MAINFORMATICS

KNS 2021 Autumn meeting

Formalism Study for Agent-based modeling in Nuclear Evacuation Simulation

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01 Introduction

- Background
  - Disaster prevention
    - ✓ Structural measures : Visible structures. (Ex. radiation monitoring facilities, radioactive protective equipment.)
    - ✓ Non-structural measures : Invisible structures. (Ex. emergency planning zone(EPZ), evacuation time measurement.)
  - Society becomes more complex, non-structural measures are important.

01 Introduction

- Research Background
  - Defense-in-Depth
    - ✓ 5th level : off-site emergency preparedness/response → not only safety(science) but also relax(feeling).
    - ✓ Relaxation will follow itself if safety net is faithful.
  - Disaster response
    - ✓ IT industry : Plan to protect public safety by providing real-time situations in the disaster.[1]
    - ✓ Focusing on providing real-time information, does not deal with the distinctiveness of nuclear facilities.
  - Emergency preparedness/response due to an accident in nuclear facilities
    - ✓ Massive scale, long-term progress, specific impact on people and environment.

01 Introduction

- Research Background – nuclear emergency preparedness/response strategy
  - Radiological Environmental Report (RER)
    - ✓ Specific matters related to evacuate public or accident response are not mentioned.
  - Radiological emergency plan, level 3 PSA
    - ✓ Deterministic variable : source term, population distribution, exposure pathway, emergency-preparedness response.
    - ✓ Radiological Environmental Impact Assessment : not consider dynamic characteristics.
  - Purpose
    - ✓ Development of agent-based model for infrastructure elements involved in emergency-preparedness response.

02 Methods

- Problem definition
  - Purpose of the evacuation model
    - ✓ An evacuation model that considers infrastructure elements and expresses interaction
    - ✓ Expression of the agent-based model using formalism

- Problem definition
  - Agent-Based Model (ABM)
    - ✓ Computational model : explaining macroscopic phenomena through interaction with microscopic agents' actions.
    - ✓ Macroscopic phenomena : difficult to simply explain massive and complex system in terms of elements, formulas, structures.
  - Why ABM?
    - ✓ Model capability : real world's movements and results made by individual agent's action.
    - ✓ Realistic assumptions and intertwined relationships can be expressed by the model.
    - ✓ Sufficient data can be collected to construct the model due to open source data.

- Problem definition
  - Agent-Based Model (ABM) - agent
    - ✓ Concept similar to an object used in programming.
    - ✓ But, it is capable of judging and making decisions on their own, at least simple actions according to conditions.
  - Agent-Based Model (ABM) – behavioral rule
    - ✓ Processes and consequences : An agent affects another agent or environment, or vice versa.
  - Agent-Based Model (ABM) – environment
    - ✓ Space : agents' actions, interactions take place between agents.
    - ✓ Resources or restrictions : agents' decision-making and behavior.

02 Methods

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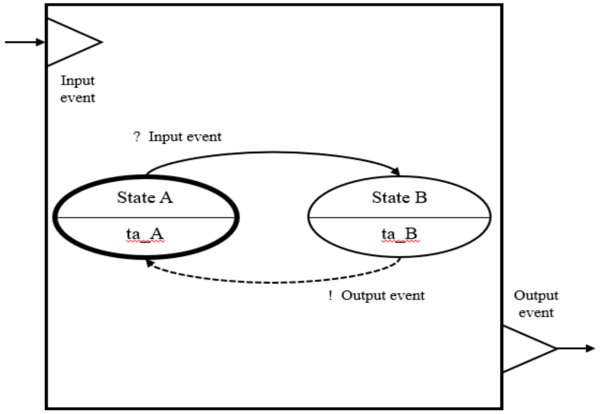
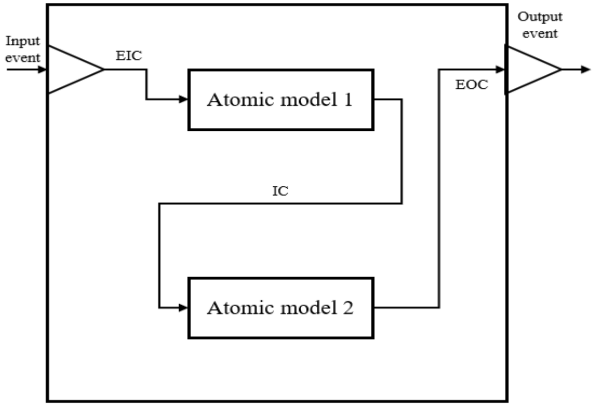
- Problem definition
  - Agent-Based Model (ABM)
    - ✓ Microscopic agents : agent who acts on his or her own and interacts with other agents.
    - ✓ Environment : an area where interaction takes place
    - ✓ Explaining agent's unique attributes and behavior
    - ✓ Modeling by micro-level evacuation.
    - ✓ (Disadvantage) Complex interactions between agents are difficult for users to fully understand.

- Problem definition
  - Formalism
    - ✓ Well-defined expression of the ABM. (Useful for explaining social system models)
    - ✓ Agent's methodical approach is possible.
    - ✓ Representative example : discrete event system specification (DEVS).



Atomic model



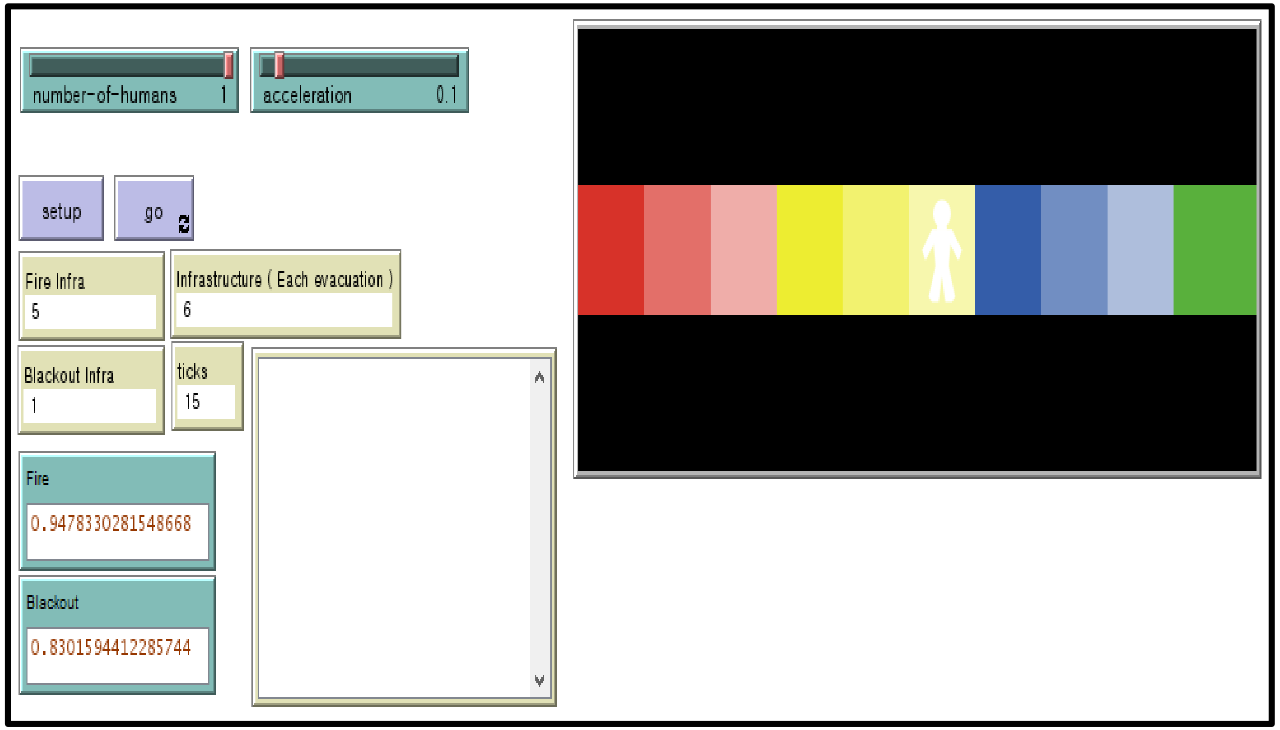
Coupled model

02 Methods

- Discrete Event System Specification (DEVS)
  - Computational basis[2]
    - ✓ Discrete event models, other basic systems formalism (Discrete time, differential equations.)
    - ✓ Implementing behaviors expression.
  - Statement of atomic model and coupled model.
    - ✓ Atomic model : internal interaction of each agent or environment.
    - ✓ Coupled model : interaction between agents, between environments, or between agents and environments.
  - Discrete system = (discrete state) + (event set).
  - Systematization & visualization : easy to understand between agents.

03 Case study

- Evacuation model
  - ✓ One evacuee
  - ✓ One dimensional space
  - ✓ 2 infrastructures (fire, blackout)
- Simulation condition
  - ✓ $Position = x_i \ (i = 1, \dots, 100)$
  - ✓ $\vec{v_i} = \frac{dx_i(t)}{dt}$
  - ✓ $T_{real} = 2 \times \sum_{i=1}^{100} (\frac{x_i}{v_0 + \vec{v_i}}) + I(t)$

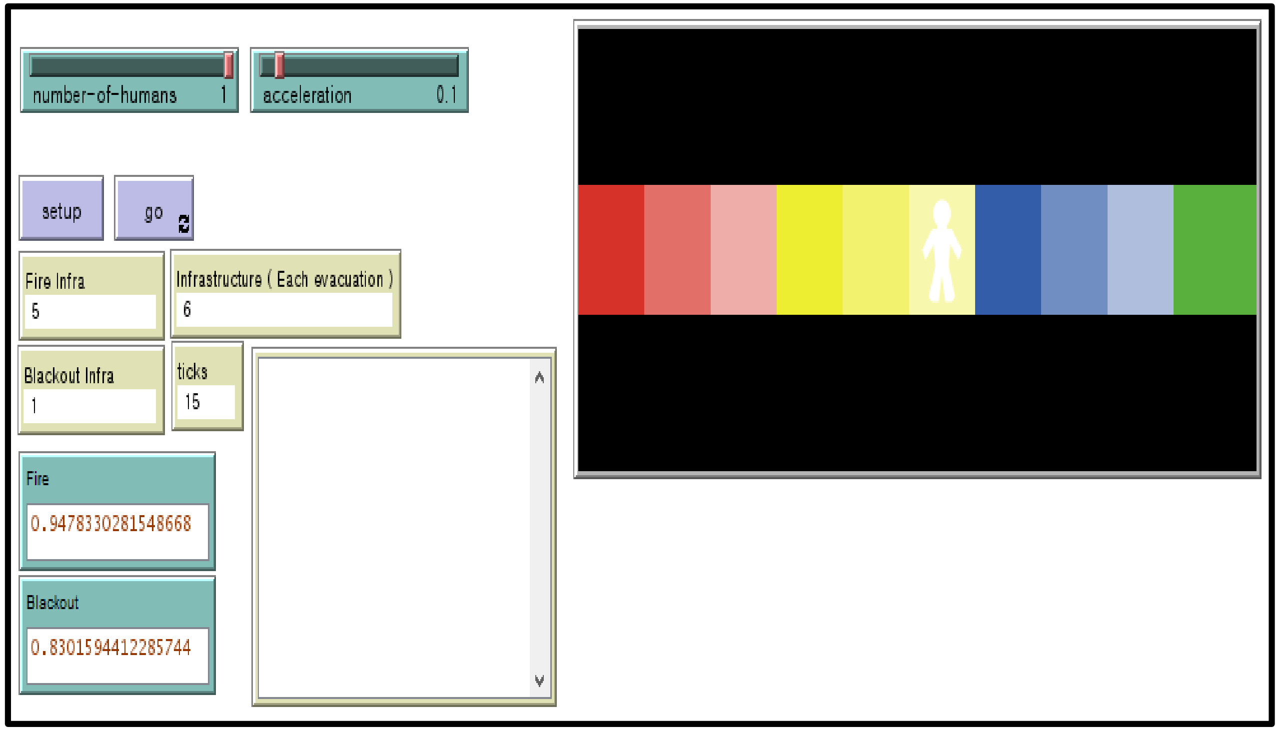


< Evacuation simulation model using 'Netlogo' ABM tool – including infrastructure >

03 Case study

- Simulation condition - infrastructure
  - ✓ $I_0 = 0 \quad , I(t) = I_0 + \sum T_{infra}$
  - ✓ $\sum T_{infra} = \sum (T_f + T_b)$

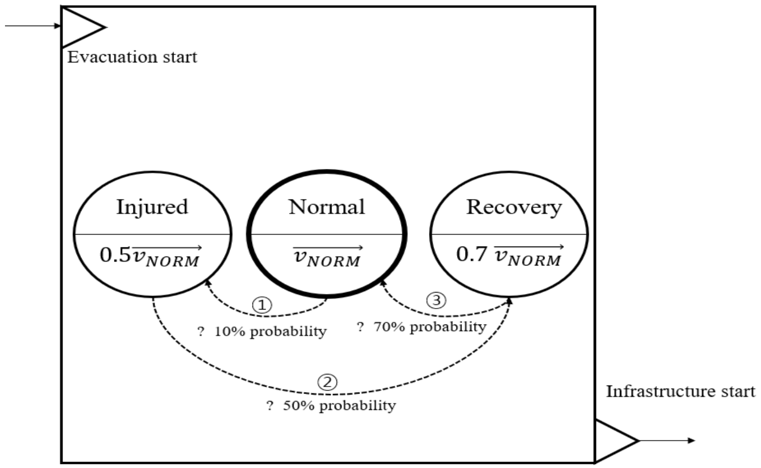
- T_f : time delay about fire infrastructure
- T_b : time delay about blackout infrastructure



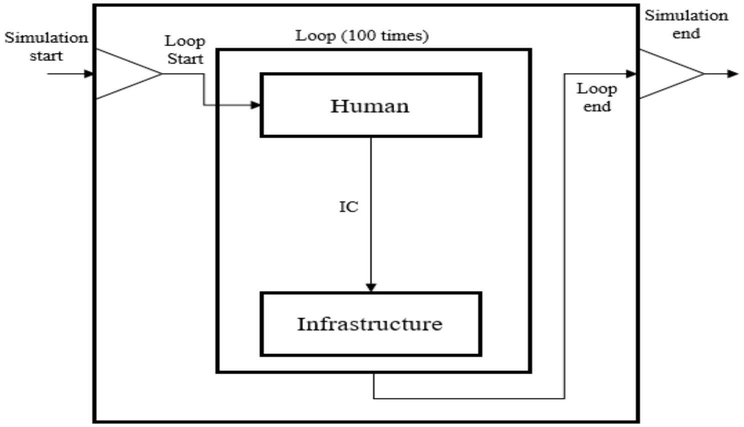
< Evacuation simulation model using 'Netlogo' ABM tool – including infrastructure >

03 Case study

- Formalism (DEVS) – Atomic model
  - ✓ Upper : state's name , Lower : time advance function value.
  - ✓ Dotted line : internal transition function
  - ✓ Solid line : external transition function
  - ✓ Bold outlined ellipse : initial state of the model
  - ✓ Question mark : triggering event of the transition
- Formalism (DEVS) – Coupled model
  - ✓ IC : internal coupling



< Atomic model >



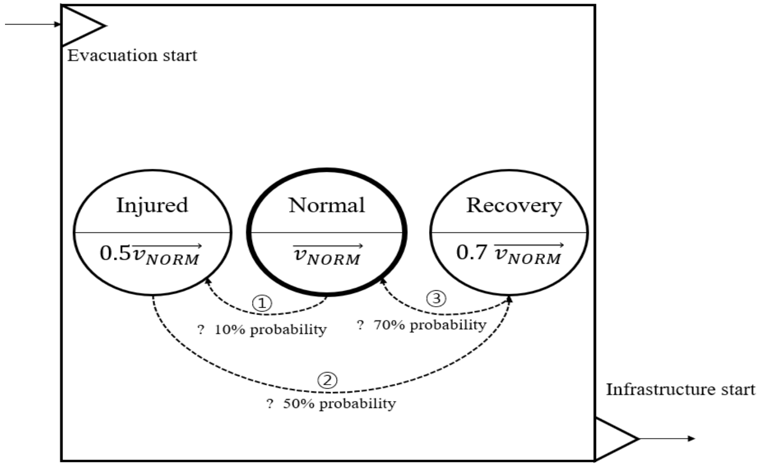
< Coupled model>

03 Case study

- Formulation

  ✓ $Evacuee = < X,\ Y,\ (S_1, S_2, S_3),\ \delta_{int} >$

  - ✓ X: a set of input events (evacuation start)
  - ✓ Y: a set of output events (infrastructure start)
  - ✓ S_n: a set of sequential states (S_1: normal, S_2: injured, S_3: recovery)
  - ✓ δ_{int}: an internal transition function (velocity)



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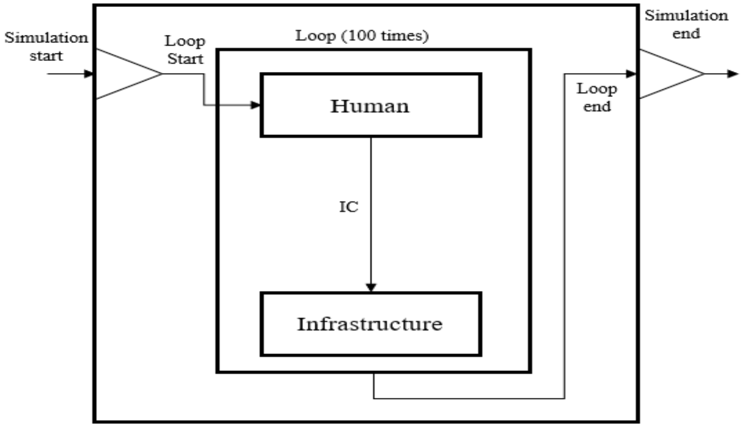


< Coupled model>

03 Case study

- Formulation

  ✓ $Infra = < Z,\ W,\ (Q_1, Q_2, Q_3),\ \delta_{int},\ \lambda >$

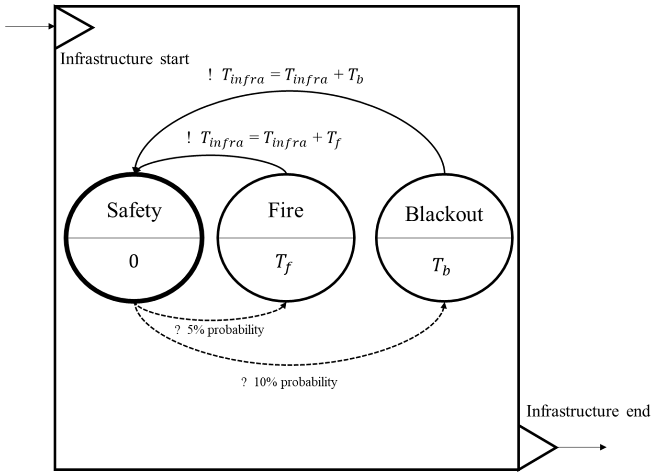
  ✓ Z: a set of input events (infrastructure start)

  ✓ W: a set of output events (infrastructure end)

  ✓ Q_n: a set of sequential states (Q_1: safety, Q_2: fire, Q_3: blackout)

  ✓ δ_{int}: an internal transition function (T_{Infra})

  ✓ λ : an output function (loop end)



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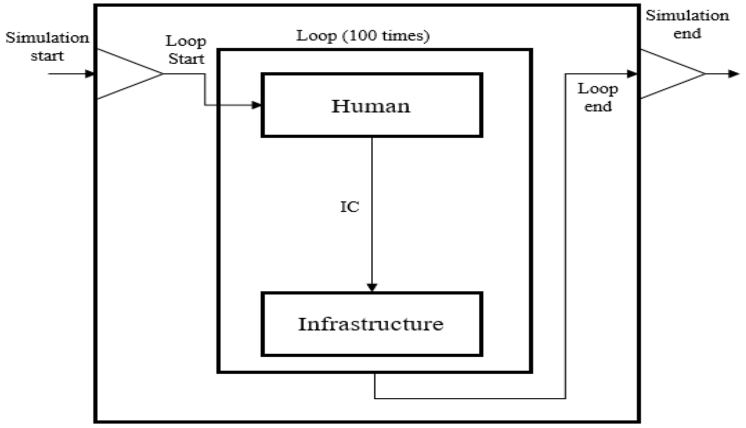
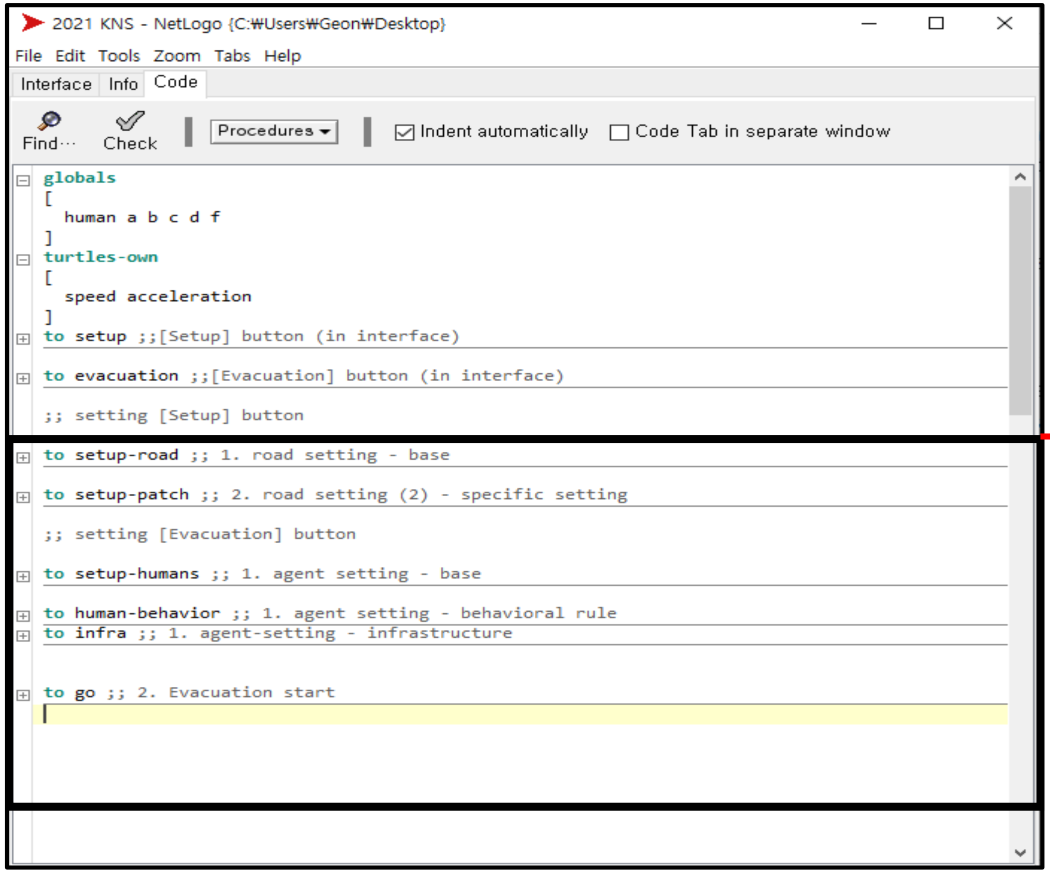
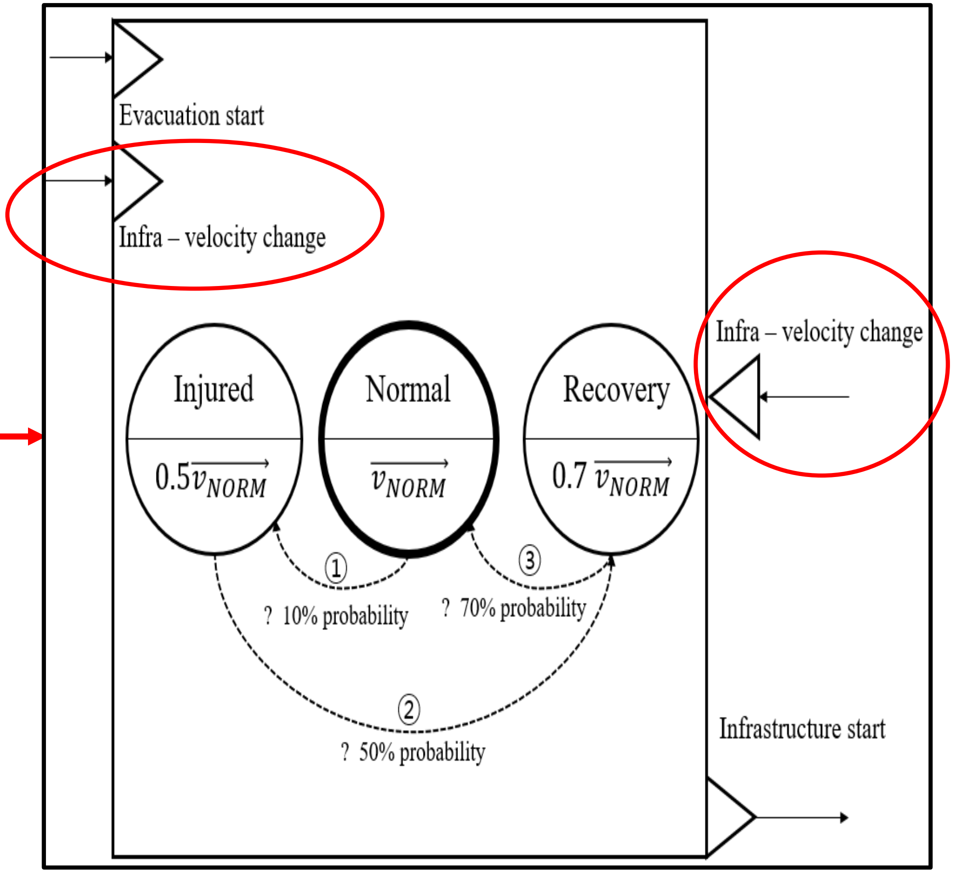


< Coupled model>

04 Conclusions & Discussions

- Future work





04 Conclusions & Discussions

- Conclusions
  - ✓ Agent-based model in evacuation situation was made.
  - ✓ Advantages(visualization and formulation) were performed by DEVS model.
  - ✓ Formalism will make it easier to obtain agents' states which are interacted each other.
- Discussions
  - ✓ More infrastructure should be established. (Reality)
  - ✓ Evacuation dimensions should be increased.
  - ✓ Validity of a set of rules must be verified.

Thank you

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