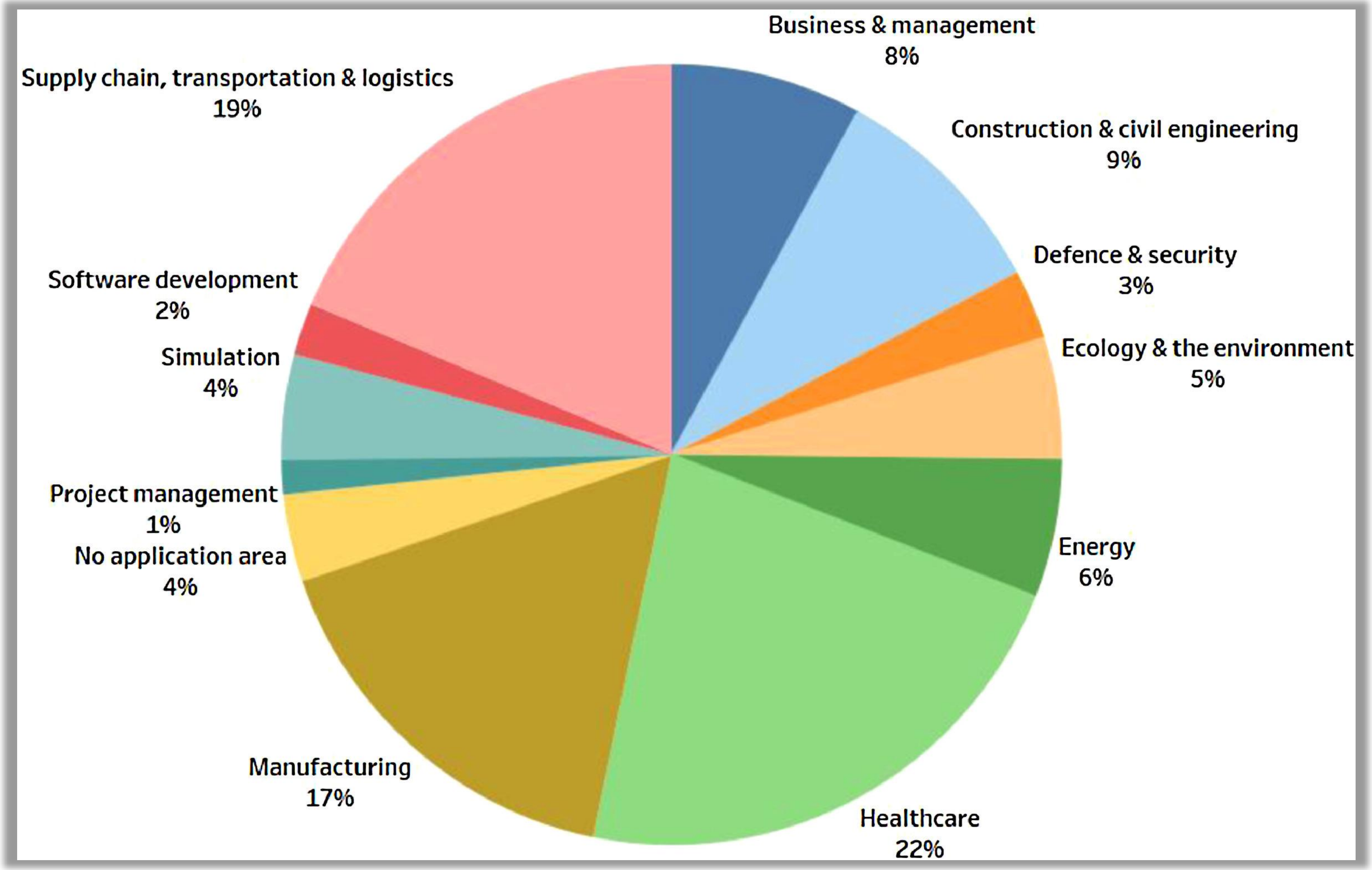
Descriptive Statistics: Numbers



Descriptive Statistics: Methods Used



Descriptive Statistics: Application Areas



Conceptual Modelling: Findings

More than 60% of the papers contained some evidence that a conceptual model had been developed.

However, the practice of conceptual modeling is not following any specific standards.

In a set of papers we found models using some specific graphical representation (e.g. causal loop diagrams, state flows, activity diagrams).

Conceptual Modelling: Opportunities for Research

Decide to hybridise or not at this stage?

Current hybrid methods seem to jump directly to the implementation stage (software) without much attention is given at the conceptual model.

There is no agreed hybrid conceptual model (or at least a way to communicate between them).

Hybrid Simulation Software: Findings

Currently only Anylogic© can facilitate automated integration.

There are some bespoke packages but are not commercial.

Even Anylogic© requires good working knowledge in programming.

Hybridisation is not readily accessible for pure modellers.

ABS is a good modelling approach but does not have many visual tools.

Hybrid Simulation Software: Opportunities for research

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There is a need for linking platforms that support pragmatic hybridisation.

Less coding more modelling.

More innovative ways are needed to tackle licences issues.

Verification and Validation: Findings

Less than 25% of the papers mentioned verification and/or validation.

- This is disappointing but not entirely surprising.

In the models where there were evidence of verification and/or validation, mostly focused on “intra-modular” VV separately.

There was no evidence of verification of links between submodels, (inter-modular).

Verification and Validation: Opportunities for Research

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“intra-modular” VV of submodels similar to existing approaches for single-method models.

Diversity of approaches needed is the most immediate challenge

- validation of quantitative numerical models, e.g. DES, requires statistical methods.
- validation of qualitative models (verbal or causal theories) in SD implies validation during the modelling process.
- ABS models are often based on assumptions and beliefs about the micro-level relationships between agents and behavioral rules.

Hybrid Simulation Skills: Findings

The **biggest challenge** of all is the rarity of multiple skills by one person.

There seems to be a dominance of solo methods in certain disciplines.

People are educated based on a single method rather than the concept of simulation in general.

There are some philosophical differences between the approaches that makes difficult to learn each one perfectly.

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Are people fundamentally inclined to learn one method than others, or is it the education practice?

There maybe a need to consider collaborative simulation (Simulation 2.0).

- Several modellers upload their models on a GitHub-like platform.
- Resurrection of the grab-and-glue simulation.

Hybrid Simulation & Covid-19

A Pragmatic Perspective

11 Decision Points for Simulation

Table 1. Summary of the main modelling methodologies suggested for each of the decisions identified below.

Decision	Suggested Modelling Methods
1. Quarantine strategies and case isolation	SD for population-level models; ABM for models that capture individual behaviour.
2. Social distancing measures	SD for population-level models; ABM for models that capture individual behaviour, DES and HS for operational models
3. How to manage the end of lock down	SD for population-level models; ABM for models that capture individual behaviour.
4. Delivery of testing	Targeting of testing: SD for population-level models; ABM for models that capture individual behaviour. Delivery of testing: DES.
5. Targeting of vaccination	Targeting of vaccination: SD for population-level models; ABM for models that capture individual behaviour. Delivery of vaccination: DES.
6. Capacity of inpatient hospital beds and critical care	DES or SD for models of resource requirements. HS, combining DES models of hospital operations and SD model describing the progression of the epidemic.
7. Staffing	DES models of hospital operations. SD models to represent workforce availability at a national level.
8. Management of resources within a region	SD or DES models of logistics and supply chains, ABM for behavioural models of individuals
9. Investigation of the thresholds for admission and discharge of patients	DES for operational models and SD for a more strategic view.
10. Minimising the impact on other patients	DES models of operations, SD for feedback on rationing care
11. Health & well being	SD models for population-wide impacts or HS combining SD and ABM.

Currie, C. S. M., Fowler, J. W., Kotiadis, K., Monks, T., Onggo, B. S., Robertson, D. A., et al. (2020). How simulation modelling can help reduce the impact of COVID-19. Journal of Simulation

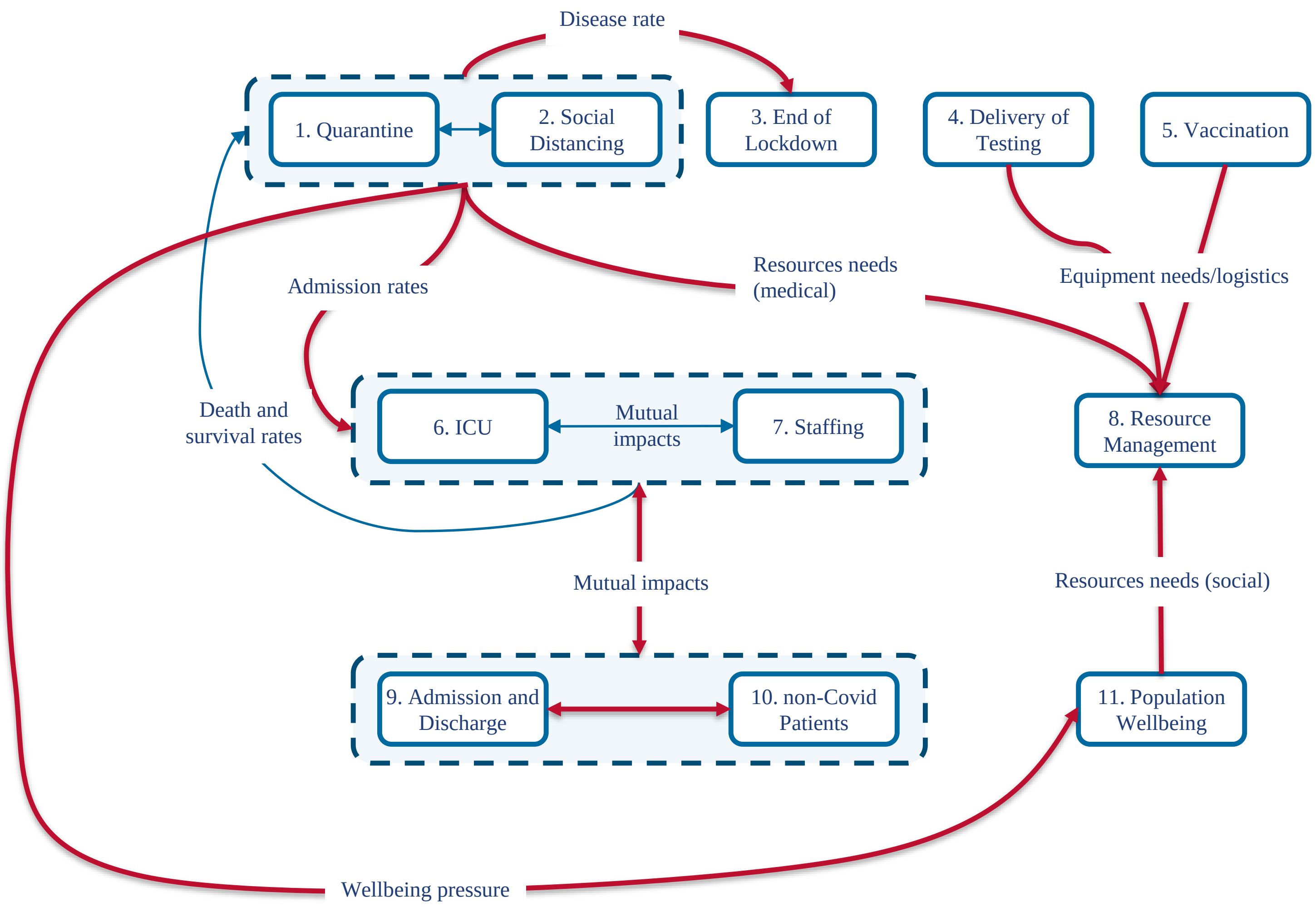
Variable Exchange Table 1

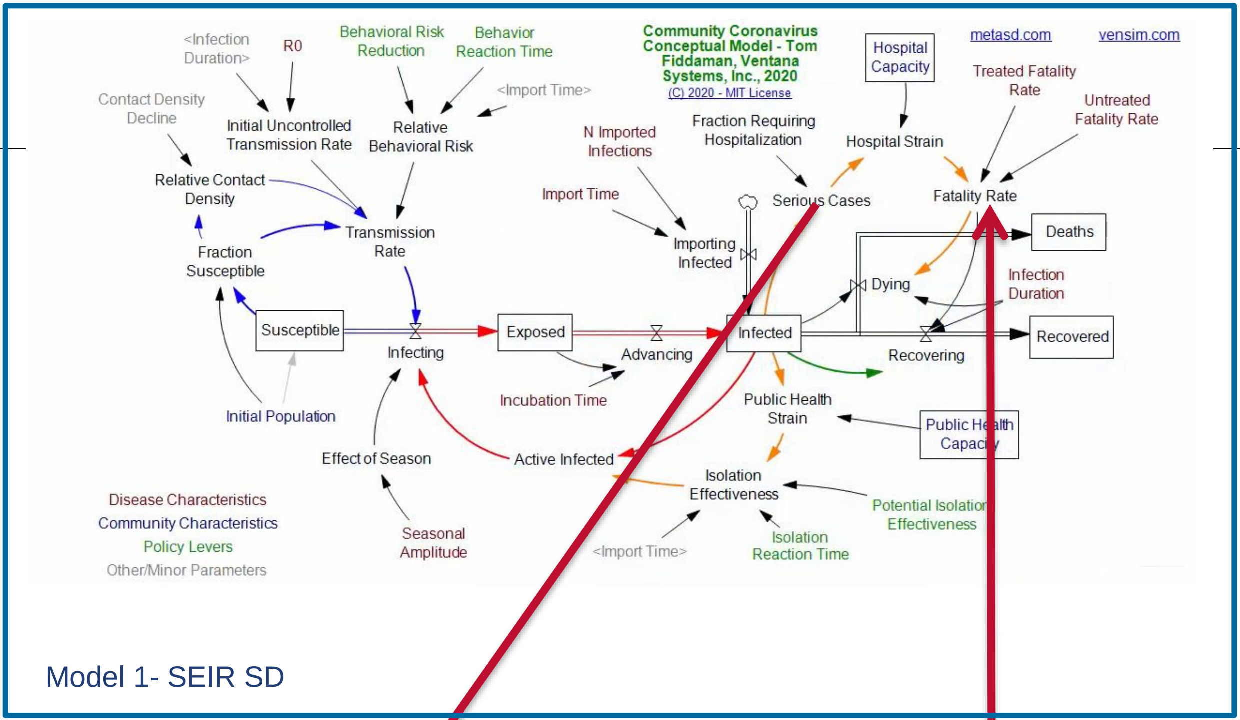
Decision	Suggested Modeling Methods	Receives variables from:	Sends variables to:	Model(s) available online
1. Quarantine Strategies, Case Isolation, and Contact Tracking	SD for population-level models; ABM for models that capture individual behavior.	Decision 6 (Hospital death and survival rates).	Decision 3 (Disease progression rates). Decision 8 (Demand levels for food and PPE resources and People buying rates). Decisions 6/7 (ICU arrival rates). Decision 11 (rates of people in isolation and shielding).	Behavioral Infectious Disease Simulator (Struben 2020); The COVID-19 Simulator (isee systems 2020); COVID-19 Outbreak and Policies (Castillo 2020a).
2. Social Distancing Measures	SD for population-level models; ABM for models that capture individual behavior; DES or HS for operational models	Decision 6 (Hospital death and survival rates).	Decision 3 (Disease progression rates). Decision 8 (Demand levels for food and PPE resources and People buying rates). Decisions 6/7 (ICU arrival rates). Decision 11 (rates of people in lockdown).	Behavioral Infectious Disease Simulator (Struben 2020); The COVID-19 Simulator (isee systems 2020); COVID-19 with social distancing (Castillo 2020b).
3. How to Manage the End of Lock Down	SD for population-level models; ABM for models that capture individual behavior.	Decisions 1/2 (Disease progression rates).	Decisions 1/2 (update disease progression to assess impact).	A Community Coronavirus Model for Bozeman (Fiddaman 2020)
4. Delivery of and Targeting of Testing	SD for population-level models; ABM for models that capture individual behavior; DES for delivery of testing.		Decision 8 (Demand levels test equipment and logistics).	Behavioral Infectious Disease Simulator (Struben 2020); The COVID-19 Simulator (isee systems 2020).

Variable Exchange Table 2

Decision	Suggested Modeling Methods	Receives variables from:	Sends variables to:	Model(s) available online
5. Delivery of and Targeting of Vaccination	SD for population-level models; ABM for models that capture individual behavior; DES for delivery of vaccination.		Decision 8 (Demand levels vaccination equipment and logistics).	Behavioral Infectious Disease Simulator (Struben 2020); The COVID-19 Simulator (isee systems 2020).
6. Capacity of Inpatient Hospital Beds and Critical Care	DES or SD for models of resource requirements; HS combining DES models of hospital operations and SD model describing the progression of the epidemic.	Decisions 1/2 (ICU arrival rates). Decisions 9/10 (Admission and Discharge rates for COVID and non-COVID patients).	Decisions 1/2 (Hospital death and survival rates). Decisions 9/10 (ICU beds and resources based scenarios to feed into experimentation design).	COVID-19 ICU Preparation Simulation (Stephenson 2020).
7. Staffing	DES models of hospital operations; SD models to represent workforce availability at a national level.	Decisions 1/2 (ICU arrival rates). Decisions 9/10 (Admission and Discharge rates for COVID and non-COVID patients).	Decisions 9/10 (Workload based scenarios to feed into experimentation design).	COVID-19 ICU Preparation Simulation (Stephenson 2020).
8. Management of Resources within a Region	SD or DES models of logistics and supply chains; ABM for behavioral models of individuals.	Decisions 1/2 (Demand levels for food and PPE resources and People buying rates) Decision 4 (Demand levels test equipment and logistics). Decision 5 (Demand levels vaccination equipment and logistics). Decision 11 (Demand levels for social care).		

Hybrid Simulation Pragmatic Map




Community Coronavirus Conceptual Model - Tom Fiddaman, Ventana Systems, Inc., 2020
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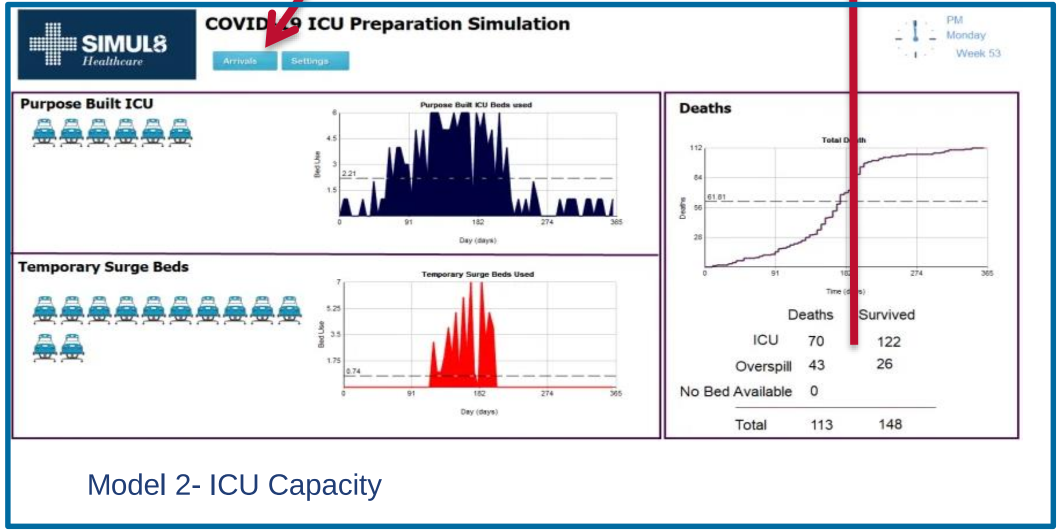
metasd.com
vensim.com
R0
Behavioral Risk Reduction
Behavior Reaction Time
Hospital Capacity
Treated Fatality Rate
Untreated Fatality Rate
Contact Density Decline
Initial Uncontrolled Transmission Rate
Relative Behavioral Risk
N Imported Infections
Fraction Requiring Hospitalization
Hospital Strain
Relative Contact Density
Import Time
Serious Cases
Fatality Rate
Deaths
Transmission Rate
Importing Infected
Fraction Susceptible
Dying
Infection Duration
Susceptible
Infecting
Exposed
Advancing
Infected
Recovering
Recovered
Incubation Time
Public Health Strain
Initial Population
Effect of Season
Active Infected
Isolation Effectiveness
Potential Isolation Effectiveness
Disease Characteristics
Community Characteristics
Policy Levers
Other/Minor Parameters
Seasonal Amplitude
Isolation Reaction Time
Model 1- SEIR SD


SIMUL8 Healthcare
COVID-19 ICU Preparation Simulation
Arrivals
Settings
PM
Monday
Week 53
Purpose Built ICU
Purpose Built ICU Beds used
Temporary Surge Beds
Temporary Surge Beds Used
Deaths
Total Death
Deaths
Survived
ICU
70
122
Overspill
43
26
No Bed Available
0
Total
113
148
Model 2- ICU Capacity

Summary

Systems are becoming more and more complex everyday.

The data tsunami is making the situation worse.

Solo simulation approaches are losing ground fast.

Hybrid simulation is the way forward.

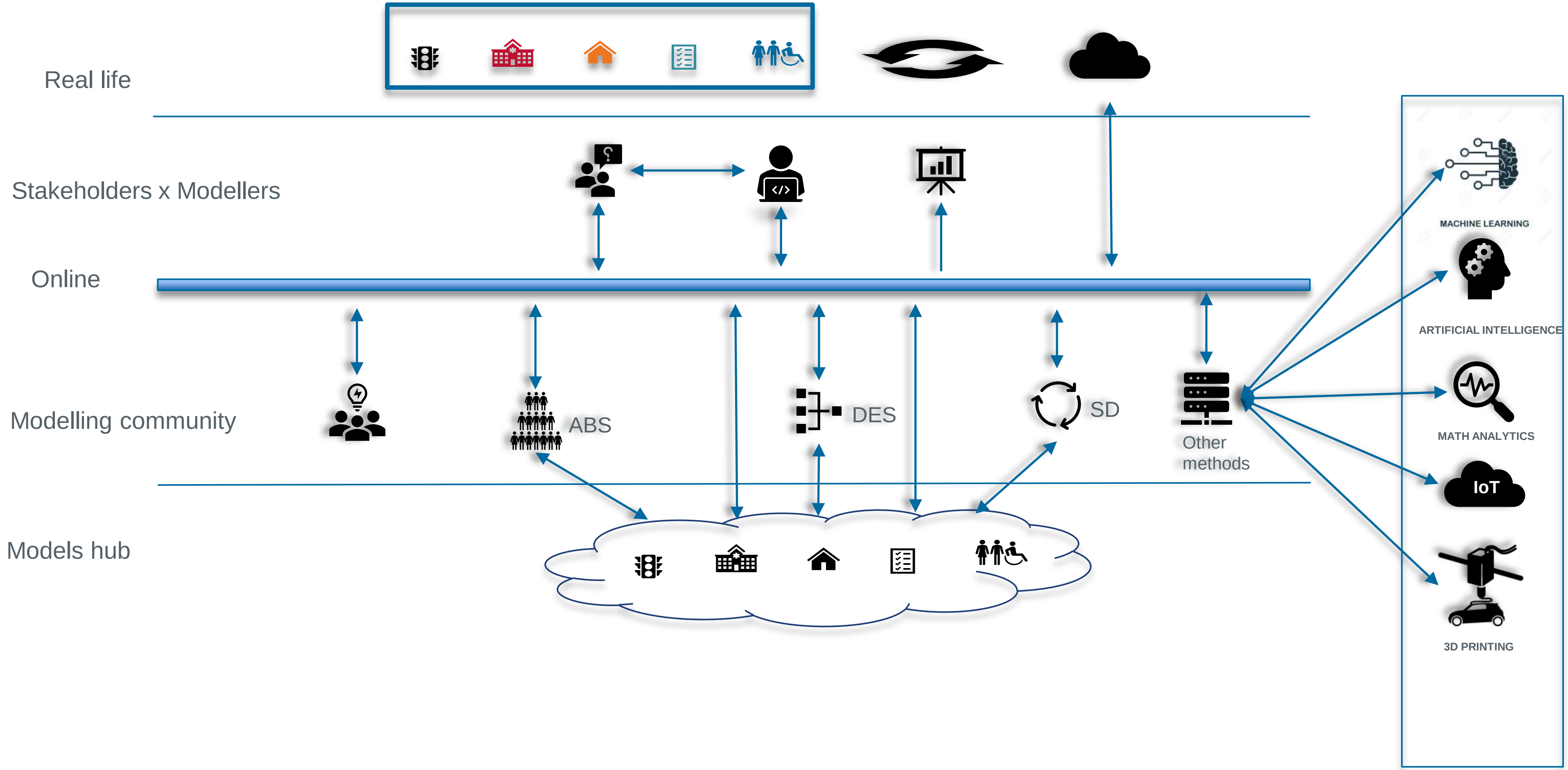
- But challenges need to be ironed out first.

Due to lack of eclectic experience, collaborative simulation is a viable alternative.

The technology is almost there to cater for developing a Simulation hub (Simulation 2.0).

- Open Rapid Hybrid Simulation.

Simulation 2.0 (Modelling hub)



and finally

Any questions or comments?

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