SE LAB KAIST

Modeling and Verification for Different Types of System of Systems using PRISM

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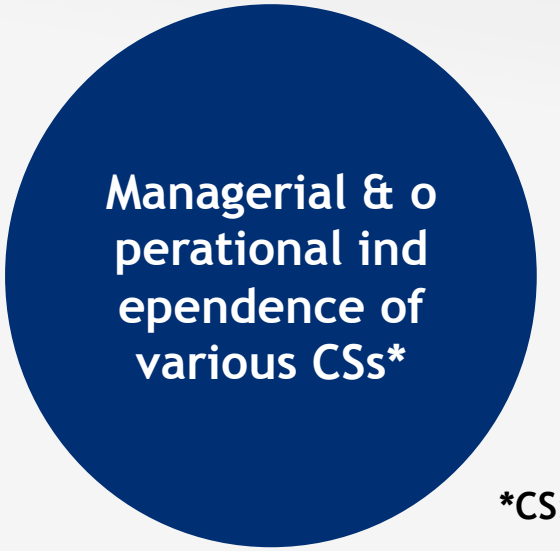
Contents

- Introduction
- Related work
- Background
- Overview
- Modeling & Verification
  - Modeling different types
  - Verification property and results
- Conclusion
  - Lesson learned
  - Summary

Introduction

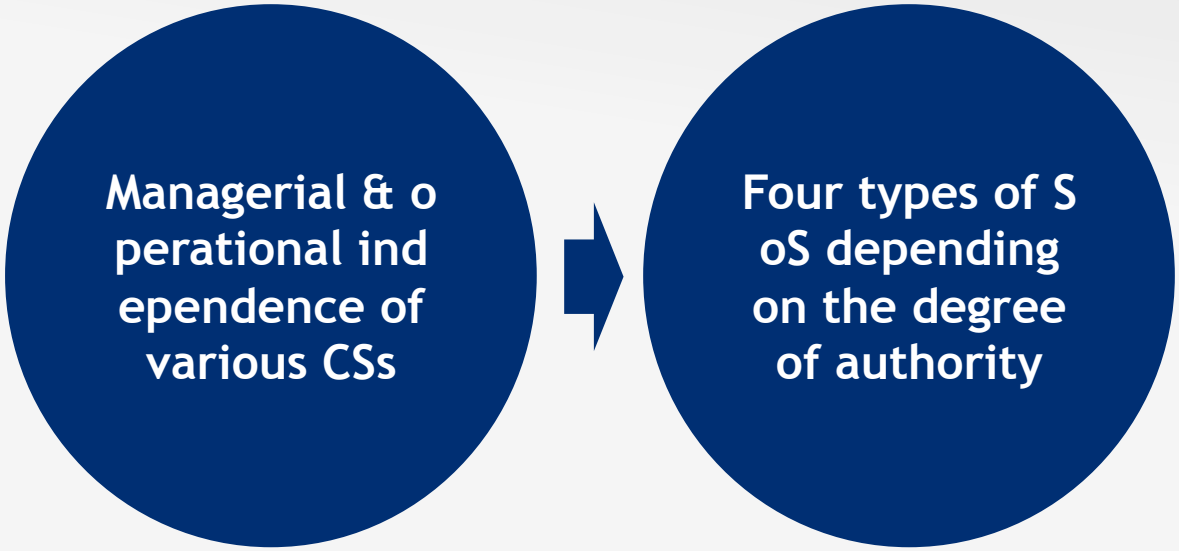


*CS: Constituent System

- Maier[1] proposed the notion of managerial & operational independence of CSs for SoS.
- SoS may not have full authority to manage or operate their CSs → Lack of authority

[1] M. W. Maier, "Architecting principles for systems-of-systems," in *INCOSE International Symposium*, vol. 6, no. 1, pp. 565–573, 1996.

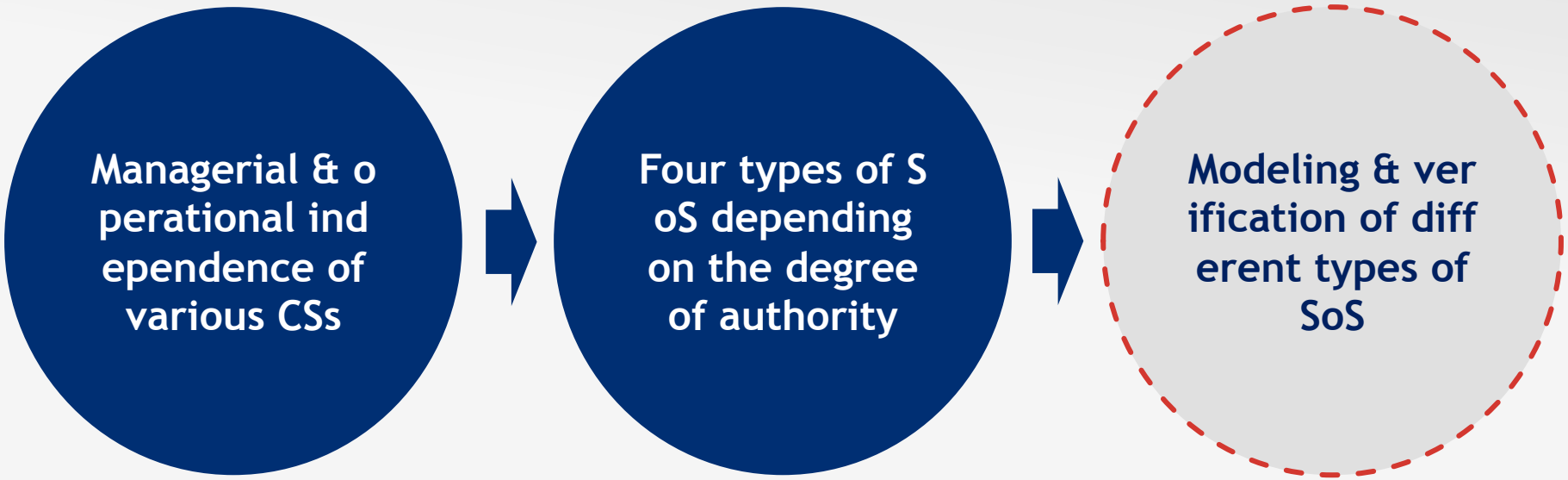
Introduction



- Four types of SoS are classified by Maier[1] and Dahmann et al. [2]
  - Directed SoS, acknowledged SoS, collaborative SoS, and virtual SoS.

[1] M. W. Maier, "Architecting principles for systems-of-systems," in *INCOSE International Symposium*, vol. 6, no. 1, pp. 565–573, 1996.
[2] J. S. Dahmann and K. J. Baldwin, "Understanding the current state of us defense systems of systems and the implications for systems engineering," in Systems Conference, 2008, pp.1–7.

Introduction



- Lack of studies considering different types of SoS in modeling and verification.
- We do a case study for the modeling and verification of several types of SoS.
  - Use "probabilistic model" to represent uncertainty of autonomous CS' behaviors.

Related Work

- Modeling and verification attempts for each type of SoS
  - Rao et al: Acknowledges SoS, SysML ➔ Colored Petri Net
  - Bryans et al: Collaborative SoS, SysML ➔ CML
  - Hammand et al: Directed SoS, SysML

- PRISM, used for verifying SoS goals
  - Calinescu et al: policies
  - Zhou et al:

➔ Have not considered various types of SoS and their characteristics in verification

Background

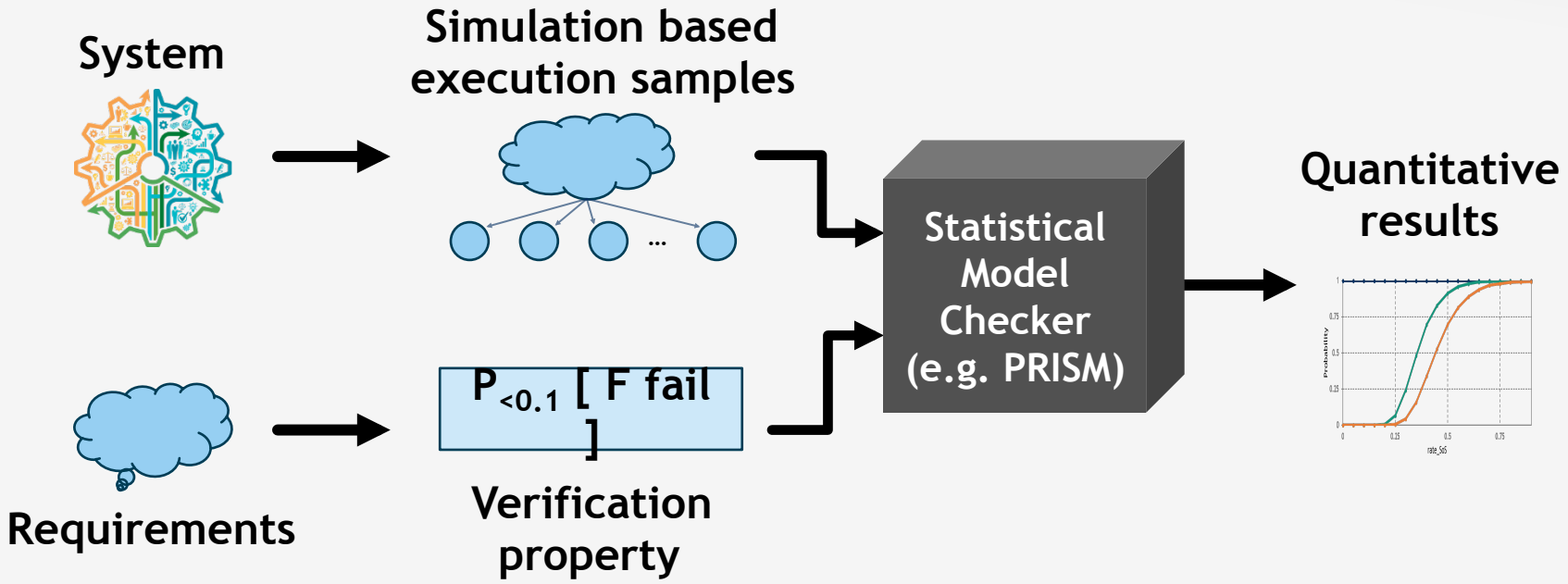
- Types of SoS
  - *The degree of authority* determines the adaptability of CSs to SoS-level goals.
  - SoS-level managers could consider which type is the most appropriate to perfo rm the desired behaviors.

	Directed [1]	Acknowledged [2]	Collaborative [1]	Virtual [1]
SoS-level goal	O	O	O	X
	Explicit objectives		Explicit/Implicit	No common goal
SoS-level organization	O	O	X	X
	Enforce	Recommend	Not exist(operational independent)	
SoS-level ownership	O	X	X	X
	Own	Not exist(managerial independent)		

[1] M. W. Maier, "Architecting principles for systems-of-systems," in *INCOSE International Symposium*, vol. 6, no. 1, pp. 565–573, 1996.
[2] J. S. Dahmann and K. J. Baldwin, "Understanding the current state of us defense systems of systems and the implications for systems engineering," in Systems Conference, 2008, pp.1–7.

Background

- Statistical Model Checking (SMC) for verification[1]
  - Hypothesis testing on given samples (i.e., system simulation traces)
  - Give a statistical verification result from probabilistic models
  - No state explosion problem



[1] Legay, Axel, Benoît Delahaye, and Saddek Bensalem. "Statistical model checking: An overview." *Runtime Verification*. Springer Berlin Heidelberg, 2010.

Overall Approach

MCI-SoS: MCI response system
DIR: directed SoS
ACK: acknowledged SoS
COL: collaborative SoS

Define SoS scenario

Mass Casualty Incident (MCI) scenario

SoS- l evel goal vs. CS- le vel g oal

Analyze SoS under types

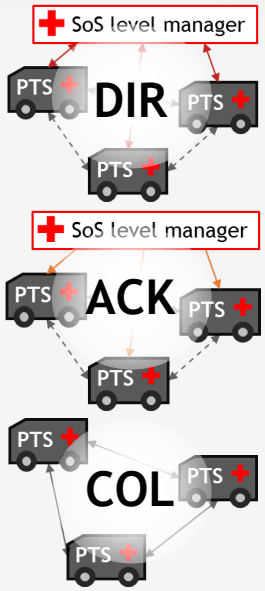
Directed MCI-SoS

Acknowledged MCI-SoS

Collaborative MCI-SoS

Degree of authority

Model each t ype of SoS



Verify SoS m odel

SoS Model

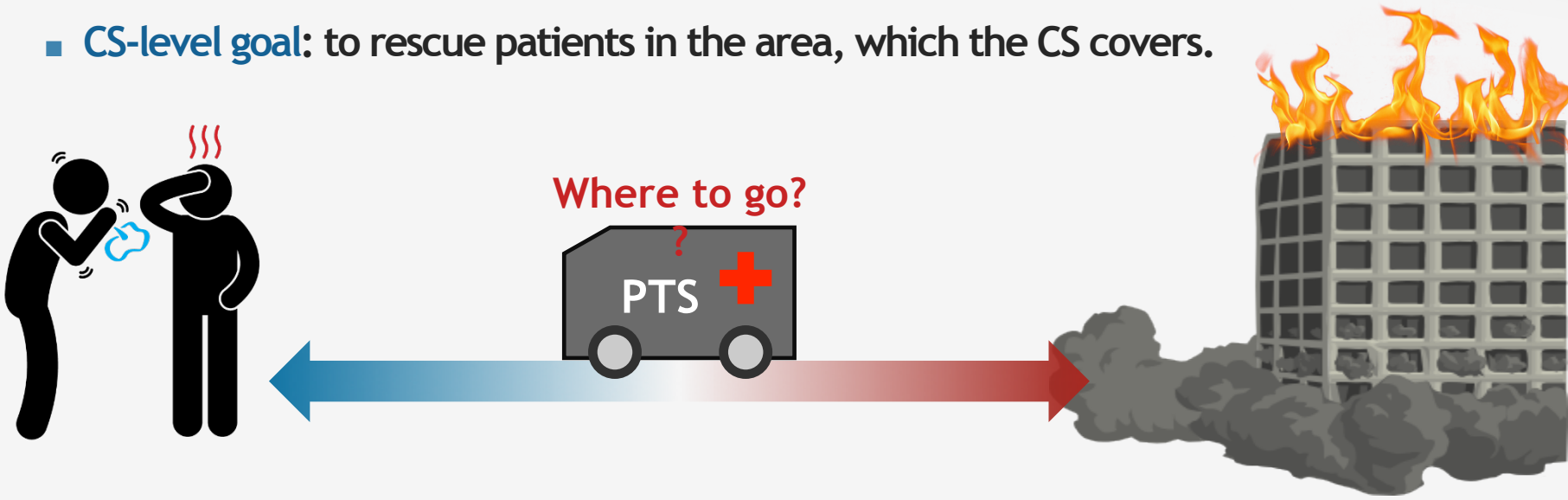
Statistical Model Checker (PRISM)

SoS-level Goal(s)

Verification Results

SoS for Mass Casualty Incident (MCI)

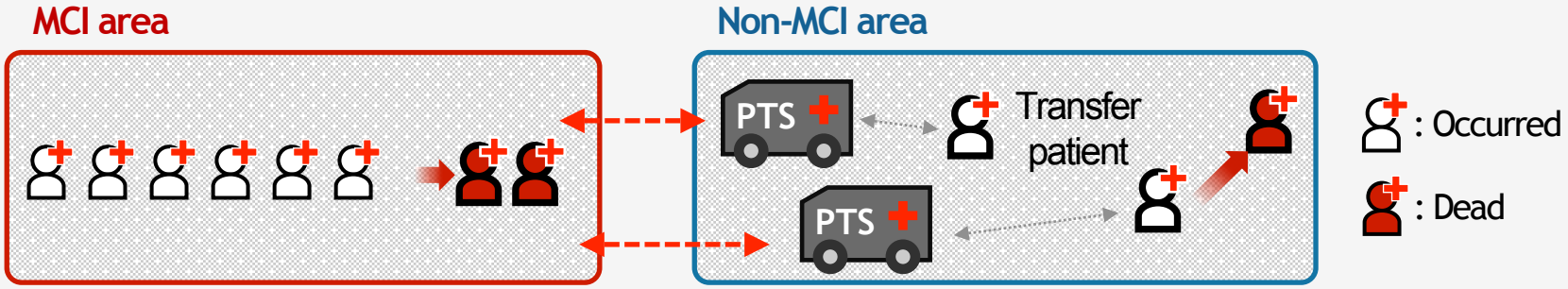
- An MCI is an incident where the resources of the emergency services are overwhelmed by the number and severity of casualties.
- An SoS tries to rescue as many patients as possible using various Patient Transferring Systems (PTSs) as CSs.
  - SoS-level goal: to rescue patients in a local area including the MCI area.
  - CS-level goal: to rescue patients in the area, which the CS covers.



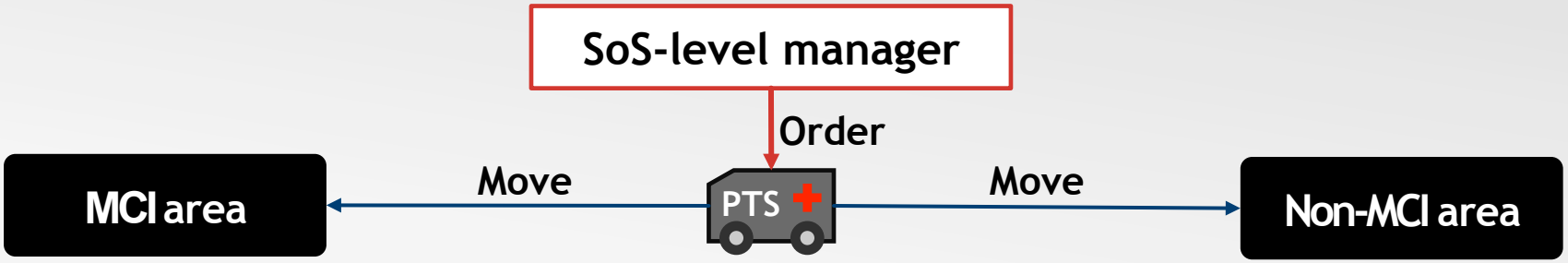
→ The CS-level goal can be yielded to achieve the SoS-level goal.

MCI-SoS: Abstracted SoS Components

- Two areas
  - There are two: an MCI area and a non-MCI area.
  - Patients occur more often in an MCI area.
- Two PTSs
  - Originally, each PTS rescues patients in the non-MCI area.
  - After the MCI happens, each PTS decides whether to follow the SoS-level goal (mo ve to the MCI area) or the CS-level goal (move to the non-MCI area).
- Patients
  - Each patient has the three states: occurred, rescued, and dead.



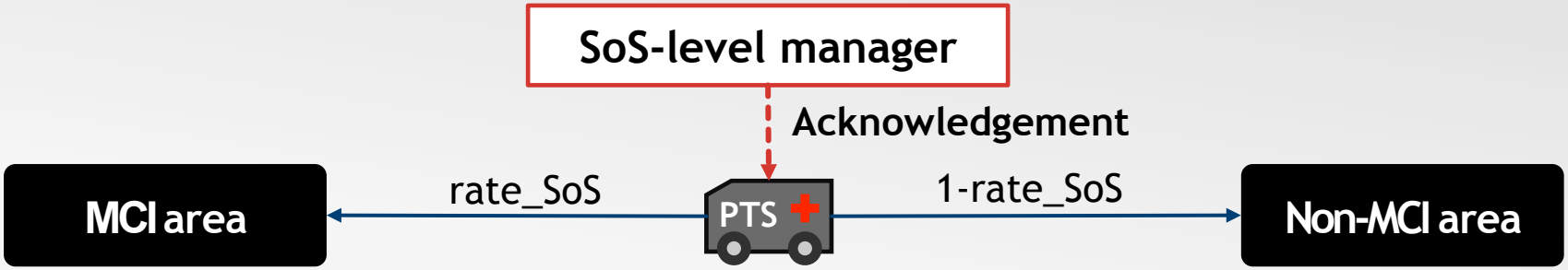
Modeling - Directed SoS




```
1  [] saved_MCI+dead_MCI<MCI_MAX -> moveTo_MCI;
2  [] saved_MCI+dead_MCI=MCI_MAX -> moveTo_non_MCI;
```

- In DIR-SoS, CSs simply follow the order from the SoS-level manager.
  - If there is a patient in the MCI area, a PTS serves the MCI patient first.

Modeling – Acknowledged SoS

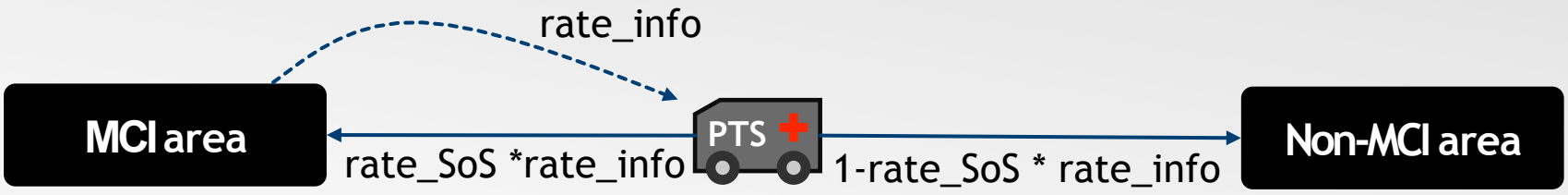



```
1  [] true -> rate_SoS:(moveToMCI=1) + (1-rate_SoS):(moveToMCI=0);
```

*** `rate_SoS`: affinity to the SoS-level goal (move to the MCI area)**

- In ACK-SoS, CSs decide their own actions using rate_SoS in PRISM.
- The difference between DIR-SoS and ACK-SoS is the decision making process.
  - Based on the rate_SoS, a CS in ACK-SoS decides autonomously its own action.
  - If `rate_SoS=0.9`, the PTS will move to the MCI area with a 90% probability.

Modeling - Collaborative SoS



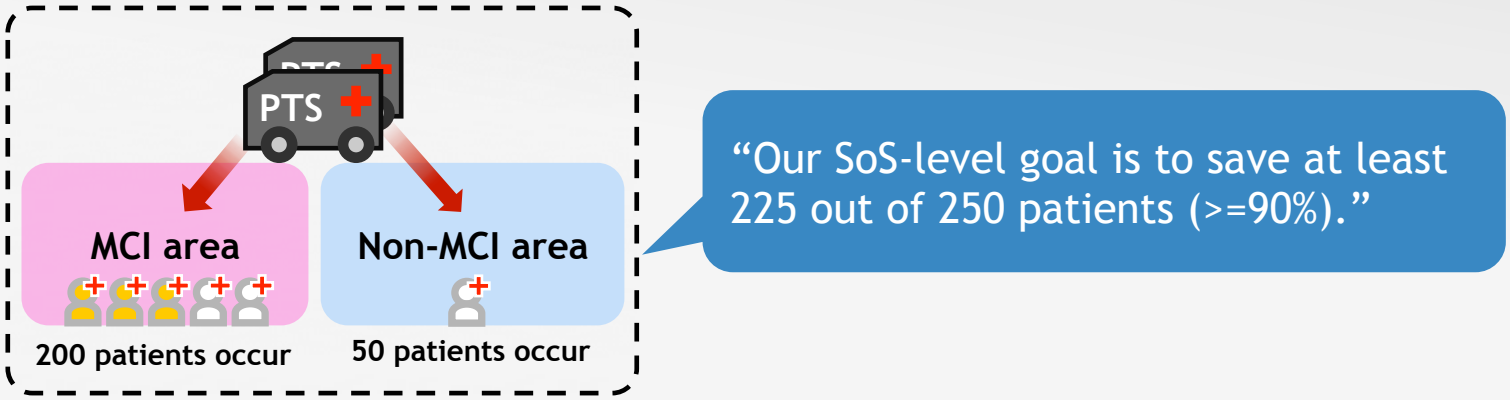

```
1   [] true -> (rate_SoS*rate_info):(moveToMCI=1)
                                  + (1-rate_SoS*rate_info):(moveToMCI=0);
```

* `rate_SoS`: the affinity to the SoS-level goal (move to the MCI area)
* `rate_info`: the quality of the information for the MCI area

- In COL-SoS, each PTS decides its action using both `rate_SoS` and `rate_info`.
- The difference between ACK-SoS and COL-SoS is the decision making of a PTS.
  - In COL-SoS, the information of the MCI area can be degraded.
  - If `rate_SoS=0.9` and `rate_info=0.3`, the PTS will move to the MCI area with a 27% probability.

Verification Property

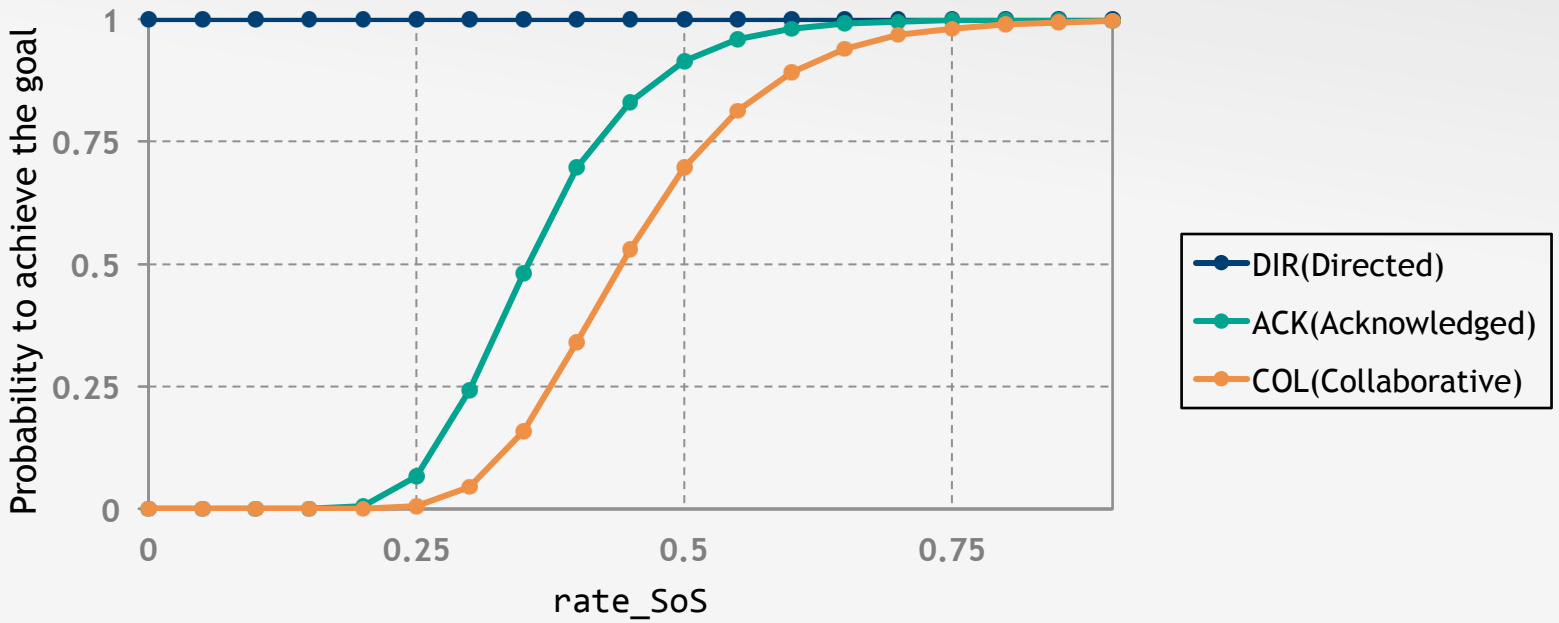
- Verify whether the SoS-level goal is achieved or not.



- Environmental settings
  - Patients in the MCI area appear *more frequently than* patients in the non-MCI area .
  - The probability of death in the MCI area is *five times higher than the* probability of death in the non-MCI area.
  - SMC takes 10,000 samples and verifies the property with 99% confidence.

Verification Result - Types of SoS

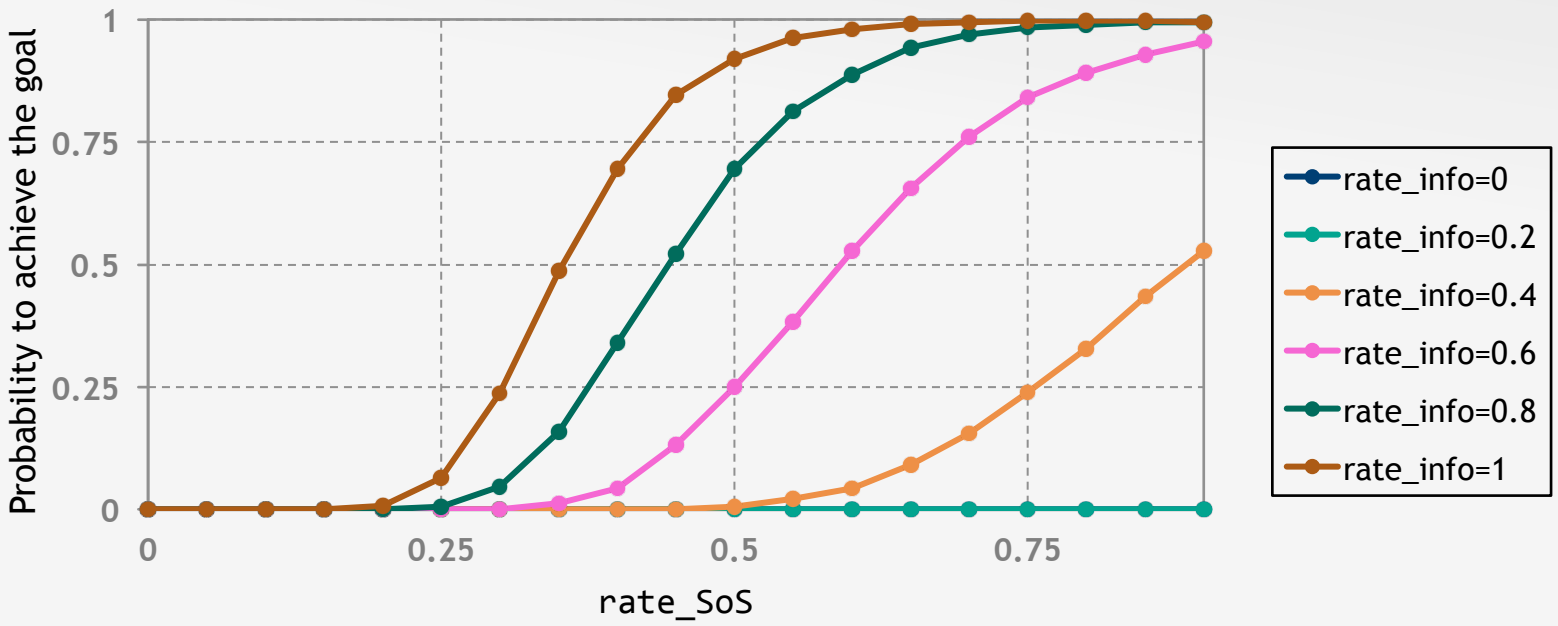
- The degree of authority (i.e., SoS type) affects the SoS-level goal achievement.



  - The better the authority to CSs, the higher the probability of achieving the SoS-level goal.

Verification Result - Degree of Information

- In a collaborative SoS, the increased possibility of acquiring MCI-related information (`rate_info`) affects the probability of goal achievement.

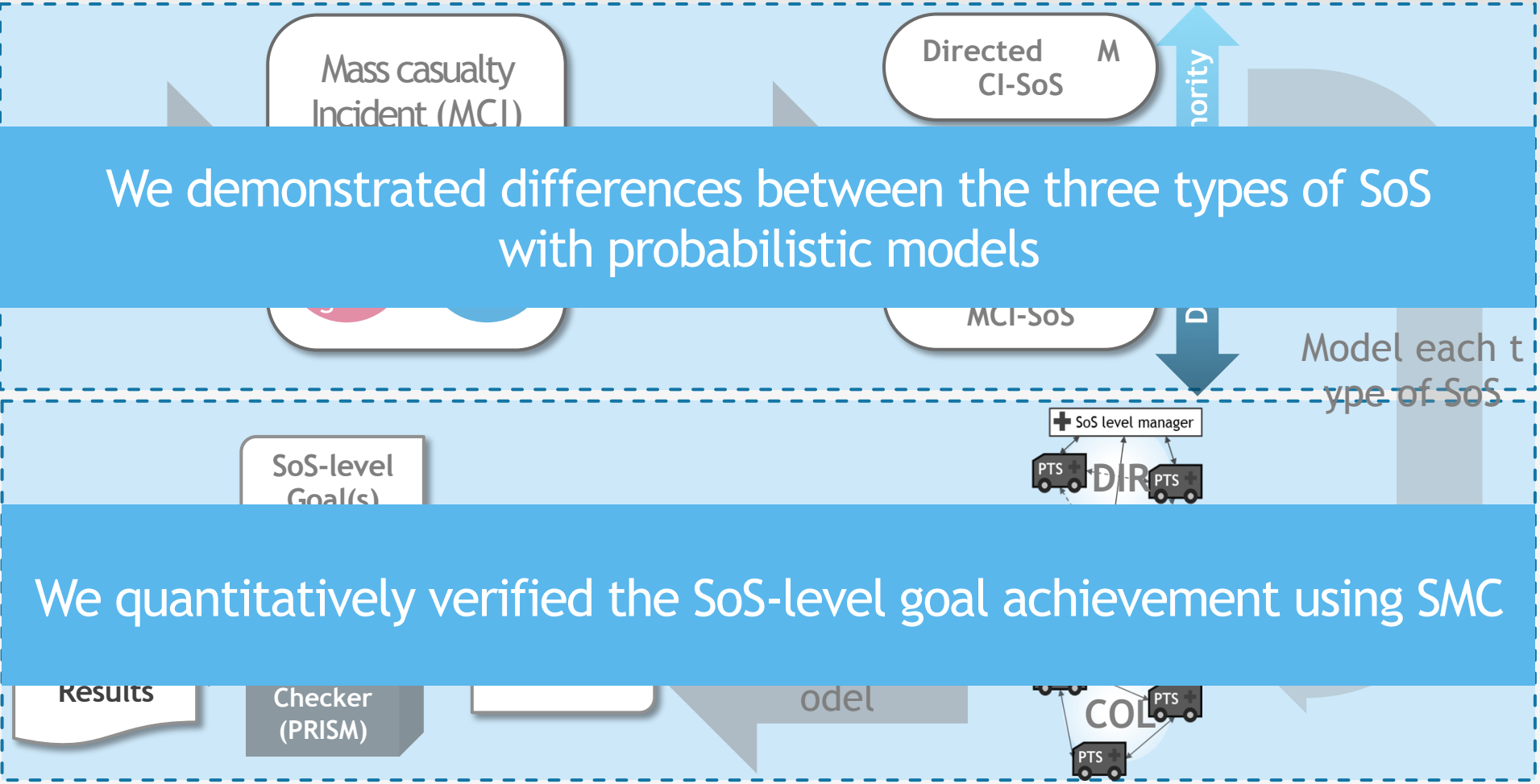


  - The better the information, the higher the probability of achieving the SoS-level goal.

Lessons Learned

- Different types of SoS can be modeled via probabilistic models and variables.
- Statistical Model Checking (SMC) is a proper way to verify the SoS-level goal achievement in a quantitative way.
- To analyze the pros and cons of types of SoS, another aspect o f SoS (e.g., cost) should be added to model.

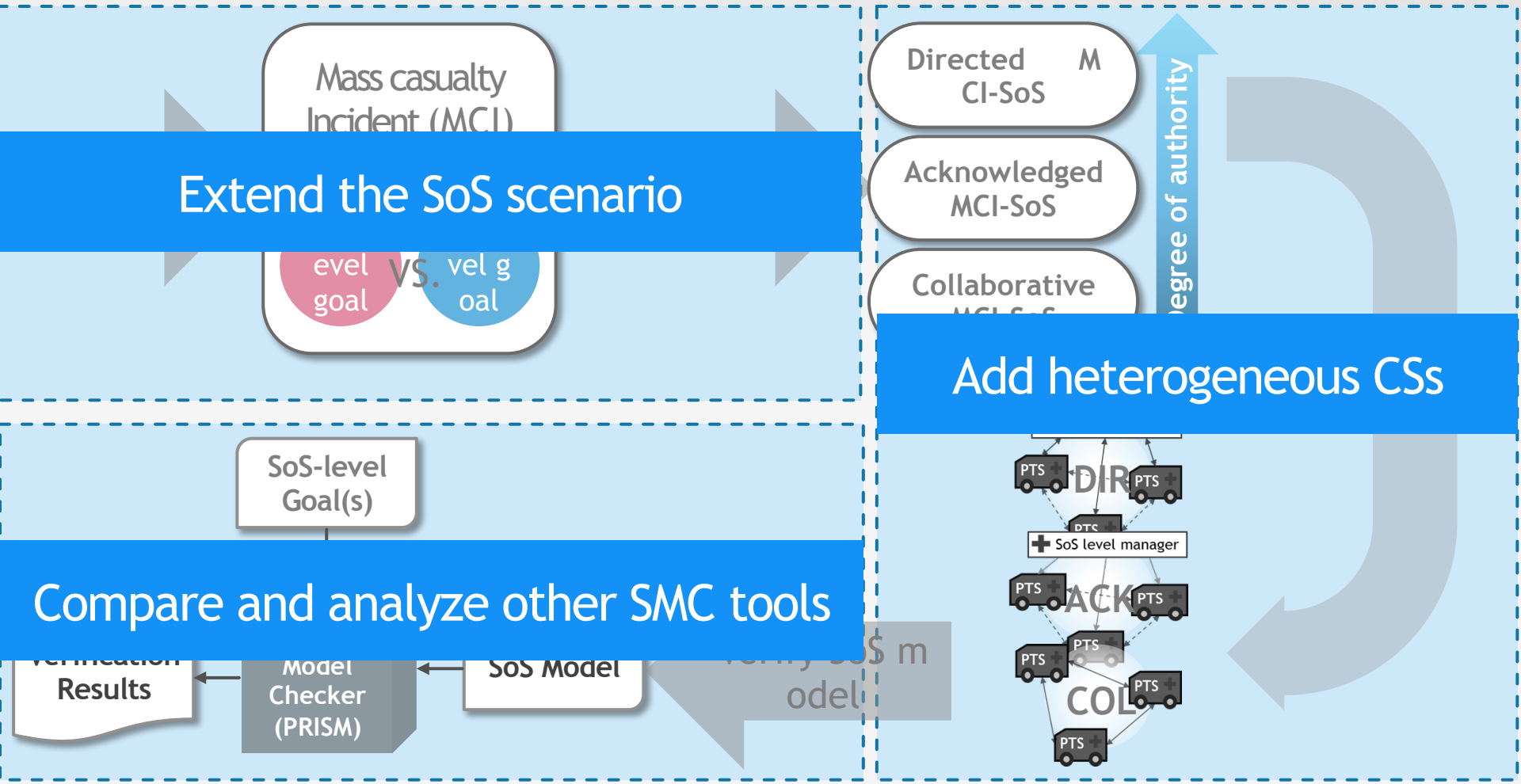
Summary



We demonstrated differences between the three types of SoS with probabilistic models

We quantitatively verified the SoS-level goal achievement using SMC

Future work

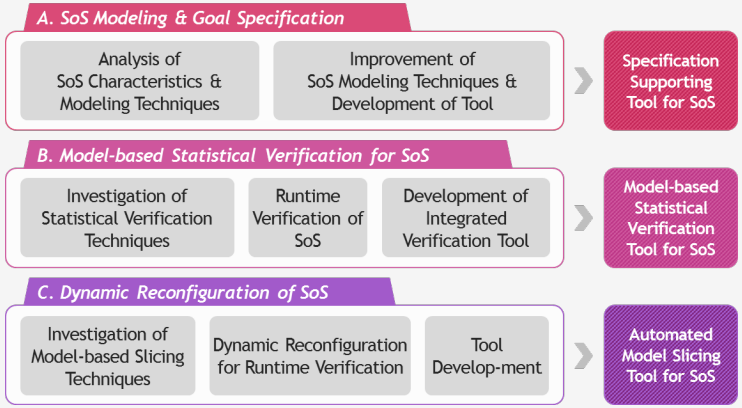

Mass casualty Incident (MCI)
evel goal
VS.
vel g oal
Extend the SoS scenario
Directed M CI-SoS
Acknowledged MCI-SoS
Collaborative
egree of authority
Add heterogeneous CSs
SoS-level Goal(s)
Compare and analyze other SMC tools
Results
Model Checker (PRISM)
SoS Model
odel
PTS
DIR
SoS level manager
ACK
COL

SE for SoS Research Group

SW연구센터(SWRC)포럼 Software Research Center Forum

KAIST

- **SW Star Lab** (http://se.kaist.ac.kr/starlab)
  - **Software R&D for Model-based Analysis and Verification of Higher-order Large Complex System** (2015.03-2023.02, funded by Institute for Information & communications Technology Promotion)
    A. SoS Modeling & Goal Specification
    B. Model-based Statistical Verification of SoS
    C. Dynamic Reconfiguration of SoS
  - **S/W tools will be released as open source. Please join us!**



Research Plan (2015-2023)

SoS Research Group 2016 Workshop

Q&A

- We appreciate for kind and valuable comments from reviewers.
- Thank you for listening.

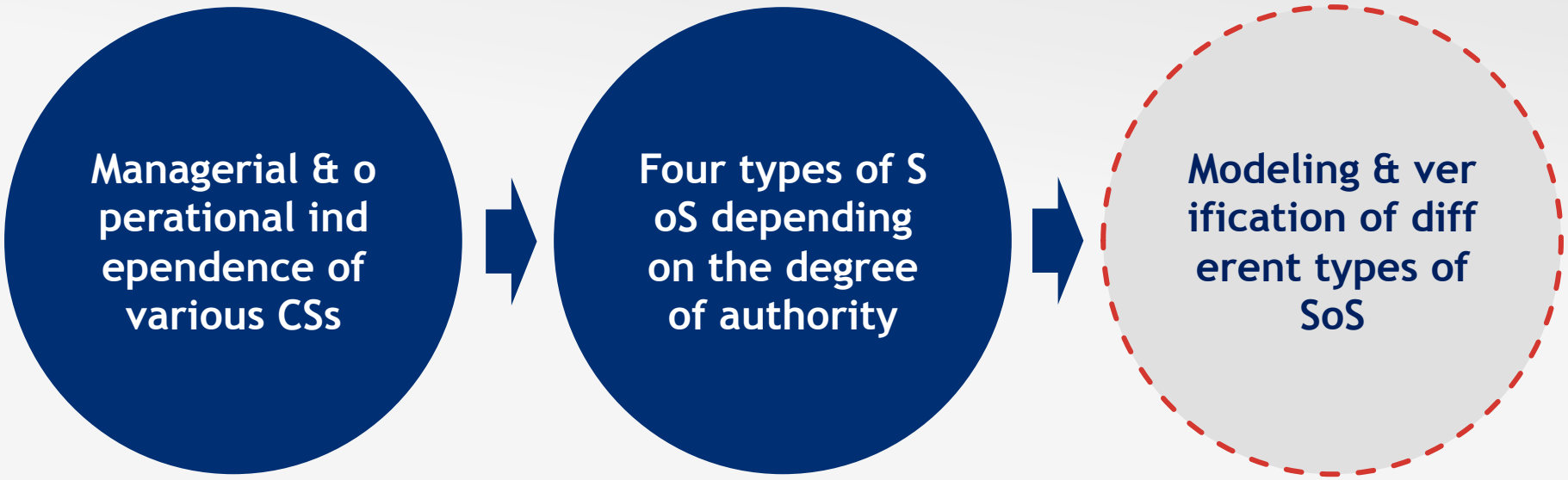
Appendix - Environment in PRISM

```
module env_MCI

        total_MCI:[0..MCI_MAX] init 0;          // cumulative number of patients.
        curr_MCI:[0..MCI_MAX] init 0;           // number of patients in the queue.
        saved_MCI:[0..MCI_MAX] init 0;          // number of saved patients.
        dead_MCI:[0..MCI_MAX] init 0;           // number of dead patients.

        // MCI patient occurs.
        [] (saved_MCI+dead_MCI+curr_MCI<MCI_MAX) ->
                (total_MCI'=min(total_MCI+MCI_OCCUR_RATE,MCI_MAX)) &
                (curr_MCI'=min(curr_MCI+MCI_OCCUR_RATE,MCI_MAX));

        // MCI patient dead.
        [] curr_MCI>=1 ->
                PR_MCI_DEAD:(dead_MCI'=min(dead_MCI+1,MCI_MAX)) & (curr_MCI'=curr_MCI-1)
                + (1-PR_MCI_DEAD):true;

        // MCI patient served by PTS1
        [serve_MCI_PTS1] curr_MCI>=1 ->
                (saved_MCI'=min(saved_MCI+1,MCI_MAX)) & (curr_MCI'=curr_MCI-1);

        // MCI patient served by PTS2
        [serve_MCI_PTS2] curr_MCI>=1 ->
                (saved_MCI'=min(saved_MCI+1,MCI_MAX)) & (curr_MCI'=curr_MCI-1);


endmodule
```

Appendix - PTS1 in PRISM

```
module PTS1

        // Case: DIR
        [serve_MCI_PTS1] saved_MCI+dead_MCI<MCI_MAX -> true;
        [serve_ETC_PTS1] saved_MCI+dead_MCI=MCI_MAX -> true;


        // Case: ACK or COL
        //s1: [0..1] init 0; // 0: CS purpose, 1: SoS purpose
        //[serve_ETC_PTS1] s1=0 -> true;
        //[serve_MCI_PTS1] s1=1 -> true;

        // Case: ACK
        //[] true -> rate_SoS:(s1'=1) + (1-rate_SoS):(s1'=0);

        // Case: COL
        //[] true -> rate_info*rate_SoS:(s1'=1) + (1-rate_info*rate_SoS):(s1'=0);

endmodule
```

Thank you



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