On Modeling and Simulation of the Networked Critical Infrastructure

Presented
by

Dr. WJ (Chris) Zhang

Professor and Director
Advanced Engineering Design Laboratory
Department of Mechanical Engineering
University of Saskatchewan
Email: wjz485@mail.usask.ca

Organization

Part I: Concept and Principle

(1) What are being modelled?

(2) Why are these modelled?

(3) How is the model developed?

Part II: A Case Study

(1) Feasibility of the work

(2) Application of the theoretical development

Part I

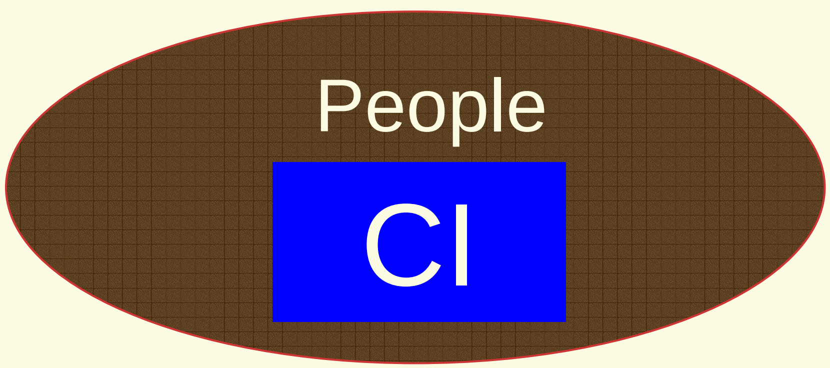
Concept &Principle

Part I

Model: What?

Model: What?

Critical infrastructure (CI):
The physical system which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of Canadians and /or the effective functioning of governments.

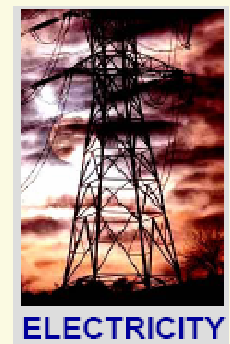


Model: What?

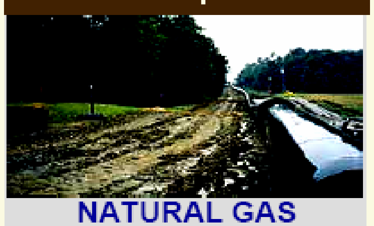
People

People

People

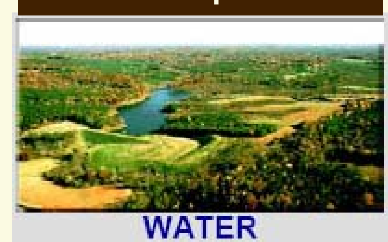


People



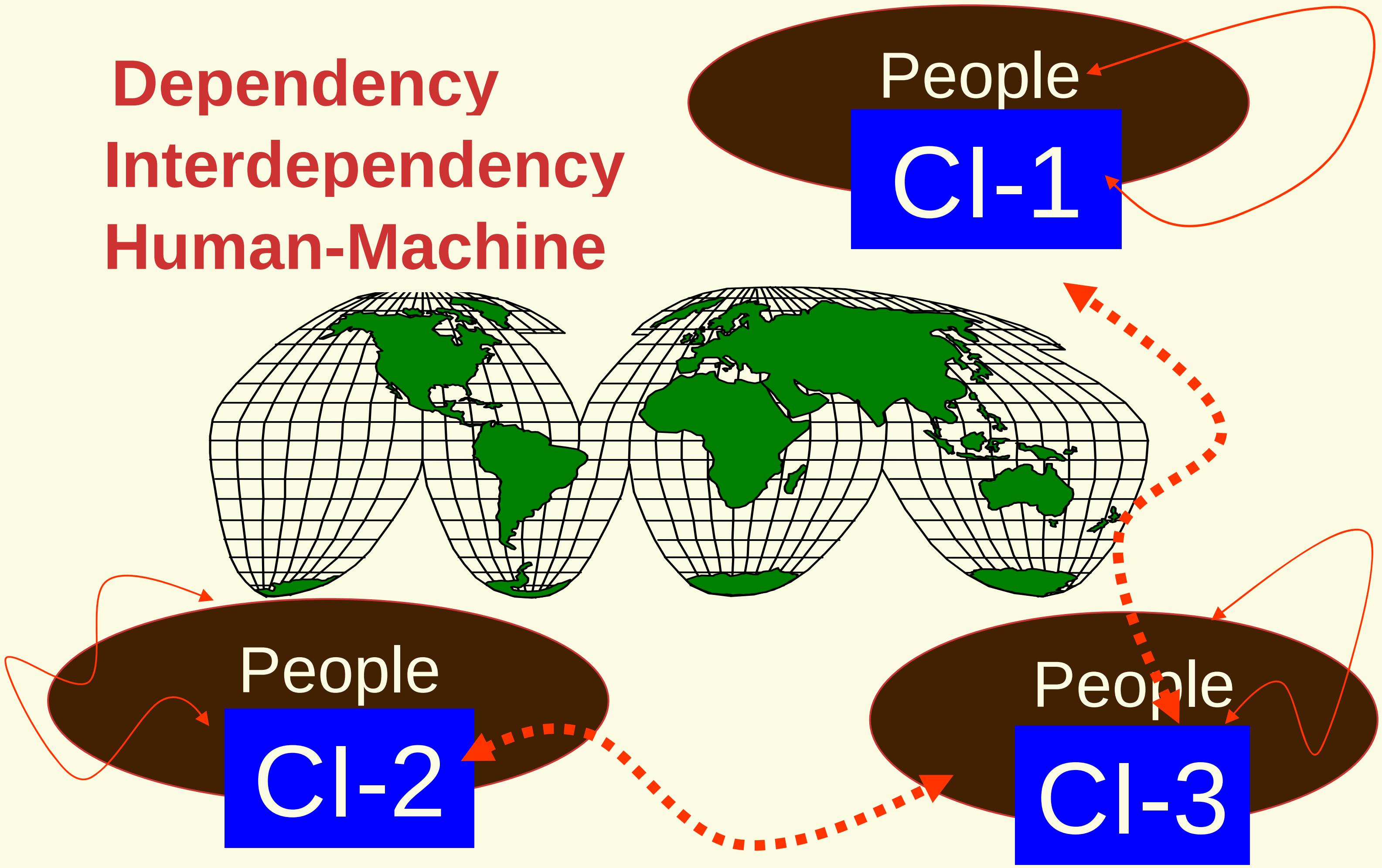
People

People

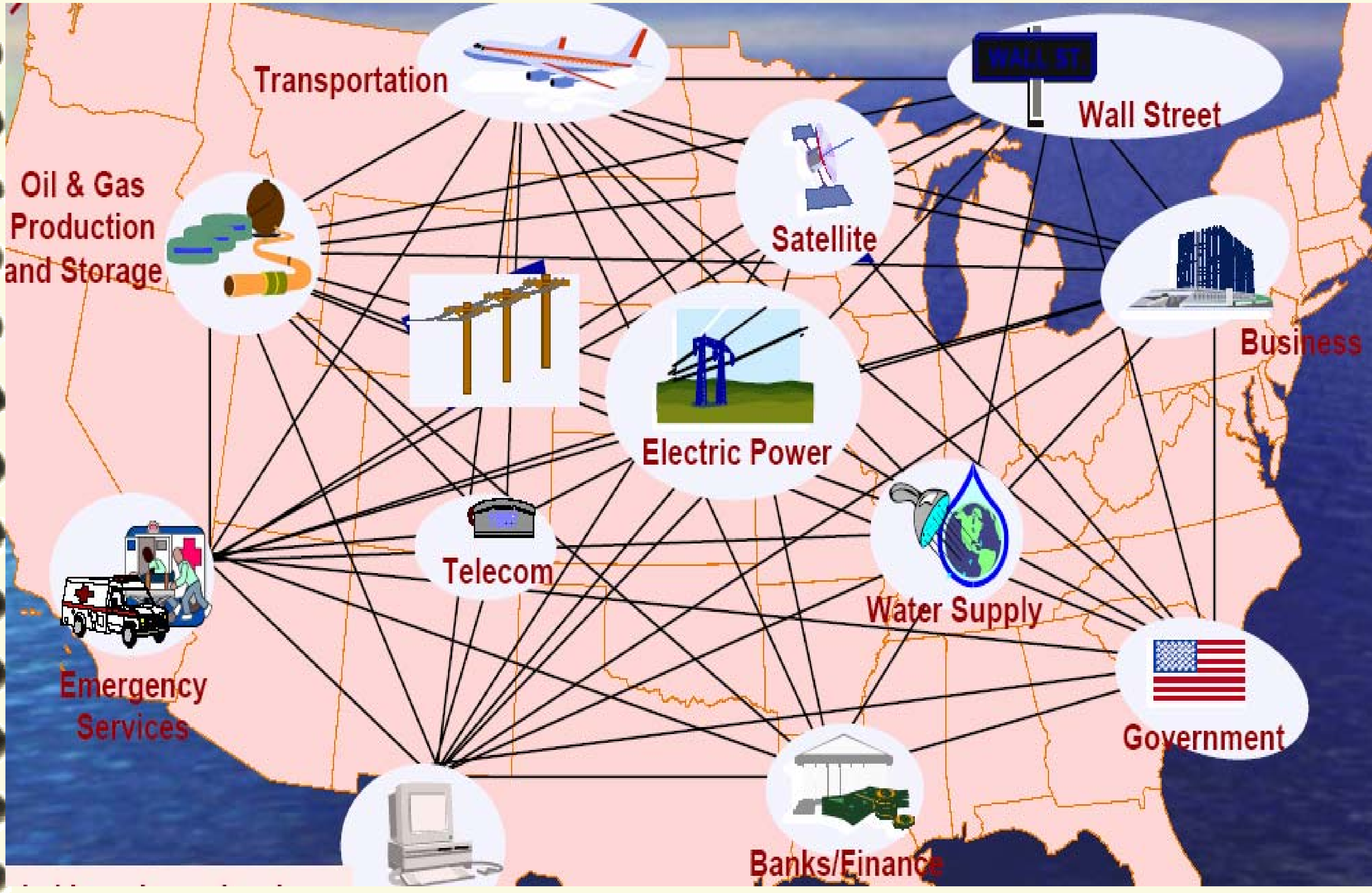


Model: What?

Dependency
Interdependency
Human-Machine

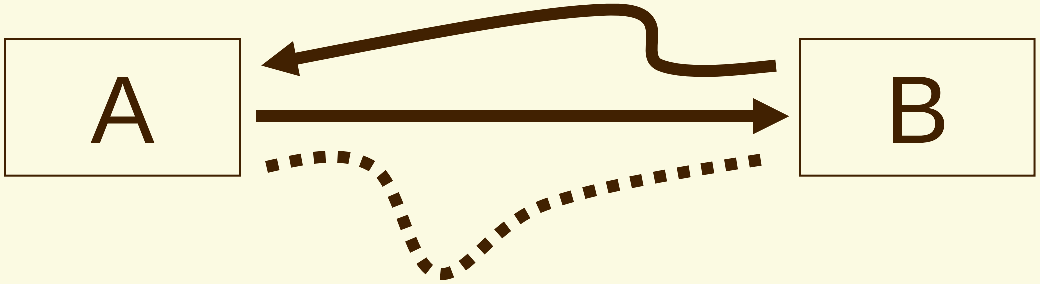


Example of Interdependency



Types of Interdependency

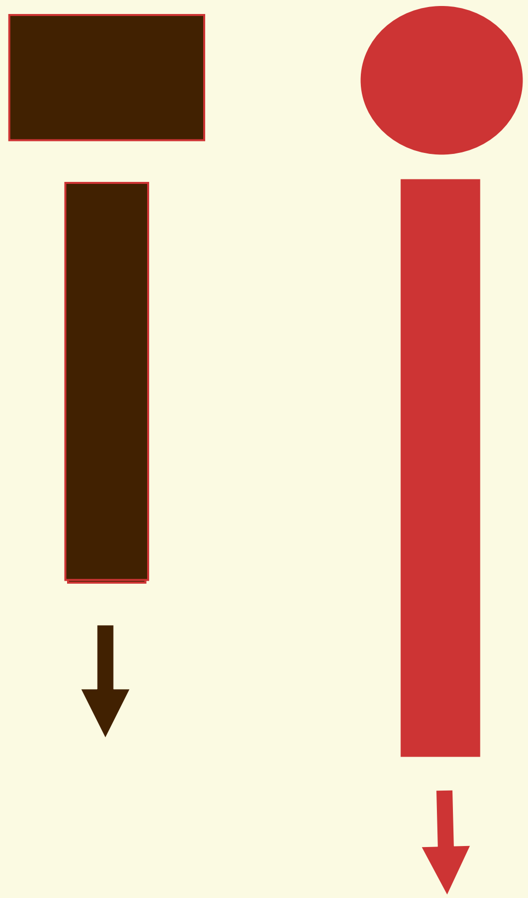
Entity: material, energy, people information & knowledge



Entity flow ⟶

No-flow Rel ▪▪▪▪▪

Process Dynamics



(1) Concurrent

(2) Asynchronous

(3) Distributed

(4) Parallel

(5) Stochastic

Part I

Model: Why?

Model: Why?

General Proposition I:

The networked CI system is a human-machine system. The prototyping approach useful to machine systems does not work here. The simulation is the only way to predict its behaviour, function or role, and performance.

Model: Why?

General Proposition II:

The networked CI system is a dynamic system. The dynamic simulation is needed, which significantly differs from the static simulation.

Model: Why?

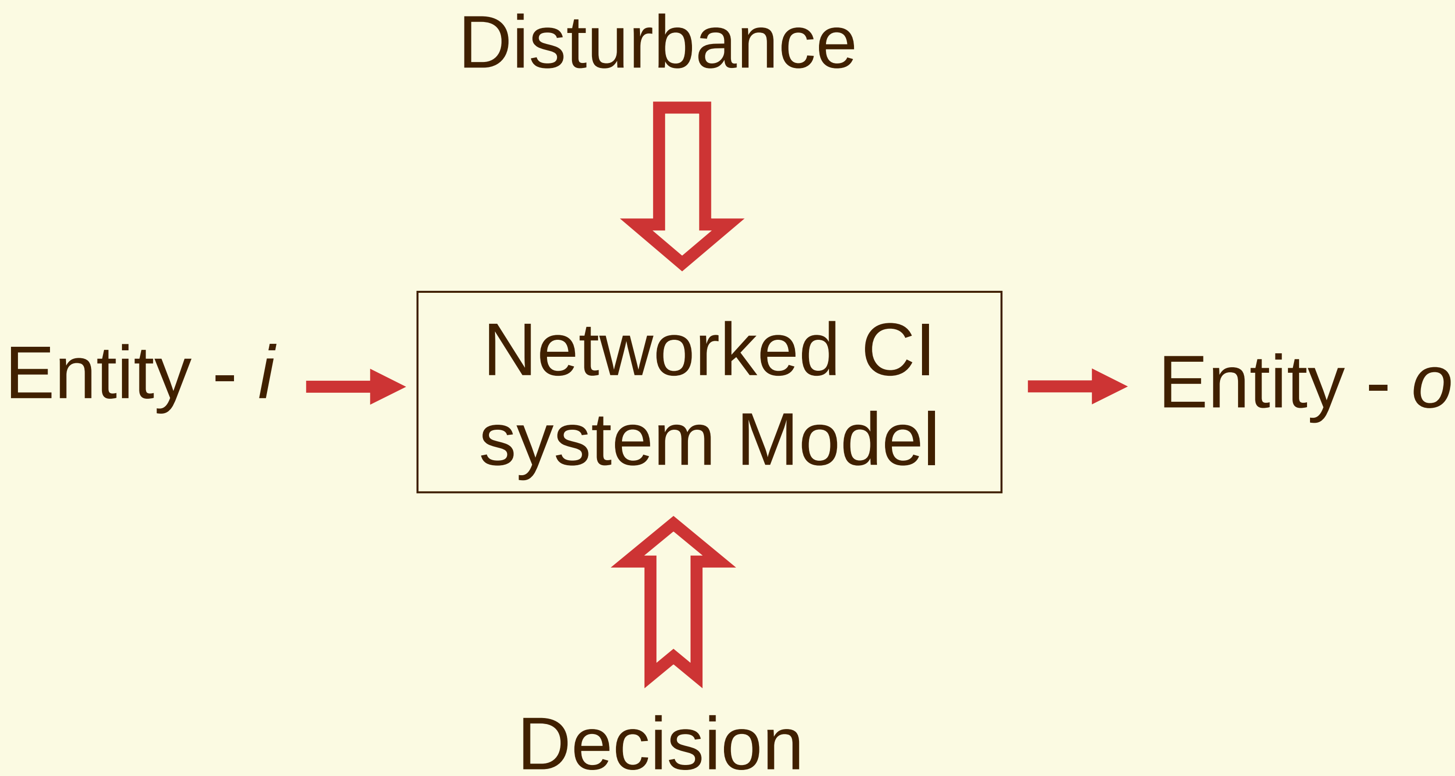
1. Identification of vulnerable areas

Basis:

Vulnerability means the area where a particular interdependence relation does not perform as desired when a networked CI system is in operation.

Model: Why?

1. Identification of vulnerable areas



Model: Why?

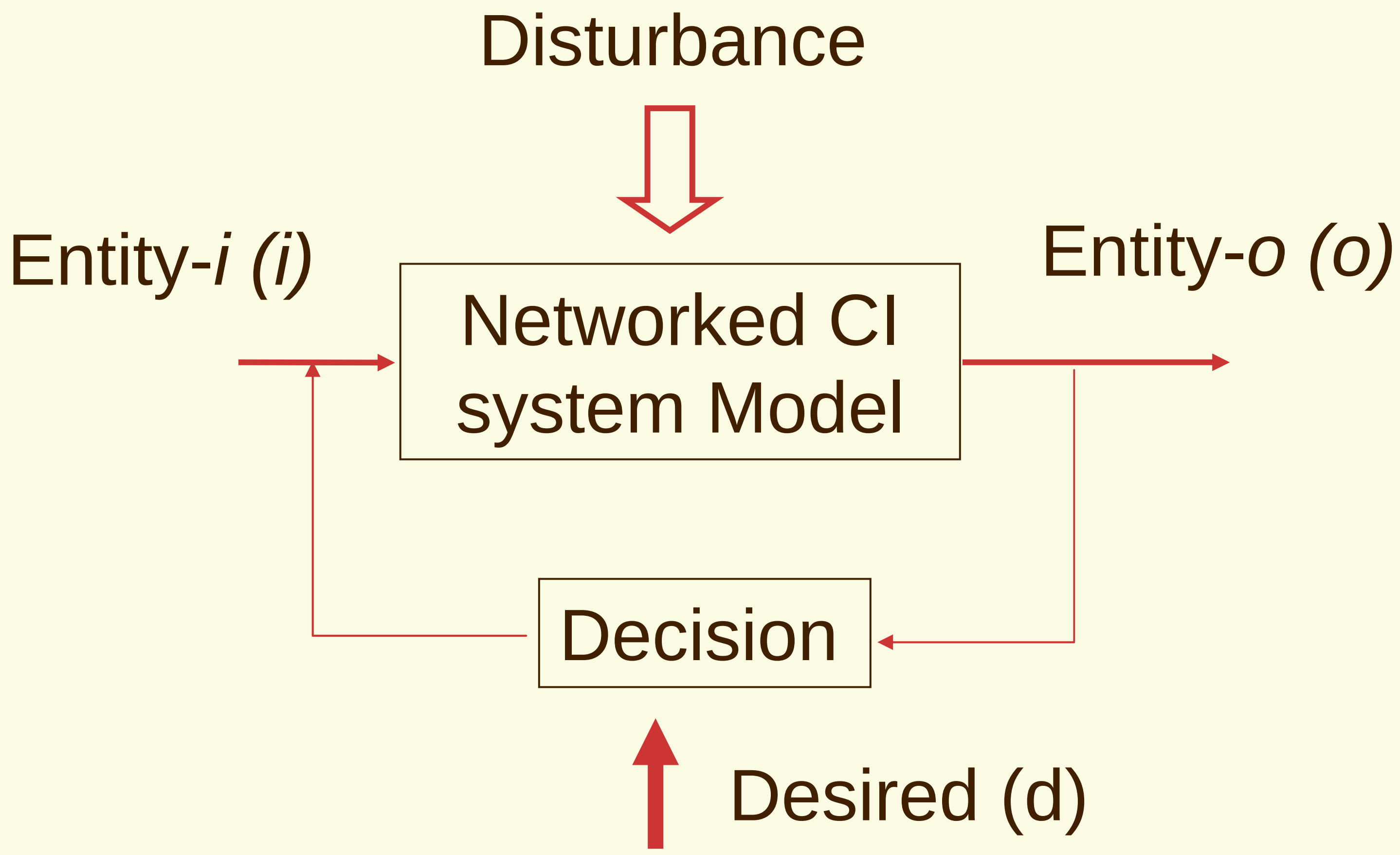
2. Validation of decisions

Basis:

Decisions apply to resource entities both in preparedness and response management.

The consequence of decisions is uncertain in terms of achieving a desired goal.

Model: Why?


Disturbance
Entity-*i* *(i)*
Networked CI system Model
Entity-*o* *(o)*
Decision
Desired (d)

Model: Why?

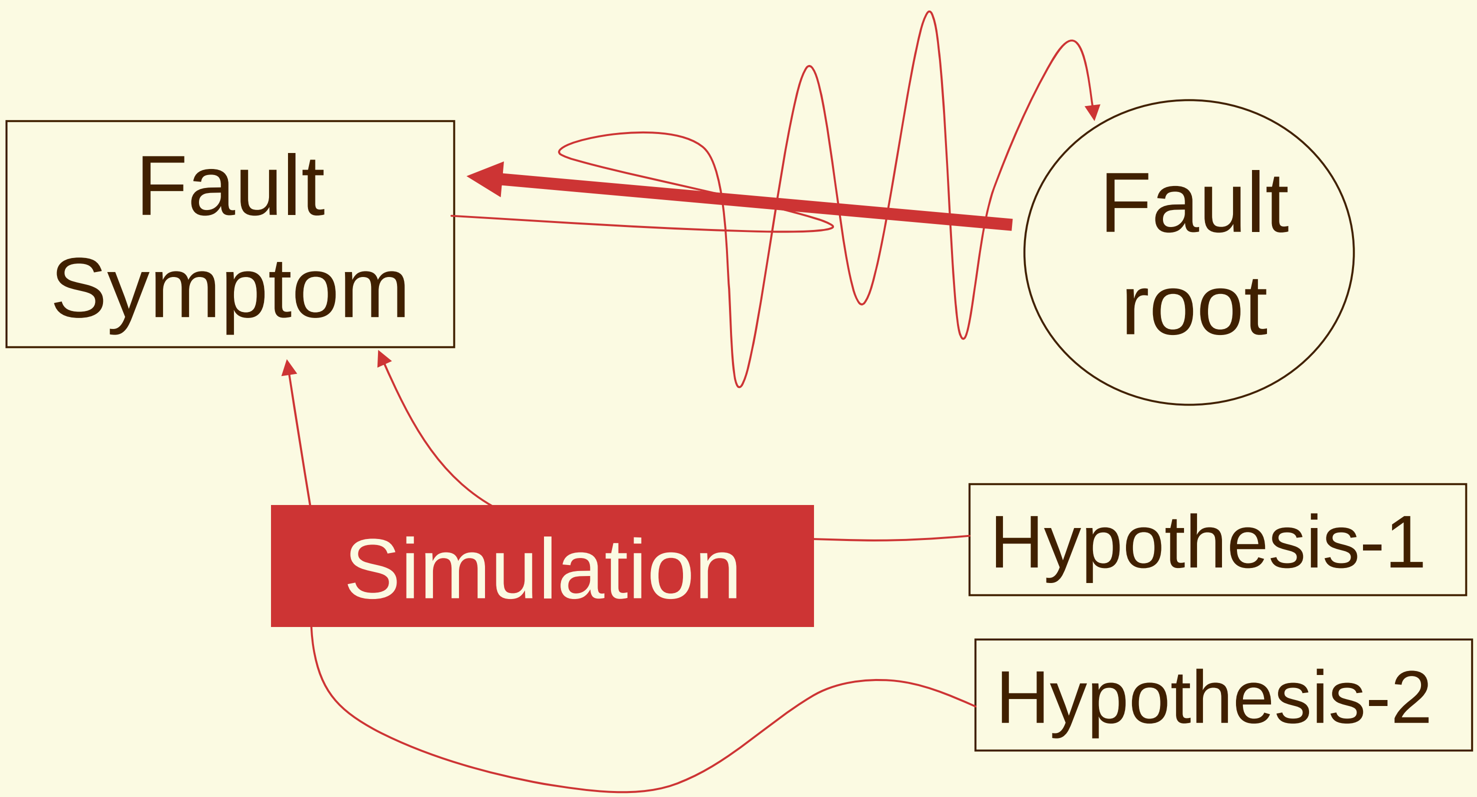
3. Support of enhancement

Basis:

Enhancement of a particular CI is dependent on a networked CI system of which that CI is a member.

Model: Why?

4. Support of fault diagnosis



Part I

Model: How?

Model: How?

Modeling tool selection

- Petri Net (PN)
- ATM
- Event tree
- Fault tree

Process

Concurrent
Asynchronous
Distributed
Parallel
Stochastic

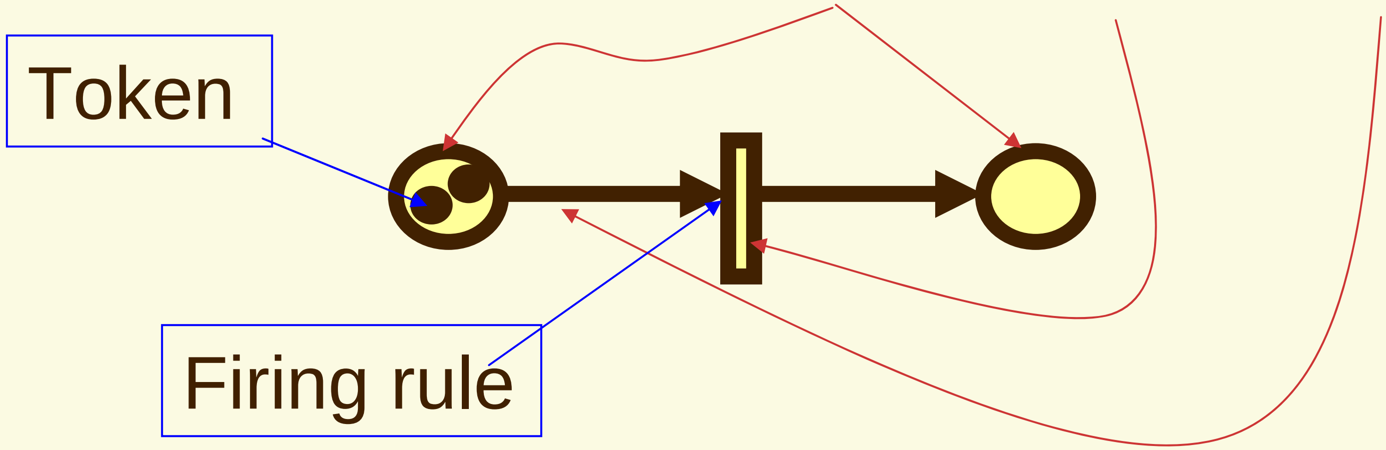
Model: How?

Petri Nets

1962: Carl Adam Petri's dissertation (University of Darmstadt, Germany)

Model: How?

Three basic notions: *place*, *transition, arc*:



Place: states of the system.

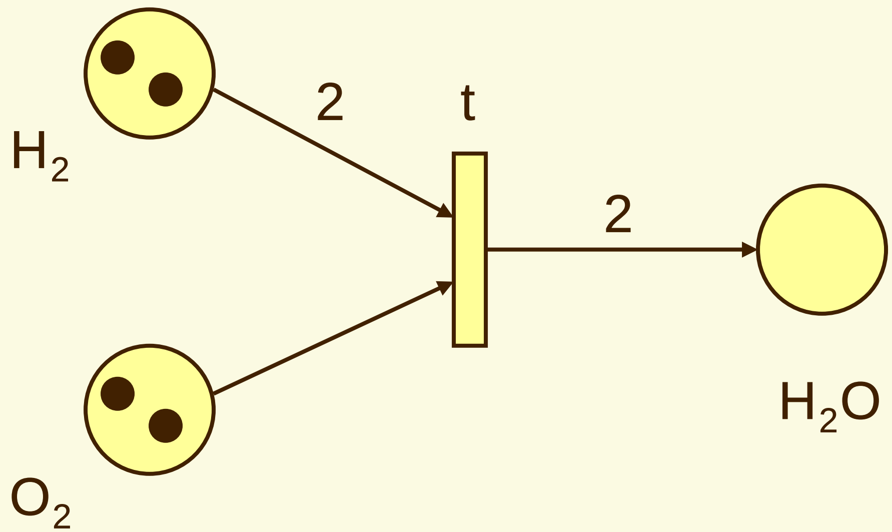
Transition: events causing the state change.

Arc: association of a place to a transition.

Model: How?

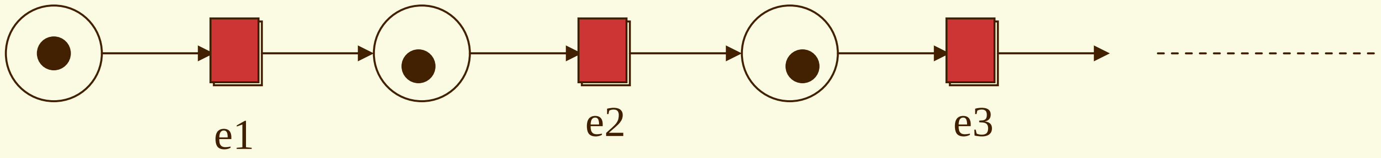
Example of firing

$$\boxed{2H_2 + O_2 \rightarrow 2H_2O}$$

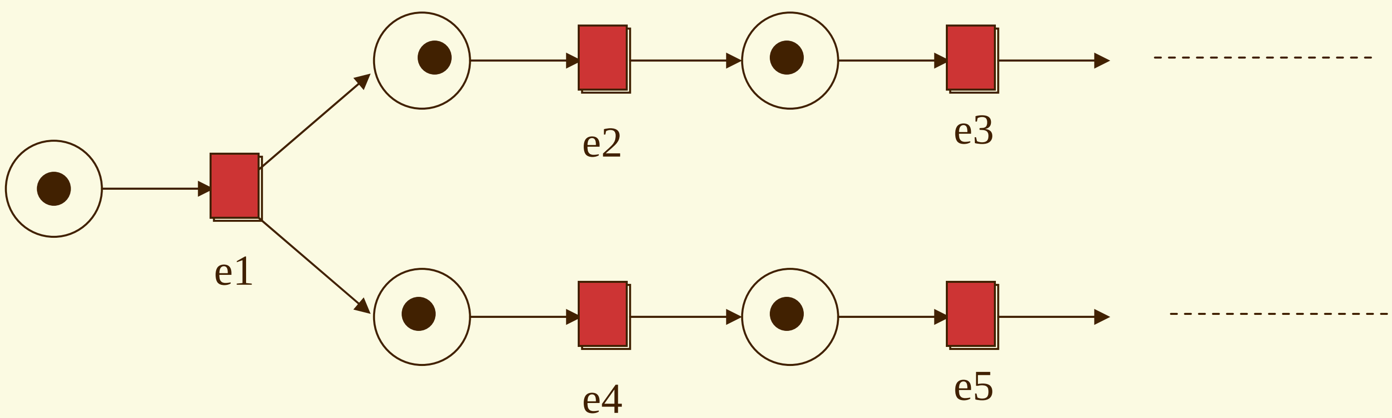


Model: How?

A sequence of events/actions:

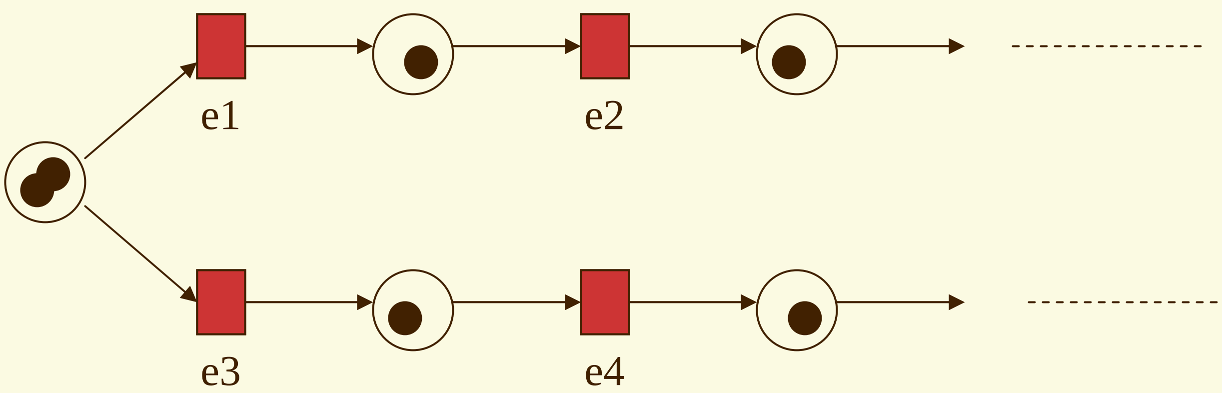


Concurrent executions:



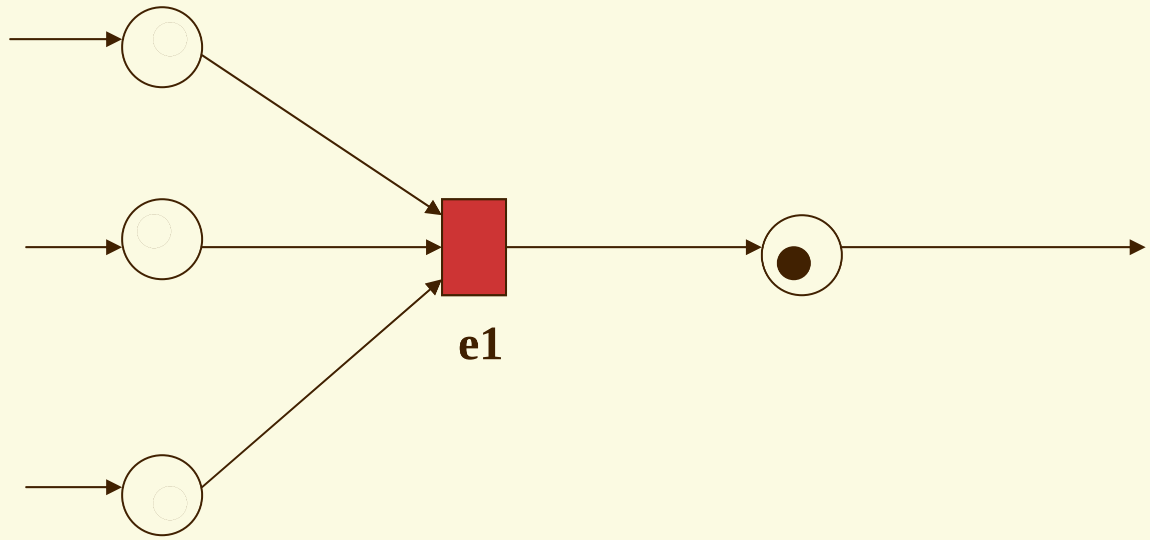
Model: How?

Non-deterministic events - conflict, choice, or decision: a choice of either e1, e2 … ,e3, or e4 ...



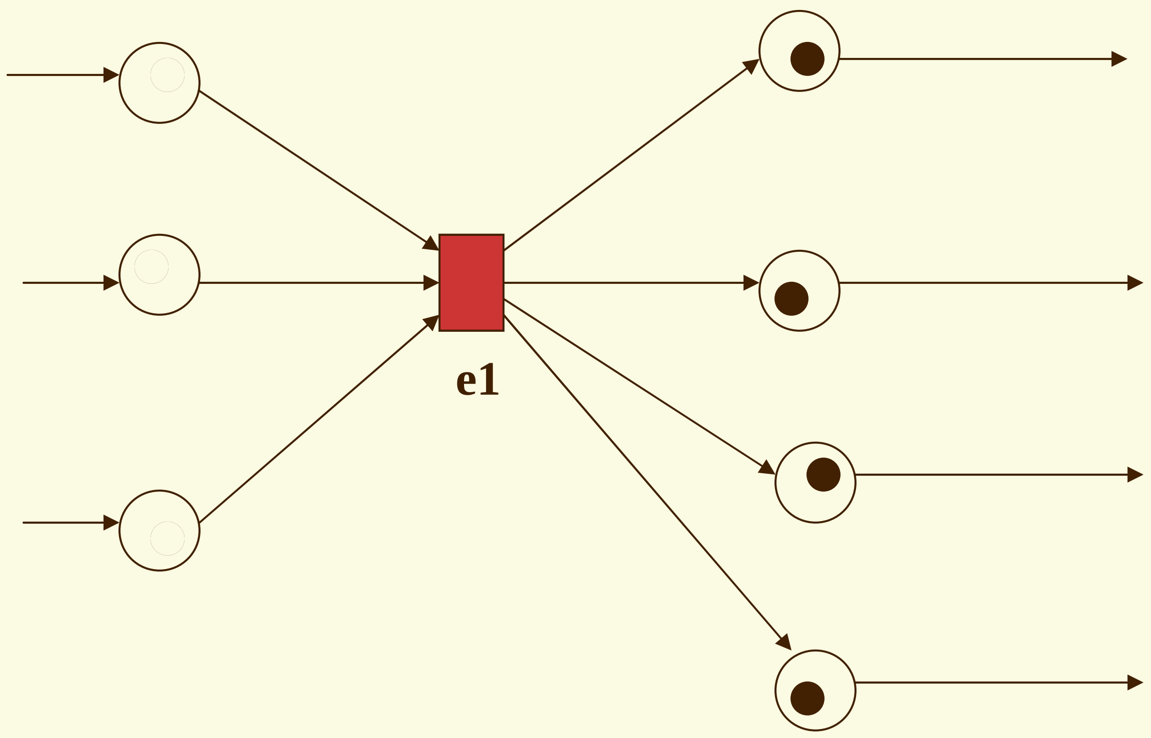
Model: How?

Synchronization



Model: How?

Synchronization and Concurrency



Model: How? Extended PN

High-level Petri net (Colored PN)

Tokens can have different types

Timed Petri Nets

(1) Time delays associated with transitions and/or places.

(2) Fixed delays or interval delays.

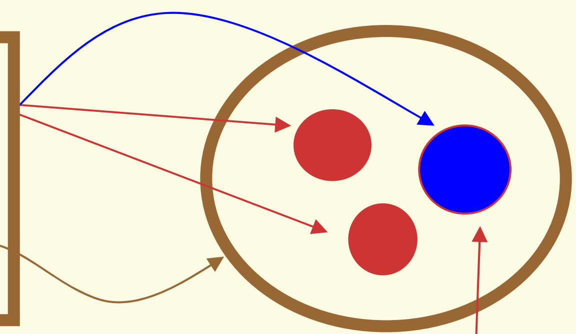
(3) Exponentially distributed random variables as delays (Stochastic Petri nets)

Model: How? Extended PN

Extend the token to composite objects

Instances of a class

Class



Agent

Object-oriented PNs

Agent-oriented PNs

Model: How? PN-CI

Petri nets (PNs)		Networked CI
Place	—	Hospital
Transition	—	Entity move
Arc	—	Relationship
Token	—	People
Firing	—	Actuating

Part II

A Case Study

Problem

Three CIs:

Petro-Process Plant, Transportation, Hospital

Accident and Response Description:

(1) Plant gets an accident; the toxic gas leaks to the surrounding community (victim people);

(2) The victim is transported through the transportation system to the hospital;

Problem

Description of the networked CI system:

(1) There are three hospitals in the town;

(2) Each CI has a limited capacity;

(3) Each CI has a limited resource;

(4) Each CI produces or serves something;

(5) Assume that the hospitals perform under 80% of their capacity;

Problem

(6) Each hospital can increase its capacity by 10% in one hour;

(7) The service time in hospital is within [-2,2] time units;

(8) The patients are divided into three levels: emergency, important, and normal;

(9) The patients arrive at the hospitals at random, varying in the range of [0,2].

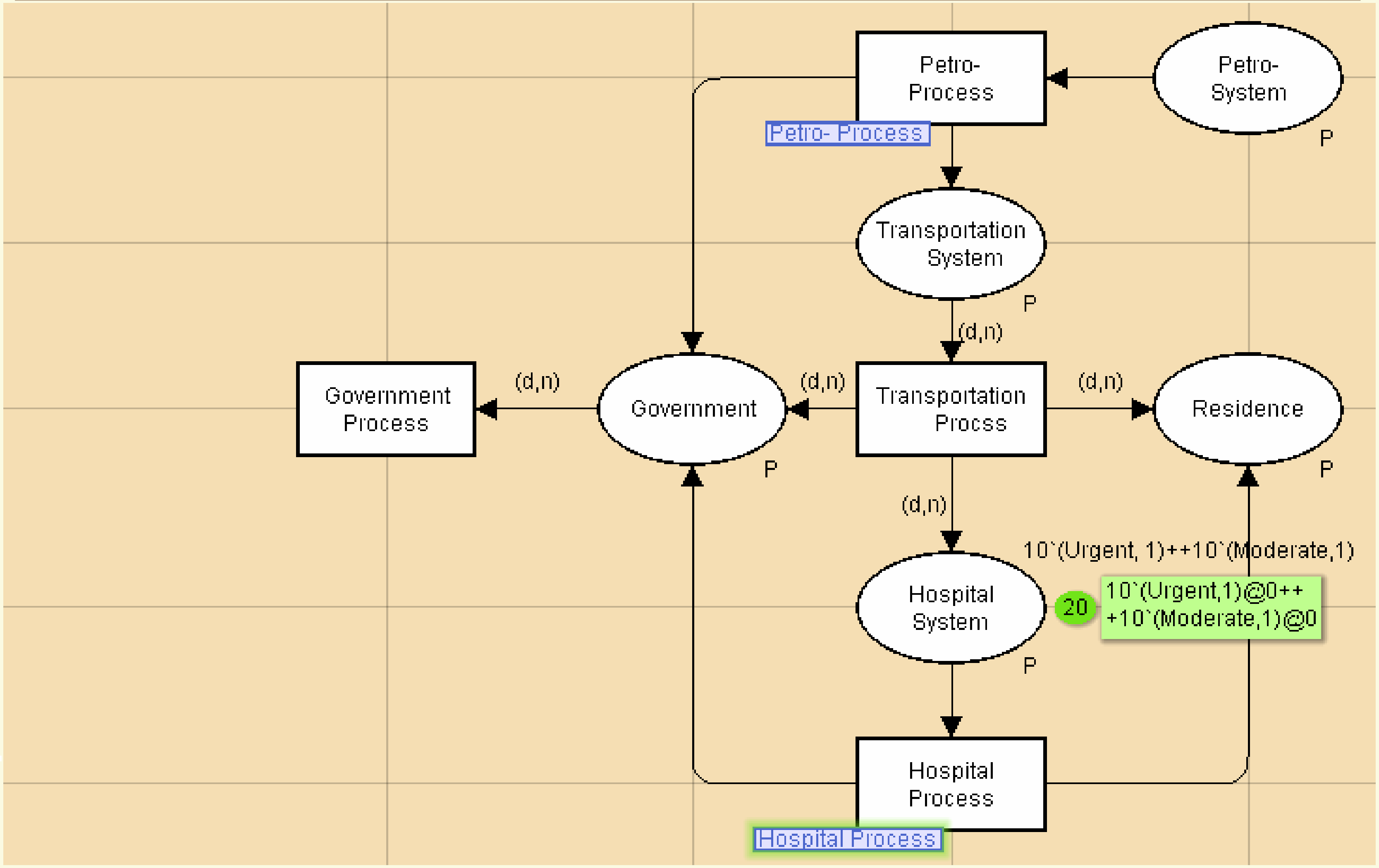
Objective

We simulate the process of the hospital in its service in this case study; in particular we examine whether the capacity of the hospital is reached at a specific time.

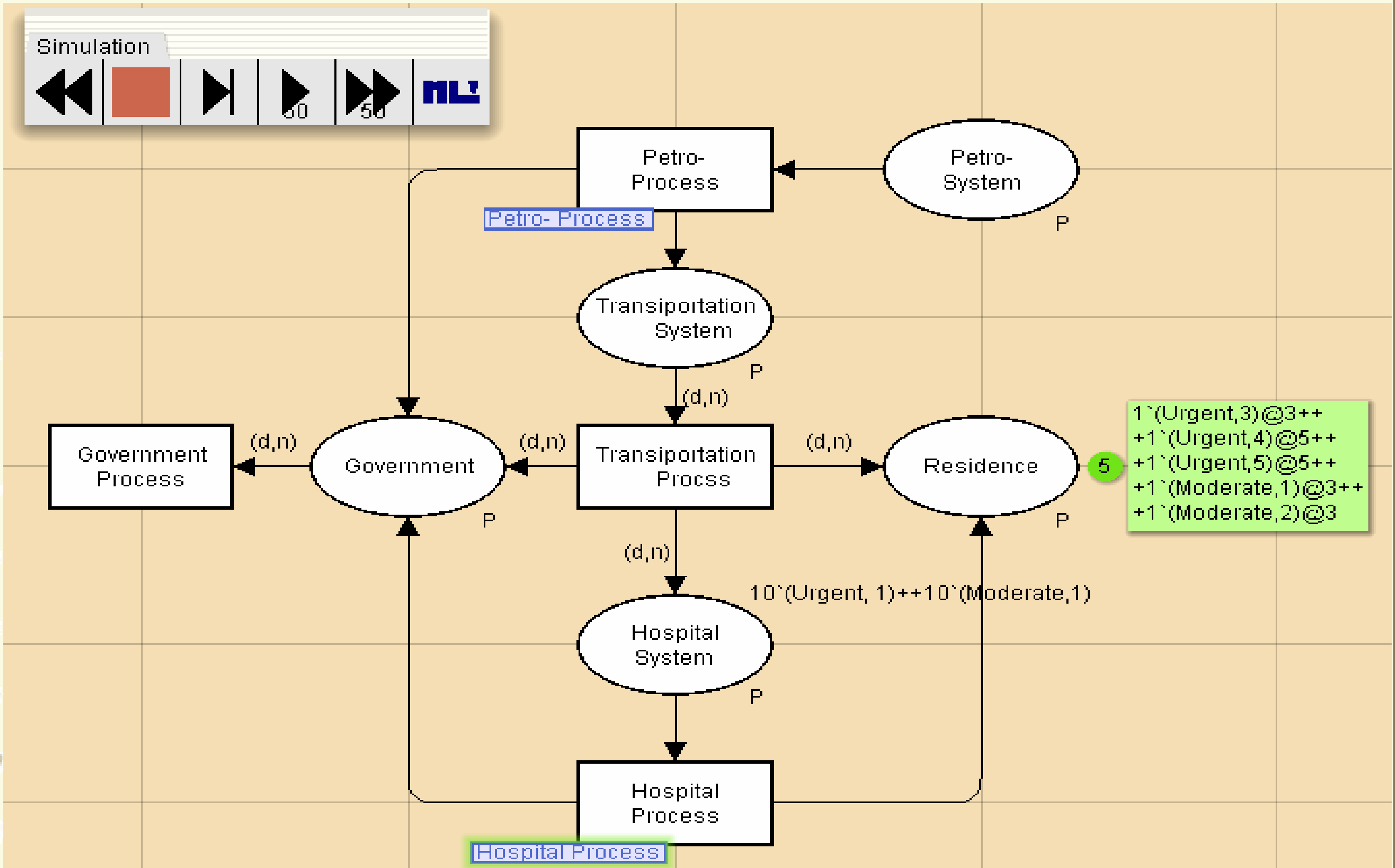
Yellow warning: work load > basic capacity

Red warning: work load > maximum capacity

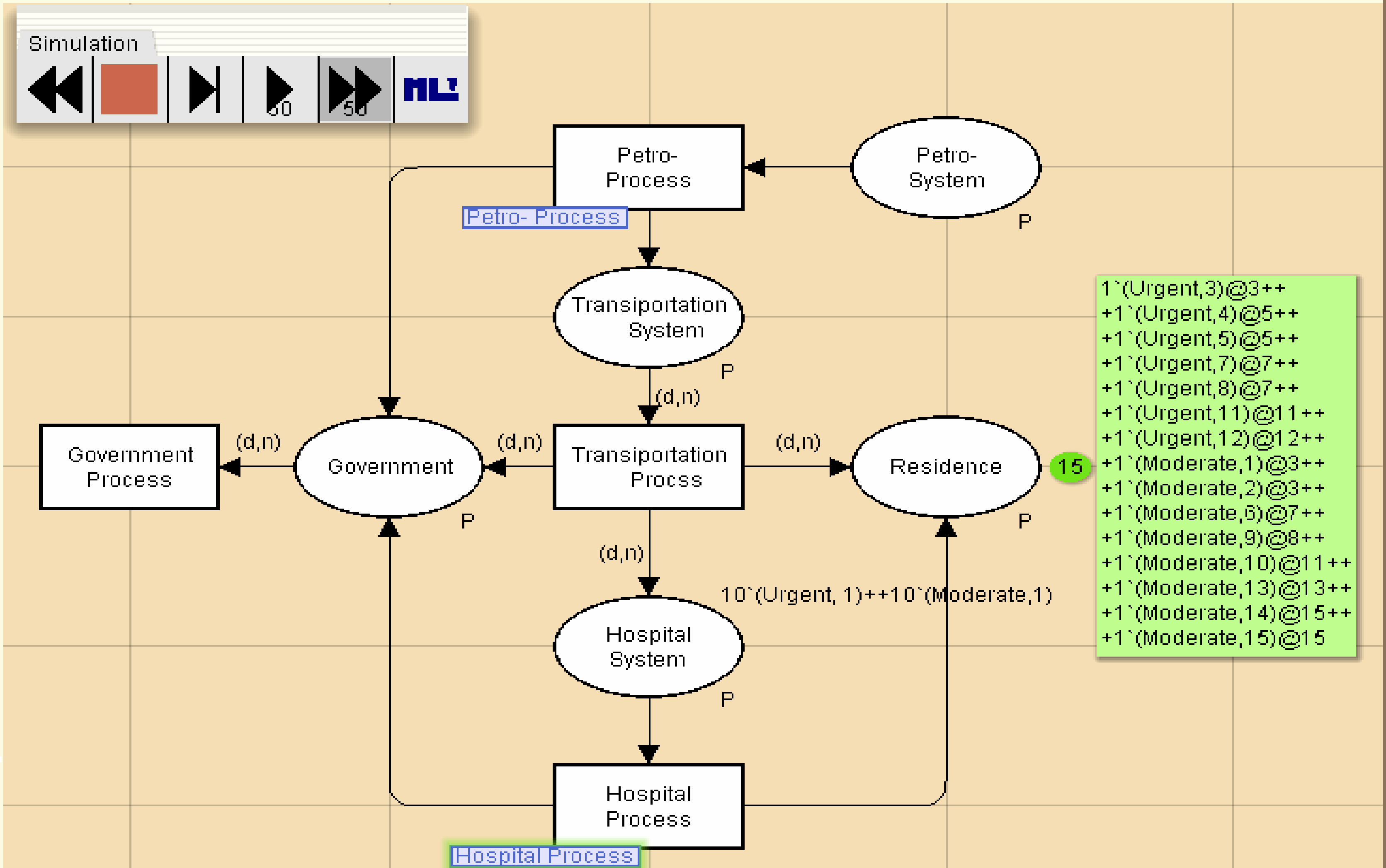
Models & Results



Models & Results



Models & Results



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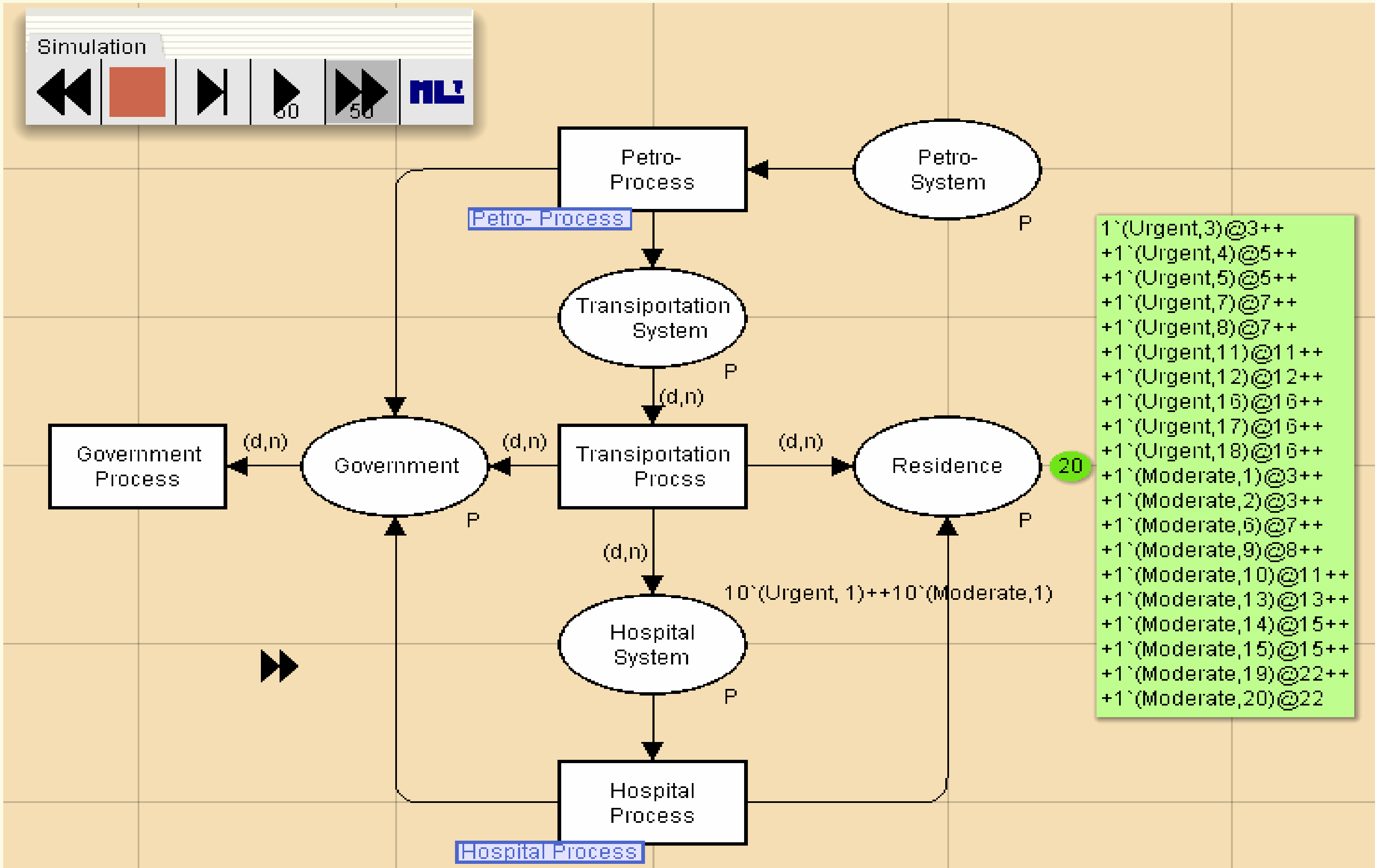

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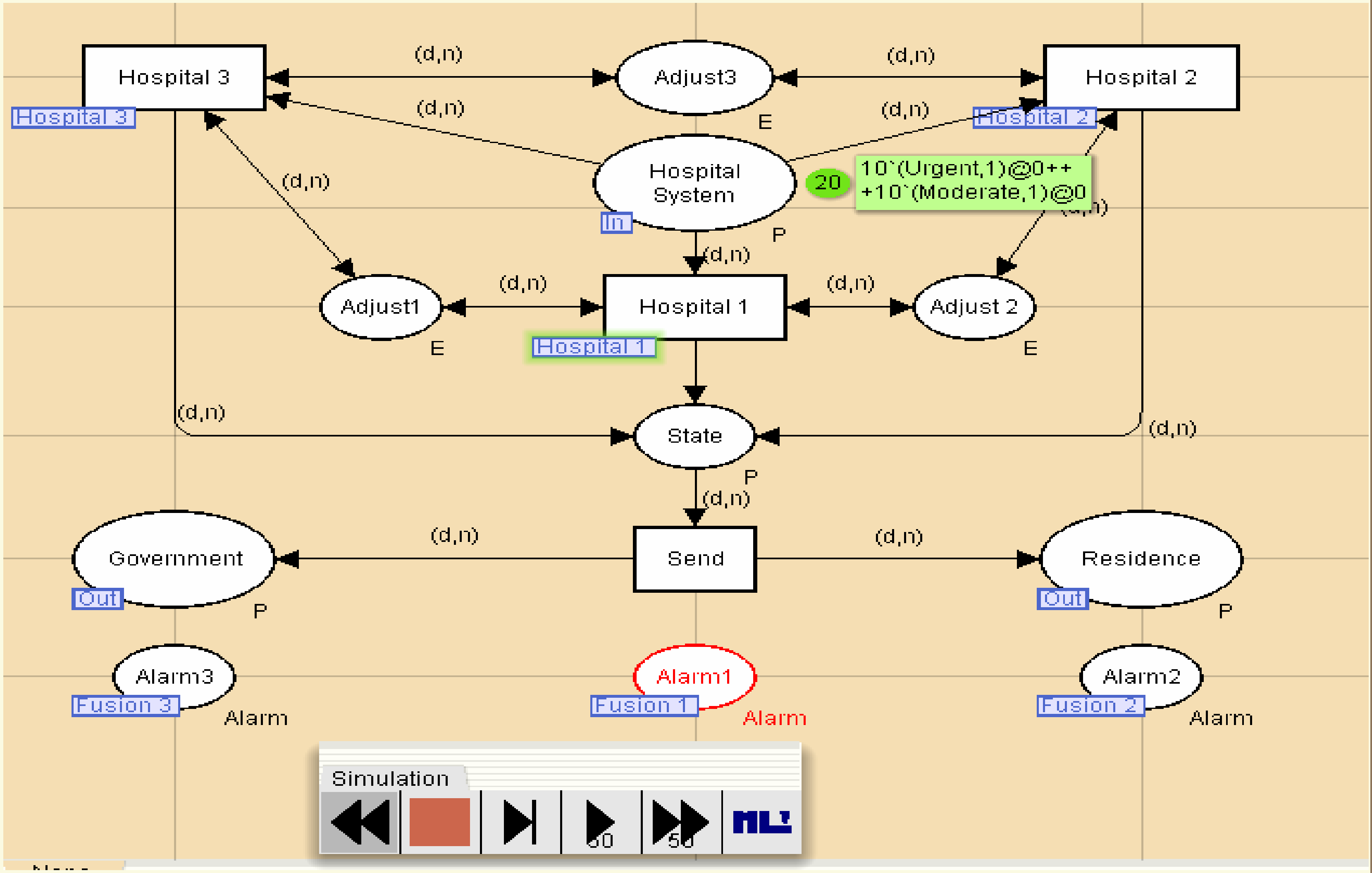

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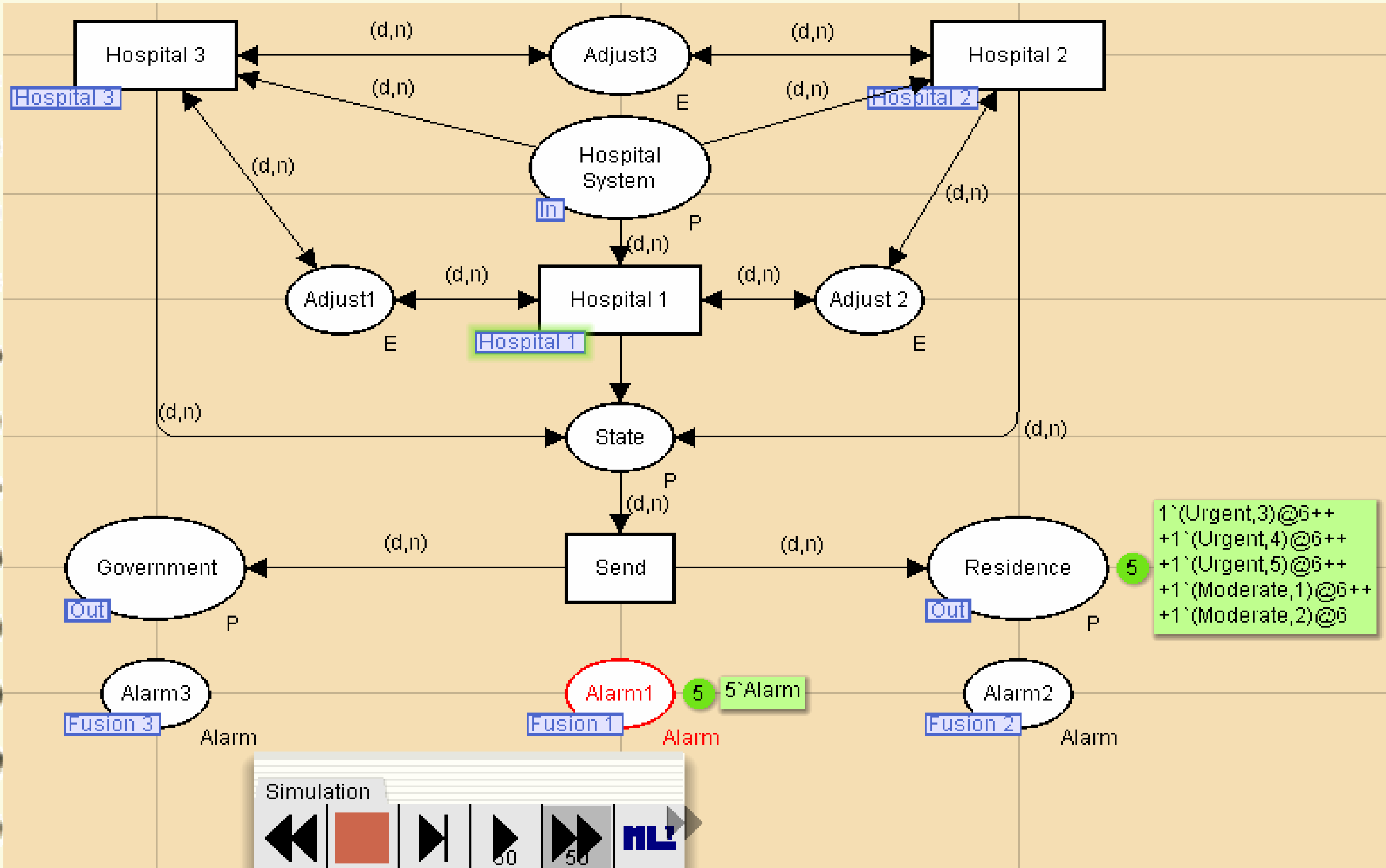

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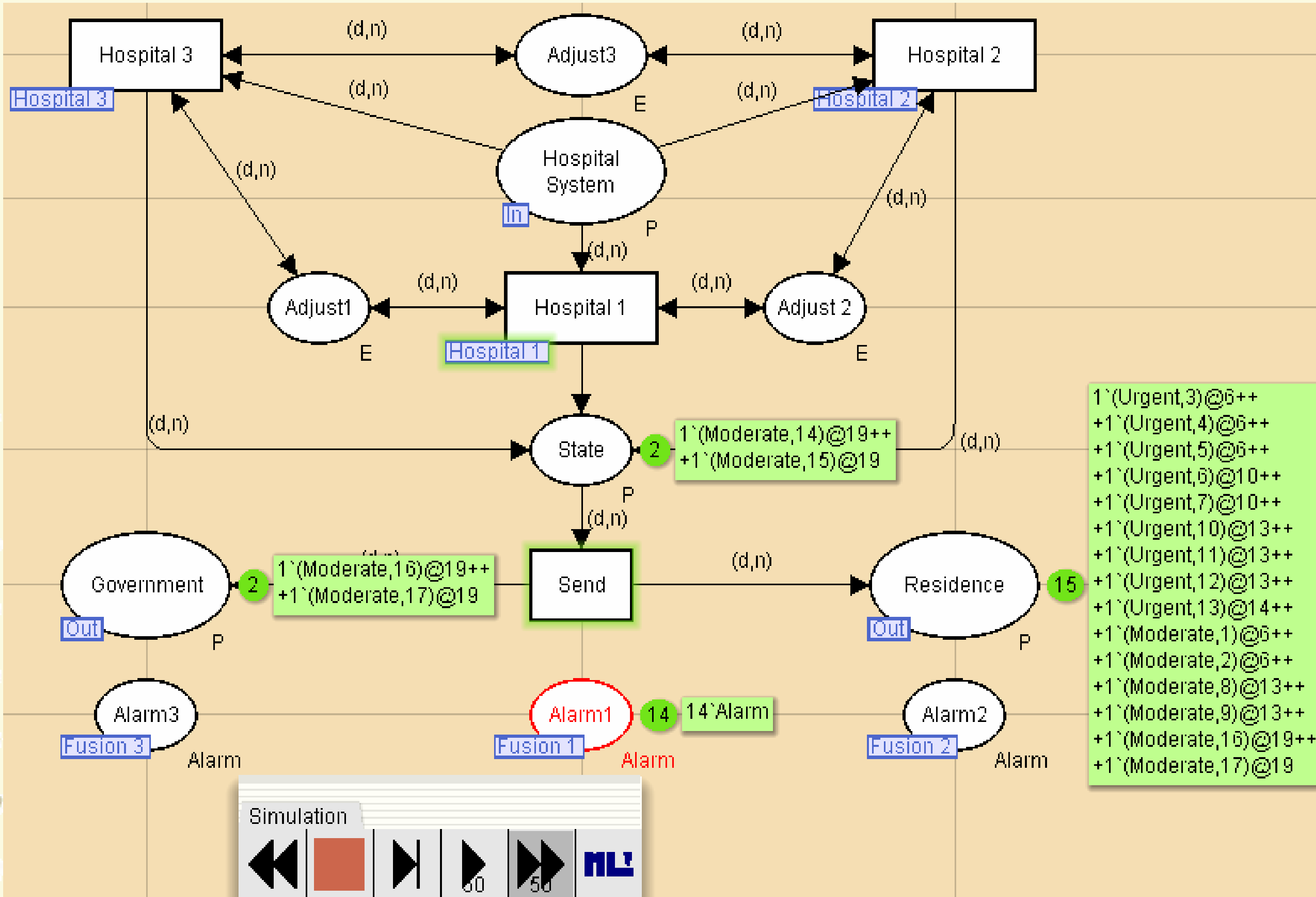


Conclusions

1. Simulation of the operation of the networked CI is feasible;
2. This enabler helps understand whether the work load is over the capacity;
3. This enabler is promising to support the decision making process further.

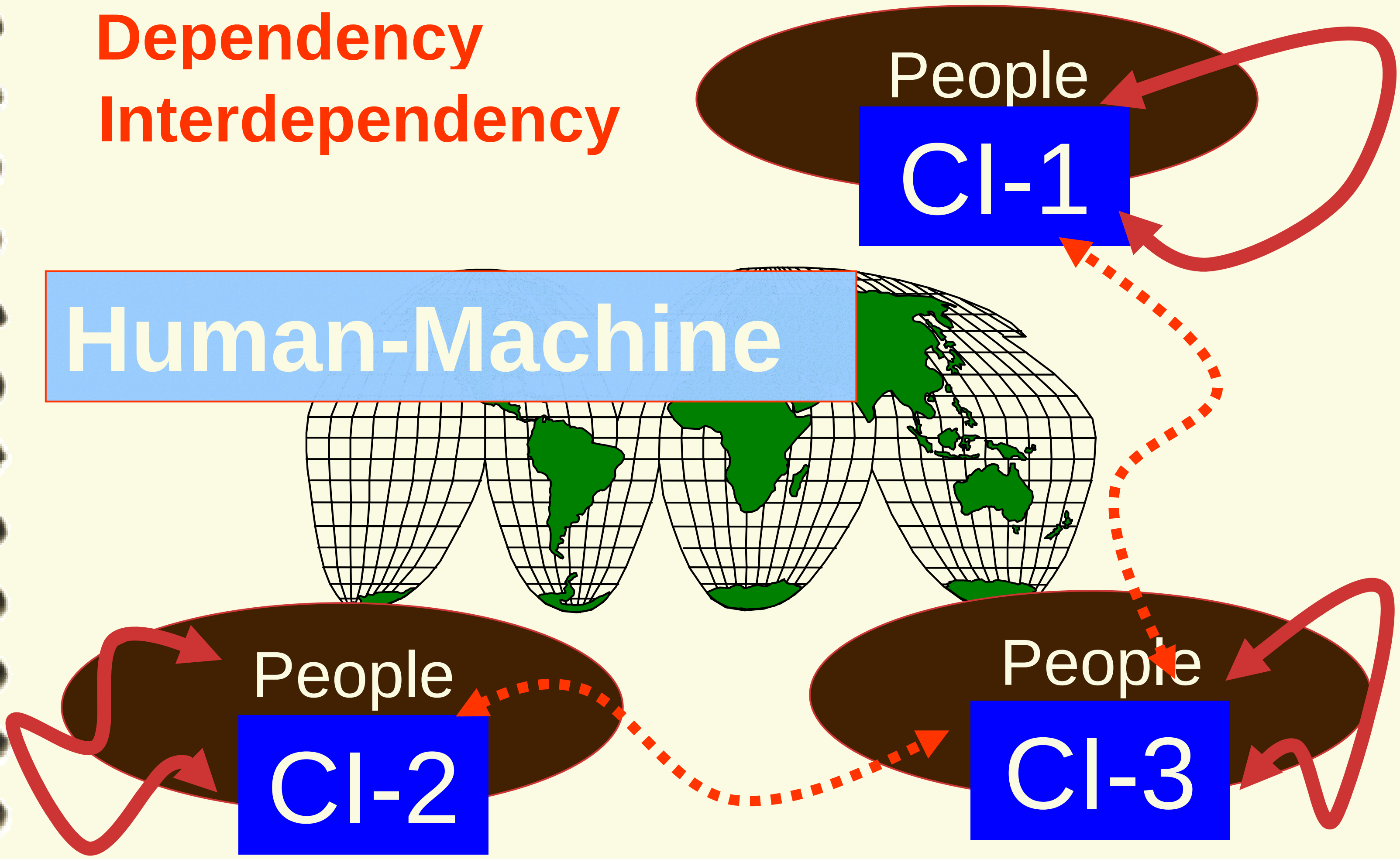
Work in Progress

1. Scalability issue (more CIs, complexity)
2. Decision support
3. Fault diagnosis
4. Vulnerable areas identification
5. Human-Machine dependency

Model: What?

Human-Machine dependency

Dependency
Interdependency



Questions & Comments?

Thank You!