Regional Studies Association

RSA Winter Conference 2018

New Horizons for Cities and Regions in a Changing World

UNIVERSITY OF PATRAS
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

A Process-Centric Approach for System-of-Systems Integration in Smart Cities

Chondrogianni V. Dimitra

PhD candidate, Department of Civil Engineering, University of Patras, Greece, d.chondrogianni@gmail.com

November 15 - 16, 2018, London

1. Introduction

- Based on the System of systems theory, cities are considered as the **target systems** which consists of a **number of subsystems**.

- This research proposes a **SoS integration** architecture by shifting the analysis from **function-oriented to process-oriented** integration, connecting systems to deliver higher efficiency/effectiveness.

- The methodology incorporates a **safety analysis process** for systematic identification of safety properties and **hazard mitigation**, reduction of services disruption, and increase of system safety.

- To demonstrate how independent systems can be integrated to **act collaboratively**, the cross-sectoral **interrelations** between a **smart grid**, **communication** and **electrified transport** (EVs) are analyzed towards the process-centric SoS approach.

2. City as a system of systems (SoS) (1/2)

- System theorists view the system of a city as a complex system of interconnected parts.
- **Connectivity** of the systems by ICT means is the key factor. There are separate systems for managing different components of the city like water, energy, transportation, security, waste emissions and ICT.
- These systems have separate data, infrastructure, responsibilities, tasks, etc.(John Post, 2009)
- City departments frequently **work in silos** when they are trying to solve **city problems**. For example, transport is dealt with by transport planners and energy is dealt with by energy managers.

2. City as a system of systems (SoS) (2/2)

This network of systems, interconnections and flows can be described as a **system of systems**.

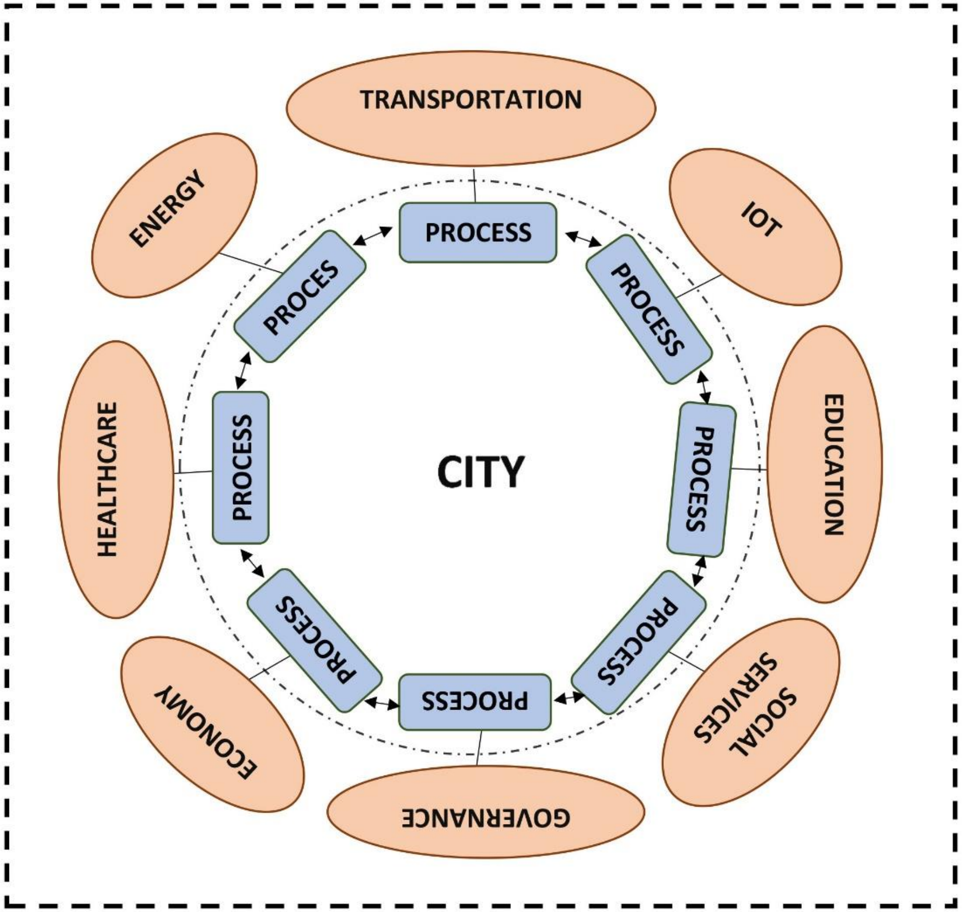


Figure 1: City as a system of systems

3. Systems thinking

- "Systems thinking" is a discipline that provides **skills** and **tools** designed to address **situations of complexity** and **uncertainty** which are difficult to grasp and manage and to which there are no simple answers.

- Systems thinking is an approach to such problems solving that uses two system-theoretic conceptual pairs:
  - ✓ systems have **emergence** and **hierarchy**
  - ✓ systems need c**ommunication** and **control**

(Checkland,1981)

4. System theoretic process analysis (STPA) (1/2)

- STPA (System-Theoretic Process Analysis) is a **new hazard analysis technique** based on an extended model of accident causation (Leveson, MIT, 2012).

- STPA assumes that **accidents** can be caused by **unsafe interactions** of system components, none of which may have failed.

- **STPA** defines **hazard** as “A system state or set of conditions that, together with a particular set of worst-case environmental conditions, will lead to an **accident (loss)**”.

- The ultimate goal is to **eliminate** or, if not possible, to **control** or **reduce** identified hazards during the system design activity.

4. System theoretic process analysis (STPA) (2/2)

STPA application

Step 1. Defining the **purpose** of the analysis

Step 2. Build a model of the system called **hierarchical control structure.** A control structure captures **functional relationships** and interactions by modeling the system as a set of feedback control loops.

Step 3. Analyze **control actions** in the control structure to examine how they could lead to the losses. These unsafe control actions are used to create functional **requirements** and **constraints** for the system.

Step 4. The fourth step identifies the **reasons why unsafe control** might occur in the system. **Scenarios** are created to explain.

5. STPA and Coordination (1/3)

- The state-of-the-art safety analysis methods have limited guidance for **analytical inquiry into coordination** between interdependent decision systems.

- **STPA-Coordination** extends STPA with additional steps for analysis of how coordination can lead to unsafe control actions (i.e. hazards).

- The controlled process can be considered a **coordinated process** (i.e. other decision systems) or a physical process.

5. STPA and Coordination (2/3)

There are **three dimensions** related to coordination interactions, including: 1) vertical or lateral coordination, 2) within or between decision system coordination and 3) coordination to control a single or multiple independent processes (Johnson, MIT, 2017).

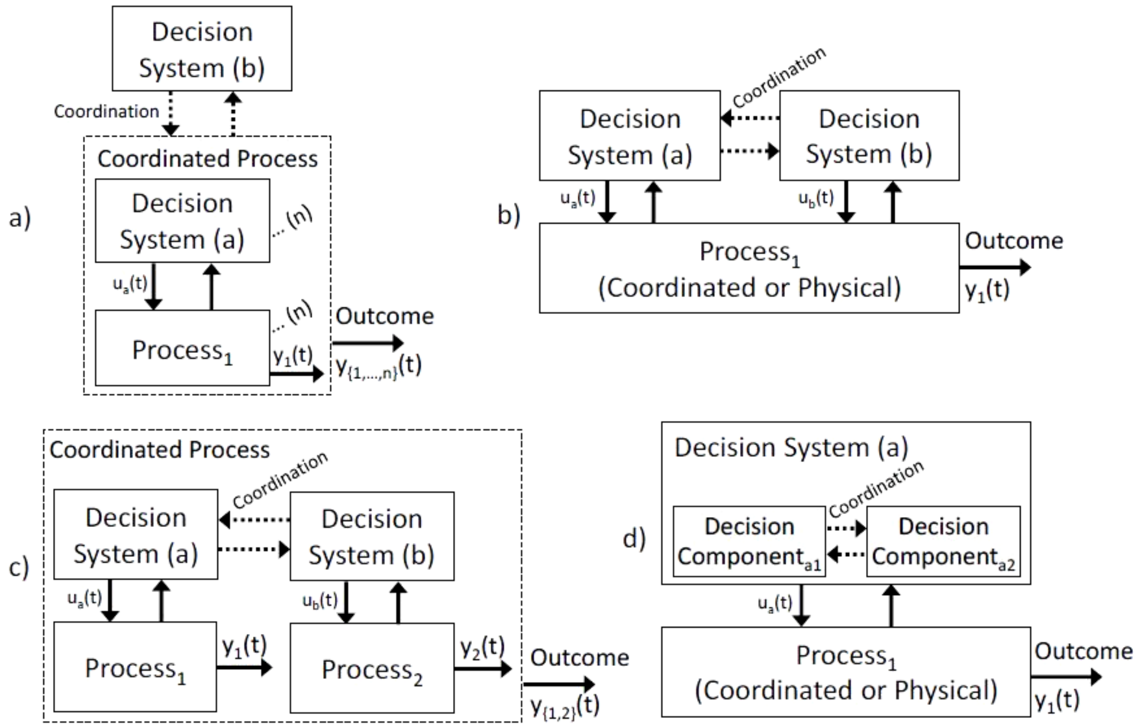


Figure 2: Fundamental Coordination Relationships in Sociotechnical Systems

5. STPA and Coordination (3/3)

- STPA-Coordination uses the **nine coordination elements**, which provide additional insights into identifying hazardous coordination scenarios that can lead to UCAs.
- In the case study, **Communication** will be the coordination element that will be analyzed.

Coordination Elements: Missing or Inadequate	Coordination Goals
	Coordination Strategy
	Decision Systems
	Communication
	Group Decision-Making
	Observation of Common Objects
	Authority, Responsibility, Accountability
	Common Understanding
	Predictability

Table 1: Nine coordination elements in Extended STPA

6. Smart grid (1/2)

- A smart grid is an **electricity network** based on digital technology that is used to supply electricity to consumers via two-way **digital communication**.

- This system allows for monitoring, analysis, control and communication within the **supply chain** to help improve **efficiency**, reduce energy consumption and cost.

- The grid as a whole can be considered as a **complex System of Systems** (SoS) whose aim is to assure a reliable power supply to all its consumers.

- A smart grid may be capable of **coordinating the power needs** of generators, operators, end-users and any other market stakeholder.

6. Smart grid (2/2)

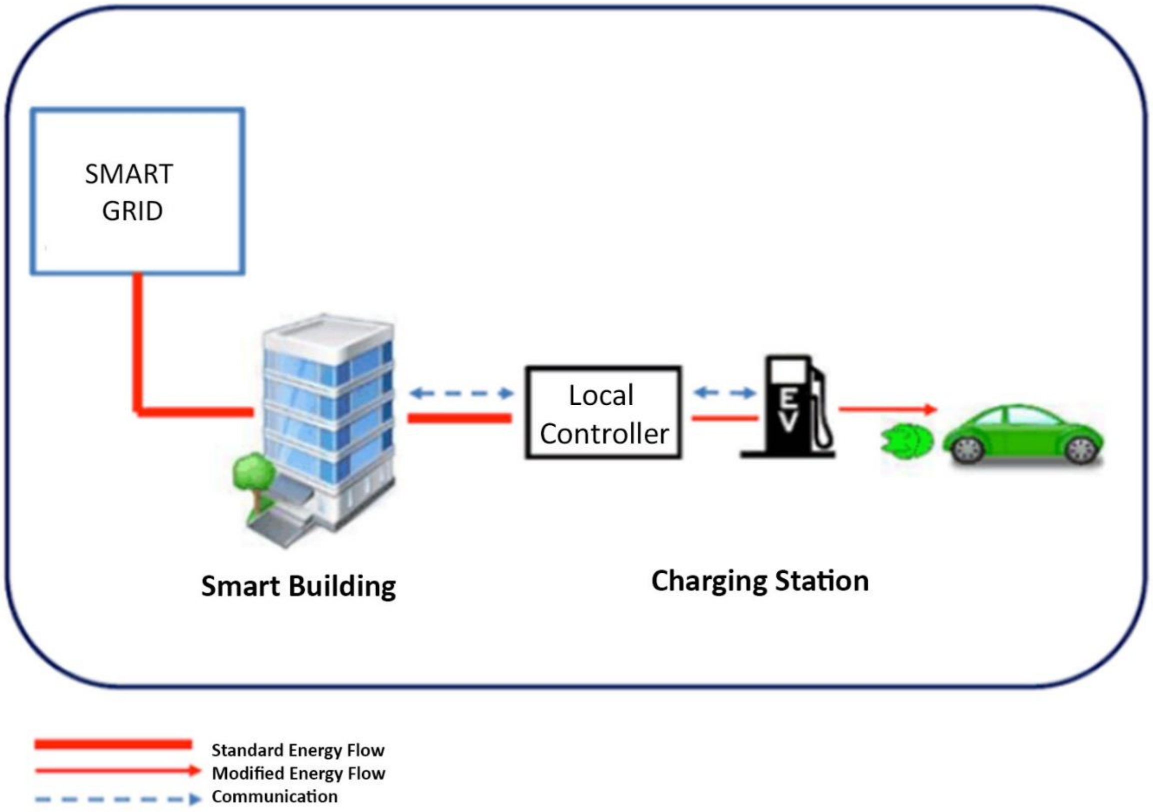
- The objective is to **operate the system** as **efficiently** as possible, minimizing costs and environmental impacts
- Smart grid provides
  a. **operational efficiency**, with distributed generation, network optimization & remote monitoring,
  b. **energy efficiency**: with reduced system and line losses, improved reactive load control & peak-load shaving,
  c. **customer satisfaction**, as the grid will improve the communication between producers and consumers,
  d. **CO2 emission reduction**: via Demand-side load management system (DSL-MS)

7. Electric Vehicles (1/2)

- Electric vehicles (EVs) have gained **interest** in the global research and industrial sector.
- The major factor causing the promotion of EVs is the **pollution- and emission-free transportation** that they offer.
- **High electric energy demand** of plug-in EVs (PEVs) on the one hand and their increasing number on the other will impose a **significant load** on smart grids.
- This load, if not controlled, **may cause frequency deviation** and even power system instability.
- It is essential to **upgrade electricity networks**, install charging stations and identify the risks undergoing in the communication and coordination of the two systems.

7. Electric Vehicle (2/2)

EV battery is loaded through chargers, which can actually **manage the charging process**. The availability of information concerning the smart grid (provided by smart meters) allows an **optimization** of the EV loading process, by taking into account the **needs and limitations** of the grid.



8. Cross sectoral Risk Analysis (1/7)

STEP 1: Purpose of the analysis

Accidents –Losses

No.	Title
1	Power shortages
2	Loss of customers
3	Loss of grid equipment (capacitors, lines, etc)

Hazards

No.	Title	RELATED ACCIDENTS
[1]	Smart grid has an inability to meet unexpected demands	1,2,3
[2]	Smart grid is unable to satisfy local energy demands	2
[3]	Smart grid has an inability to keep customers comfortable per their preferences	2

8. Cross sectoral Risk Analysis (2/7)

STEP 1: Purpose of the analysis

Safety Constraints

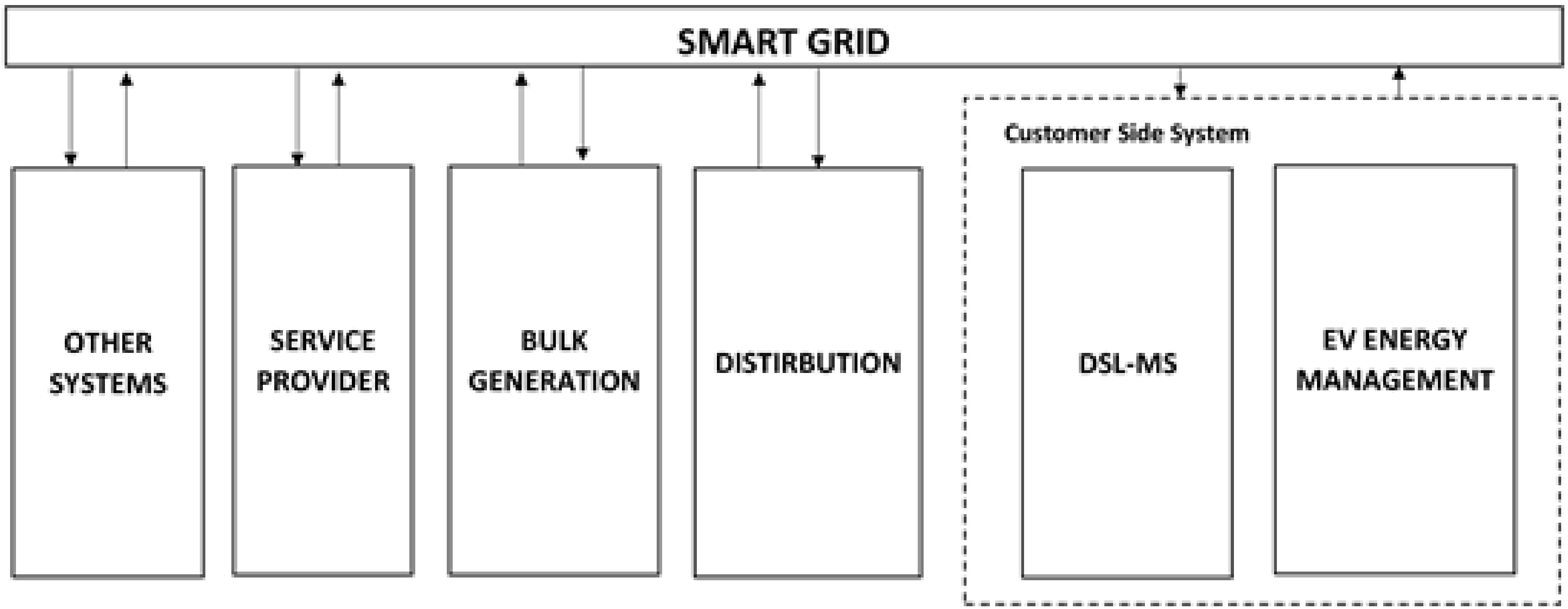
No.	SAFETY CONSTRAINT
1	Smart grid must be able to meet unexpected demand
2	Smart grid must be able to satisfy local energy demands
3	Smart grid must be able to keep customers comfortable asper context preferences

8. Cross sectoral Risk Analysis (3/7)

STEP 2: Modeling the control structure

Abstract Control structure

First, the basic systems are defined in order to enforce the constraints and prevent the hazards identifies earlier.

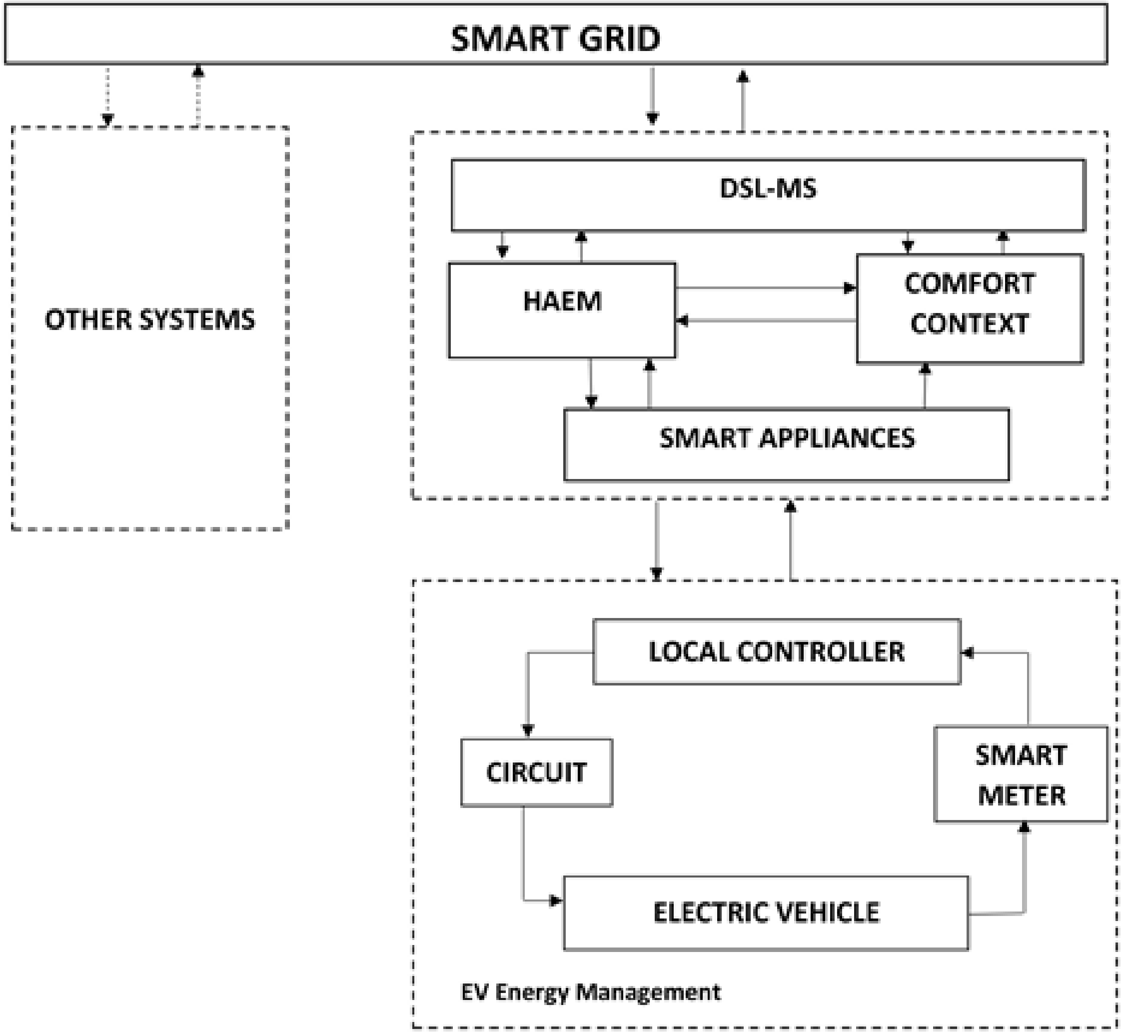


8. Cross sectoral Risk Analysis (4/7)

STEP 2: Modeling the control structure

Refined control structure

For the selected systems the control structures are refined containing the system components (controllers, actuators, sensors and control processes).

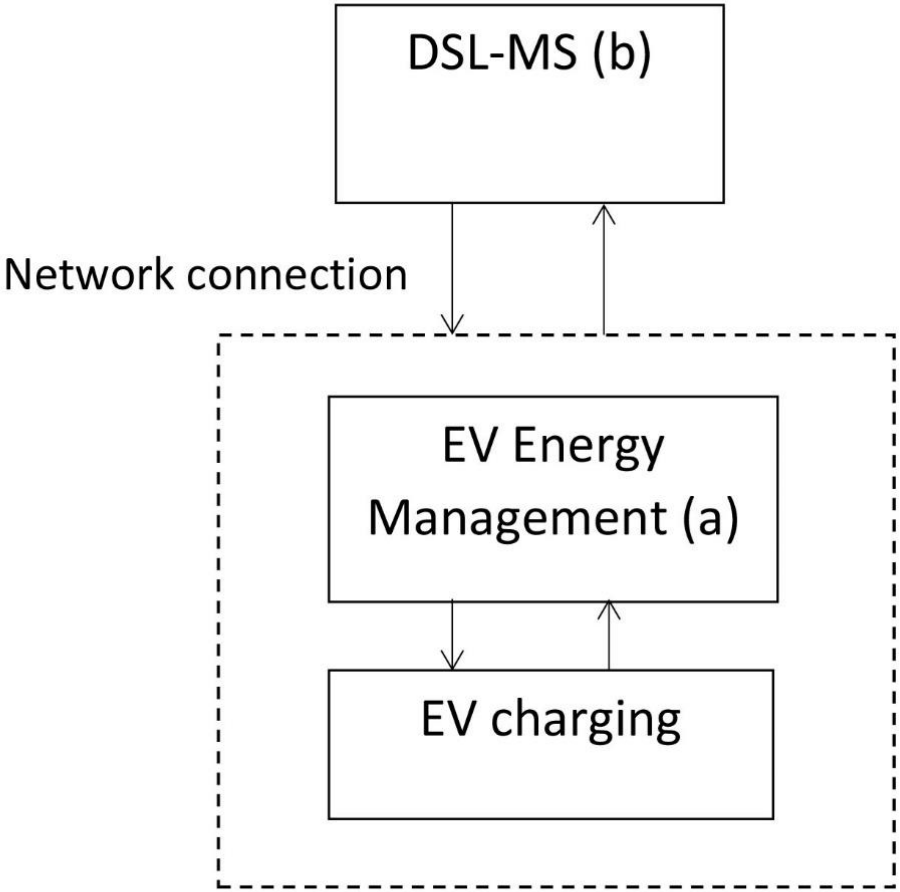


8. Cross sectoral Risk Analysis (5/7)

STEP 2: Modeling the control structure

Identify the **fundamental coordination relationship**

In the examined problem, the systems to coordinate are the **DSL-MS** (Decision System b), and the **EV Local Controller** (Decision System a), while the controlled process that dependents on the decision systems is the **EV charging.**



8. Cross sectoral Risk Analysis (6/7)

STEP3: Identifying **CAs** and related **UCAs**

Control Action	Control required for safety is not provided.	Providing control action causes hazard	Provided at incorrect time (too early/late) or in wrong sequence	Provided for incorrect duration (too soon/long)
A. Excessive capacity demand	A1. DSL-MS doesn't demand excessive capacity while there is a need to cover more loads [2,3]	A2. DSL-MS demands excessive capacity more than the required capacity for appliances to operate in the defined time horizon ahead [1]	A3. DSL-MS demands excessive capacity too late (to be done) after request [2,3]	A4. DSL-MS stops demanding for excessive capacity while overload still remains [2, 3]
B. HAEM predicts required loads	B1. HAEM does not provide accurate load prediction while there is a change to the load schedule [2, 3]	B2. HAEM makes an inaccurate load prediction [1]	B3. HAEM provides a load prediction too late after the change on the load schedule [2, 3]	
C. EV local controller (LC) sends charging request	C1. EV-LC does not send charging requests while the EV must be charged [2, 3]	C2. EV-LC sends charging requests while there is no need for charging[1, 2, 3]		C3. EV-LC stop sending charging request while the request isn't accepted yet [2, 3]

8. Cross sectoral Risk Analysis (6/6)

STEP4: Examine Hazardous Lateral Coordination Scenarios

Hazardous Lateral Coordination Scenarios	UCA	Recommendation
Communication		
a. Battery charge request is not communicated due to a corrupted cable.	A1, B1, C1	Notification alert must be send to the EV local controller.
a. Message format between the two Decision systems gets invalid.	A2, A3, A4, B1, B2, B3, C3	Compatibility regulation establishment
a. EV meter (sensor) sends wrong current charging level that is communicated to DSL-MS.	A1, A2, A3, A4, B1, B2, B3, C1, C2, C3	Irregular deviation monitoring and alert system

9. Conclusions

- Cities as systems demonstrate a high level of **complexity of interconnections** that represent both **challenges** and **opportunities**.
- The research focused on the adaptation of a **new accident analysis technique** called STPA (System-Theoretic Process Analysis) to formally specify the potential **unsafe control situations** that may lead to **significant hazards in communication** among various city decision systems and especially between smart grid and EV transportation.
- Next steps can involve:
    a. Implementation of STPA process on other **subsystems** and **processes that communicate** in the framework of a **smart city**
    b. Further expansion of the methodology to address **additional risk** and hazards with focus on the **technical operation** of smart grids and EVs.

Thank you for your attention!

Chondrogianni V. Dimitra
Architect, Civil Engineering MSc
PhD Candidate, University of Patras
Email: d.chondrogianni@gmail.com