CYTED Madrid Workshop
28-29 November 2016

Measuring robustness in SCM by links shutdown

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2. Approach to measure robustness
3. Modelling the network collapse
4. Experimental framework and results
5. Summary and conclusions

1.INTRODUCTION

1. **Introduction**
2. Approach to measure robustness
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1.INTRODUCTION

- Globalization has brought more movement of good $\rightarrow$ design of logistics networks is more important
- Logistics networks design: decisions about nodes (plants, warehouses…), links, transportation modes, locations, flows…
- Poorly designed networks led to inefficient operations (redundancies,…)

1.INTRODUCTION

	FINANCE	PROD	SERV	TIME	SUST
FINANCE	Azaron et al. (2008) Longinidis and Georgiadis (2013)				
PROD	+SERV: Chen and Lee (2004) +TIME: Chen et al. (2007)	Chen et al. (2003) Pokharel (2008)			
SERV	Guillém et al(2005) +TIME: Cintron et al. (2010) +PROD: Chen and Lee. (2004)	Sabri and Beamon (2000) Altiparmak et al. (2006) Liao et al. (2011) Amin and Zhang (2012) Hiremath et al. (2013) Ramezani et al. (2013) +FINA: Chen and Lee. (2004)	Gaur and Ravindran (2006) Xu et al. (2008) Fonseca et al. (2010) Franca et al. (2010) Pishvaee et al. (2010) Latha et al. (2013) Razmi et al. (2013)		
TIME	+SERV: Cintron et al. (2010) +PROD: Chen et al. (2007)	Liu and Papageorgiou. (2013) Melachrinoudis and Min (2000) +SUST: Luo et al. (2001) +FINA: Chen et al. (2007)	Che and Chiang. (2010) Li et al. (2012) +FINA: Cintron et al. (2010) +SUST: Yeh and Chuang (2011)	Zhou et al. (2003) Eskigun et al. (2005) Du and Evans (2008) Farahani and Elahipanah (2008) Pishvaee and Torabi (2010) Cardona-Valdés et al. (2011) Bevilacqua et al. (2012) Javanshir et al. (2012) Mehrbod et al. (2012) Olivares-Benitez et al. (2012) Olivares-Benitez et al. (2013) Zhang et al (2013)	
SUST	You et al. (2012)	+TIME: Luo et al.(2001)	+TIME: Yeh and Chuang (2011)	Dotoli et al. (2006) +PROD: Luo et al. (2001) +SERV: Yeh and Chuang (2011)	Hugo and Pistikopoulos (2005) Dotoli et al. (2007) Frota Neto et al. (2008) Pinto-Varela et al (2011) Wang et al. (2011) Chaabane et al. (2012) Jamshidi et al. (2012) Paksoy et al. (2012) Pishvaee and Razmi (2012) Pishvaee et al. (2012) Amin and Zhang (2013) Ruiz-Femenia et al. (2013) Sadrnia et al. (2013) Soysal et al. (2013)

1.INTRODUCTION

Volcano Eyjafjalla Iceland, April 2010)

1.INTRODUCTION

Eastern USA, “Superstorm of 1993”

1.INTRODUCTION

Sandy tropical storm (NY, 2012)

1.INTRODUCTION

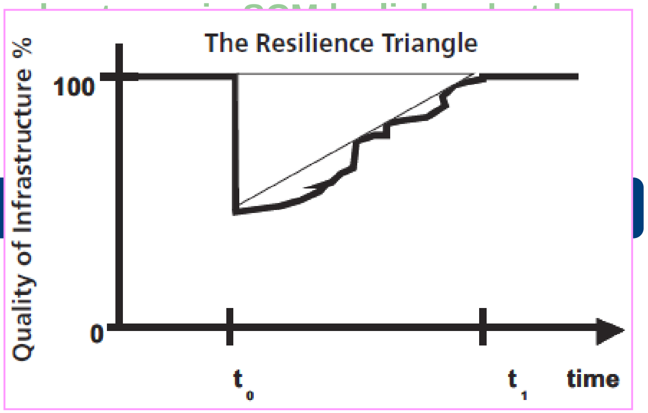
Tsunami Japan, March 2011

1.INTRODUCTION

but also….

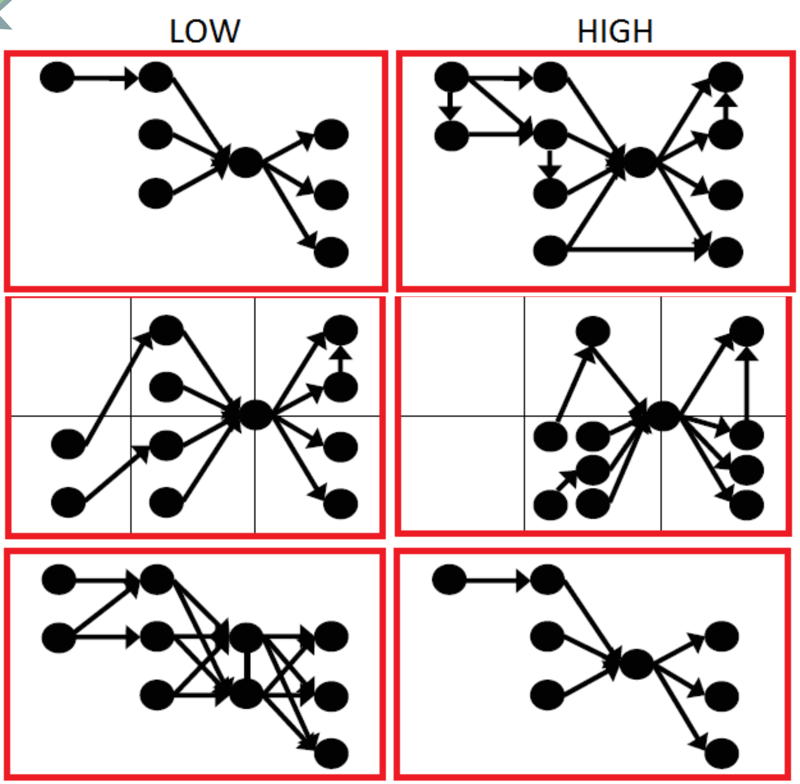
Terrorist attack, NY, Sept. 2001

1.INTRODUCTION



RESILIENCE

- SC RESILIENCE is defined as the ability of a SC to reduce:
  - ✓ probability of disruption
  - ✓ consequences of the disruptions
  - ✓ time to recovery after a disruption
- Craighead et al (2007) identified 3 main factors affecting resilience:
  - Nodes and links complexity
  - Density (geographical)
  - Node criticality
- Mohapatra et al (2015) claim excess capacity increases resilience



1.INTRODUCTION

GOALS:

- Define a bi-objective model minimizing not-served demand and costs, in order to…
- use the model to define a measure of robustness when links collapse.
- Analyse how some factors can influence that robustness

PLANNING:

We need to define:

- The **model** to decide the best network to manage demands
- The **measure** of robustness in this context
- The **factors** that could have influence in the measure
- How to generate the corresponding **instances**
- How to **analyse** the results

2.APPROACH TO MEASURE ROBUSTNESS

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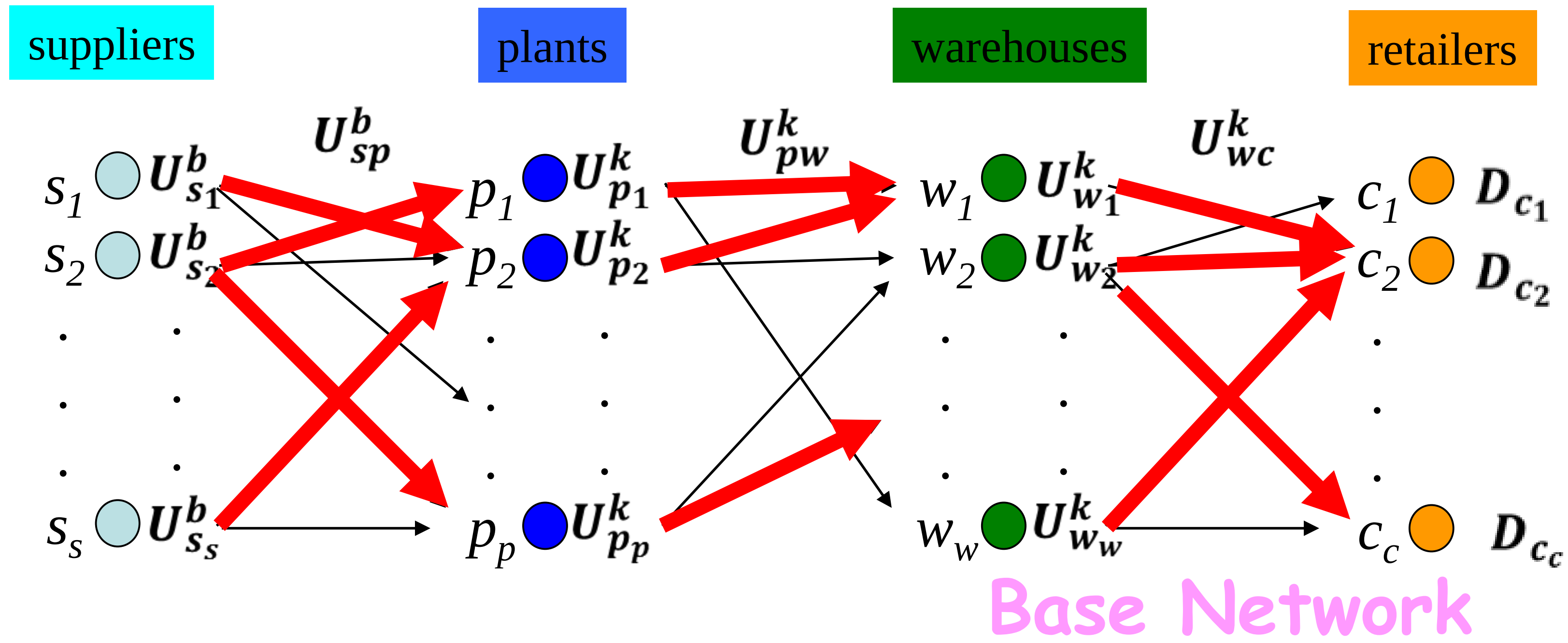
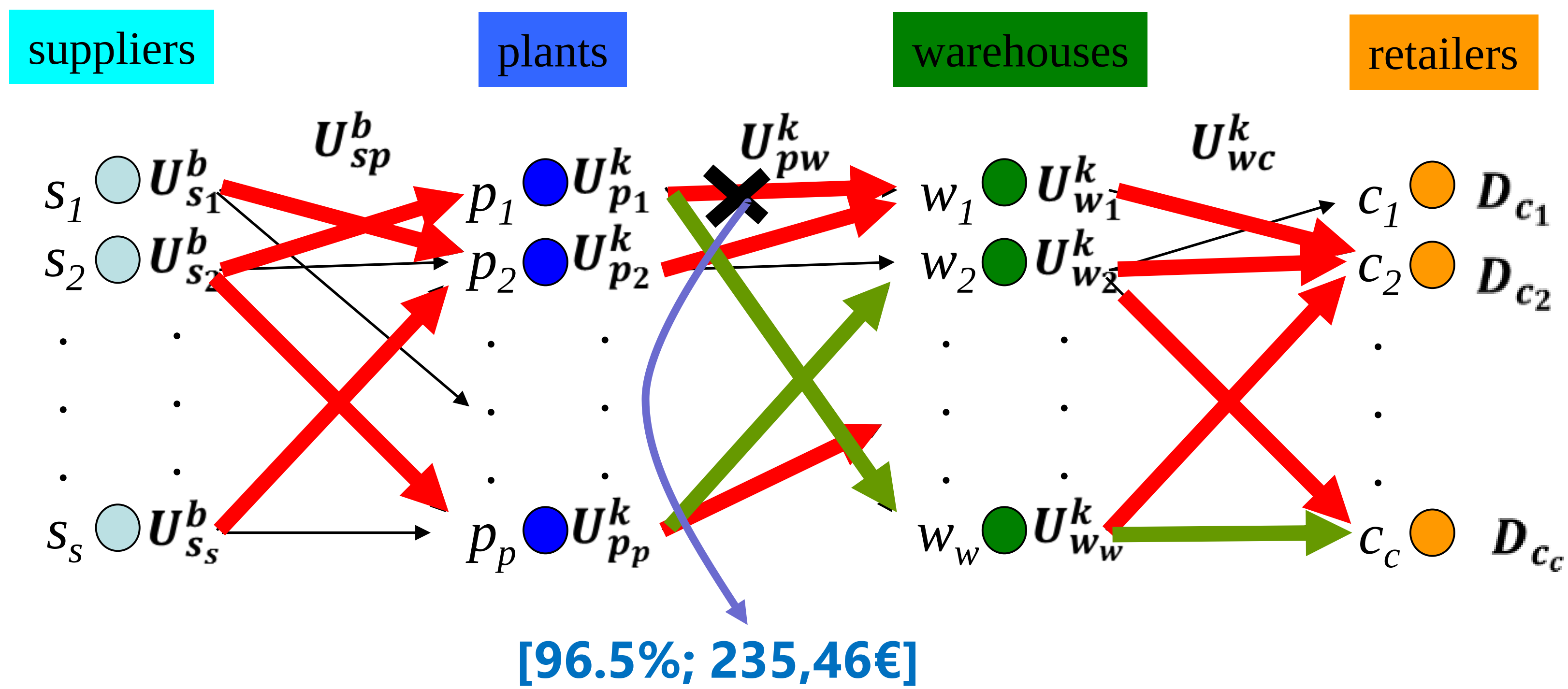
2.APPROACH TO MEASURE ROBUSTNESS



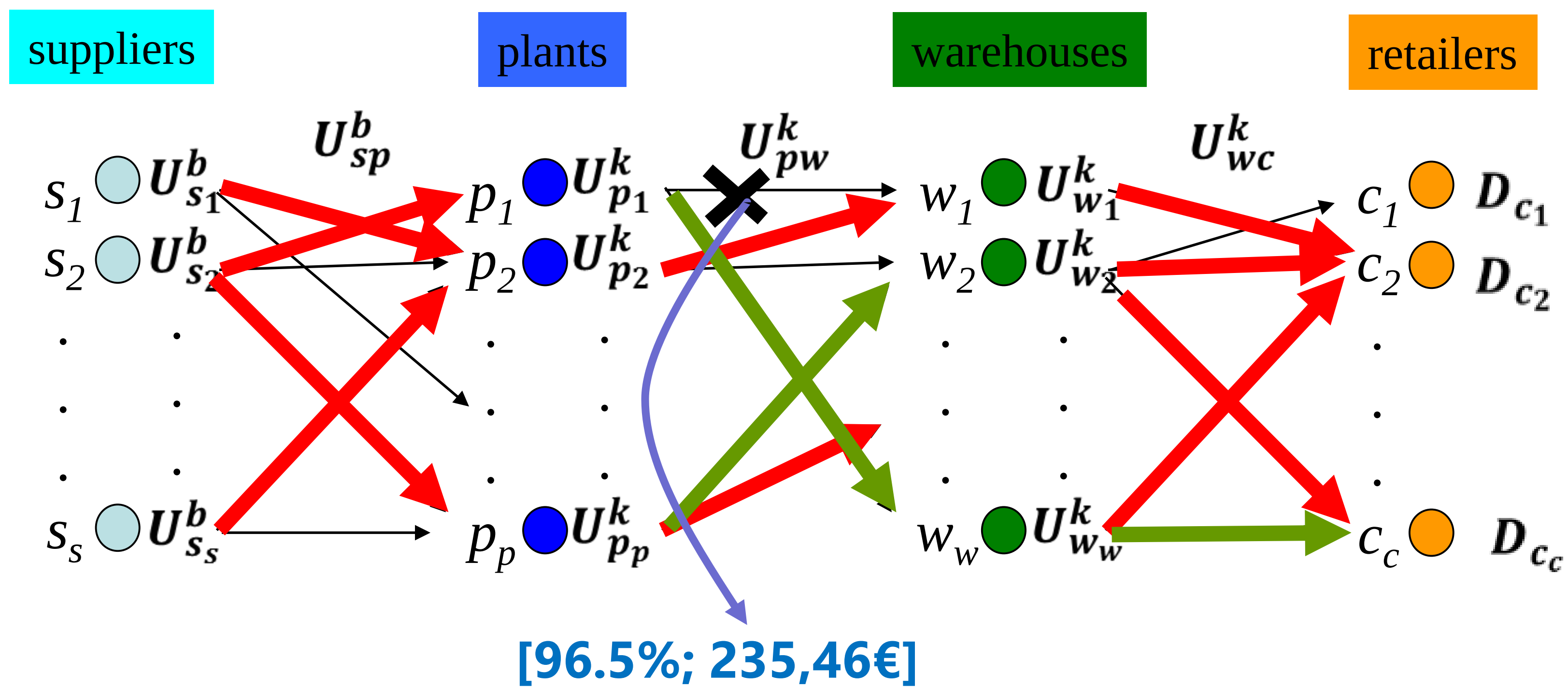
- A network with 4 echelons (demand in the last one)
- No fixed costs; max capacity in links (not nodes)
- An LP **model** minimize cost (demand must be satisfied)
- Links in the *Base Network* will be shutdown to study the effects

2.APPROACH TO MEASURE ROBUSTNESS



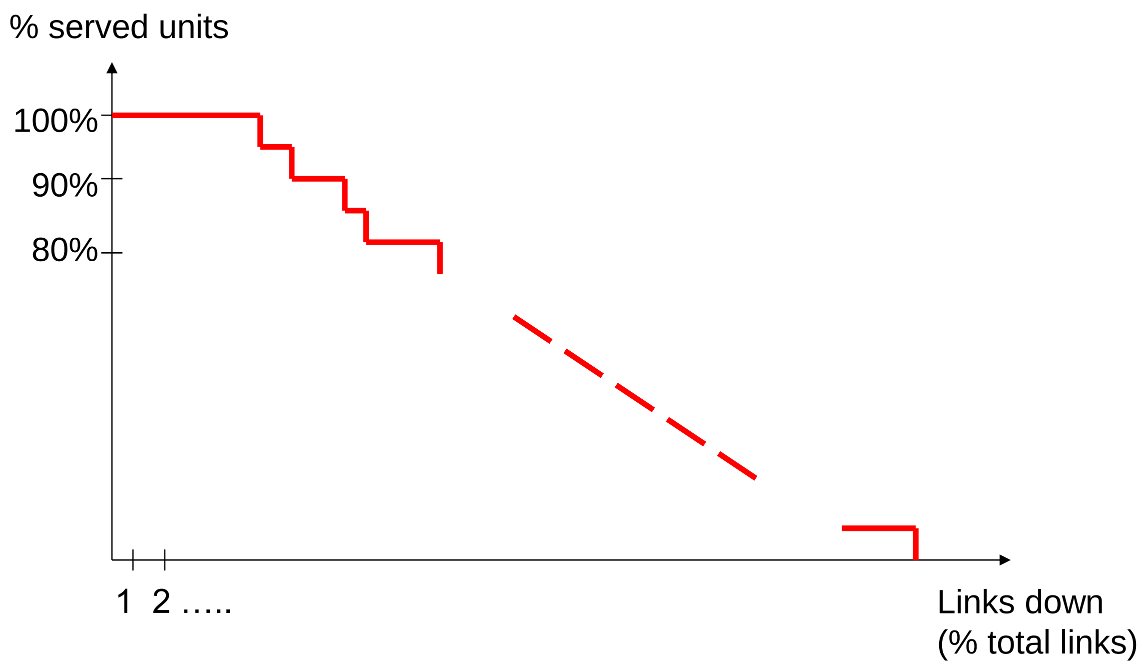
- ❑ Shutdown one-by-one links in the BN
- ❑ An LP **model** solves **lexicographically** {max service level; min cost} using any link except the forbidden ones (demand fulfillment is a soft constraint)
- ❑ Attached to each collapsed link: [% demand served; average cost per unit]

2.APPROACH TO MEASURE ROBUSTNESS



- We could sort the links according to their criticality regarding service level
- …but we could also shutdown groups of links successively (regional strike, bankrupcy of a carrier…) and study degradation (*monotonically decreasing*) in service level solving each time the lexicographic model

2.APPROACH TO MEASURE ROBUSTNESS



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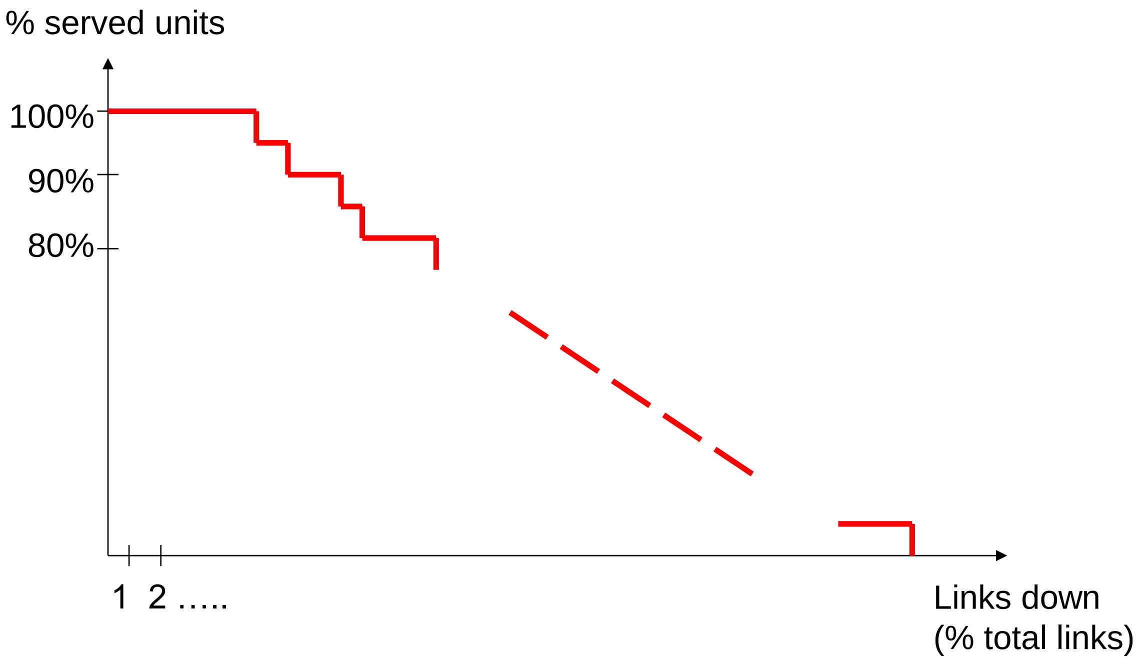
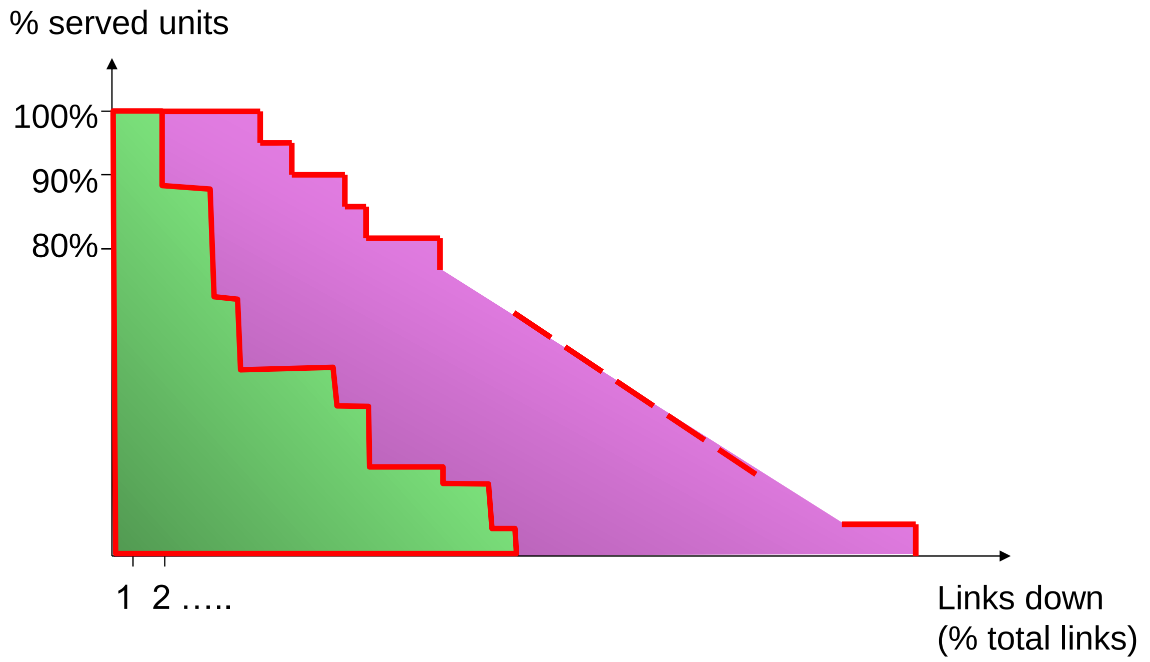


- In which order to shutdown links?
  - ***Randomly***.- Natural disasters, accidents…
  - ***Targeted***.- Someone selects what to shutdown: we sort them according to higher flows in the BN solution

2.APPROACH TO MEASURE ROBUSTNESS



- Considering the area under the ladder divided by the No. of links, we could define a measure of the the robustness against succesive links collapse
  - ✓ $R^{target}(N)$ (deterministic)
  - ✓ $R^{rand}(N)$ (average of a number of replications)

3.MODELLING THE NETWORK COLLAPSE

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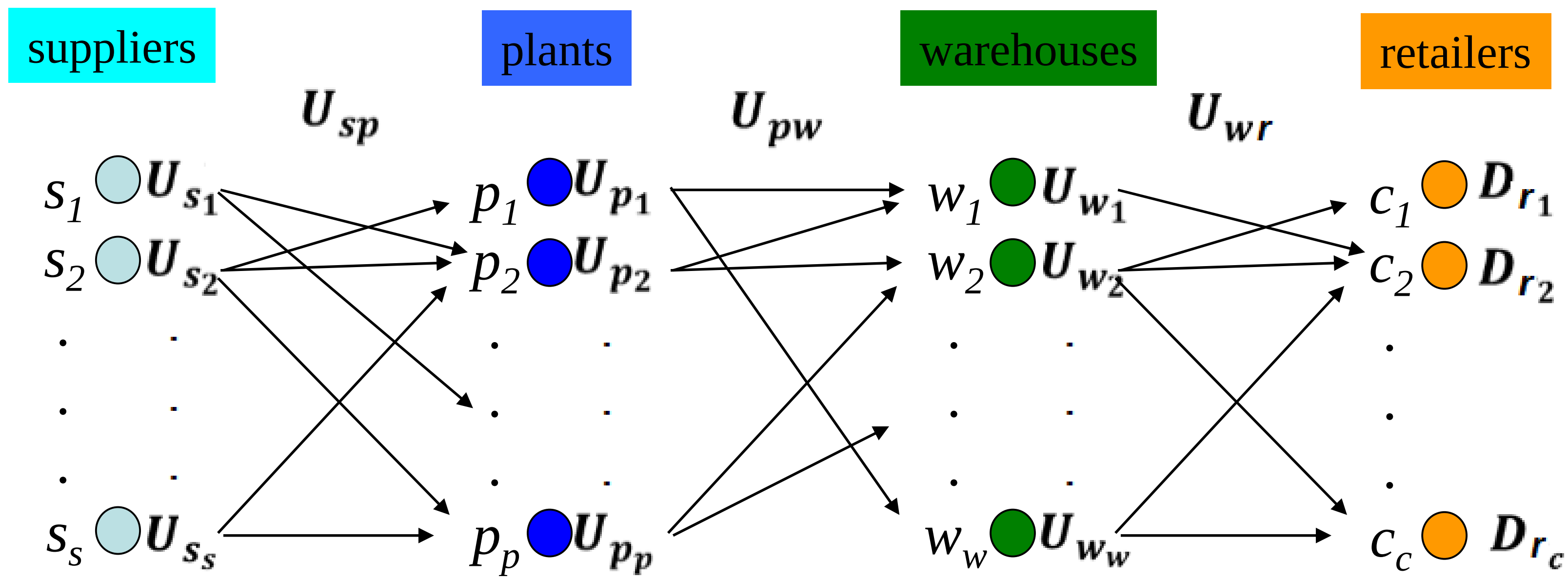
3.MODELLING THE NETWORK COLLAPSE



C_{sp} C_{pw} C_{wr}

Transportation costs

$\mathbf{x}_{sp}$ $\mathbf{x}_{pw}$ $\mathbf{x}_{wr}$

Decision variables

3.MODELLING THE NETWORK COLLAPSE

BN MODEL

$$\text{Min} \quad \sum_{s}\sum_{p} c_{sp} \cdot x_{sp} + \sum_{p}\sum_{w} c_{pw} \cdot x_{pw} + \sum_{w}\sum_{r} c_{wr} \cdot x_{wr}$$

transport cost

$$\sum_{w} x_{wr} = D_r \qquad \forall r$$

fulfil demand

$$\sum_{s} x_{sp} = \sum_{w} x_{pw} \qquad \forall p$$

what enters, leaves

$$\sum_{p} x_{pw} = \sum_{r} x_{wr} \qquad \forall w$$

(not negativity)

capacity constraints

$$x_{sp} \le U_{sp} \qquad \forall s \, \forall p$$

$$x_{pw} \le U_{pw} \qquad \forall p \, \forall w$$

$$x_{wr} \le U_{wr} \qquad \forall w \, \forall r$$

3.MODELLING THE NETWORK COLLAPSE

LEXICOGRAPHIC MODEL

$$\text{Lex Min} \left\{ \begin{array}{l} \sum_r d_r \\ \sum_s \sum_p c_{sp} \cdot x_{sp} + \sum_p \sum_w c_{pw} \cdot x_{pw} + \sum_w \sum_r c_{wr} \cdot x_{wr} \end{array} \right\}$$

demand not served

transport cost

$$\sum_w x_{wr} = D_r - d_r \quad \forall r$$

~~fulfil demand~~

$$\sum_s x_{sp} = \sum_w x_{pw} \quad \forall p$$

$$\sum_p x_{pw} = \sum_r x_{wr} \quad \forall w$$

what enters, leaves

(not negativity)

capacity constraints

$$x_{sp} \le U_{sp} \quad \forall s \, \forall p$$

$$x_{pw} \le U_{pw} \quad \forall p \, \forall w$$

$$x_{wr} \le U_{wr} \quad \forall w \, \forall r$$

collapsed links

$$x_{sp} = 0 \quad \forall s \, \forall p \in P^-(s)$$

$$x_{pw} = 0 \quad \forall p \, \forall w \in W^-(p)$$

$$x_{wr} = 0 \quad \forall w \, \forall r \in R^-(p)$$

4.EXPERIMENTAL FRAMEWORK AND RESULTS

1. Introduction
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4.EXPERIMENTAL FRAMEWORK AND RE

F1. NODES COMPLEXITY
F2. LINKS COMPLEXITY
F3. NETWORK CAPACITY

FACTORS (2-levels, L/H)

- **F1: *No. of nodes in the network*** (10/3/10/50 nodes ; 20/6/20/100 nodes)
- **F2: *No. of links*** (70% links of complete graph ; all links of complete graph)
- **F3: Over-*capacity of nodes and links*** (1.1*average demand; 1.3*a.d.)

Replications: 50 $\Rightarrow$ $2^3 \times 50 =$ **400 instances**

F1. NODES COMPLEXITY
F2. LINKS COMPLEXITY
F3. NETWORK CAPACITY

4.EXPERIMENTAL FRAMEWORK AND R

SOME PRELIMINARY RESULTS

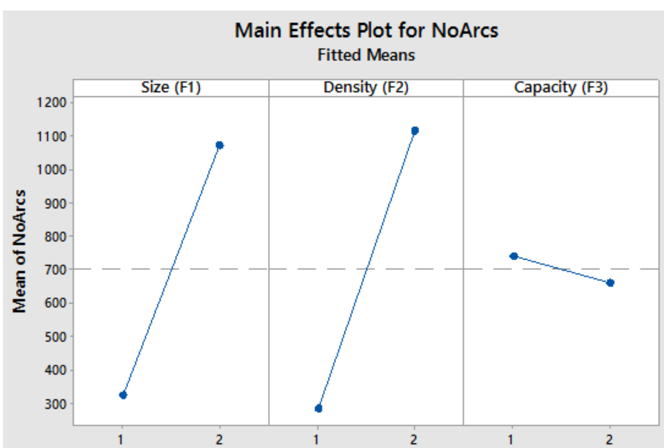
- Regarding the Base Network calculation, F1 and F2 are both significant on No. of Links and Total Cost (more complexity → more links and costs)
- Capacity has no influence

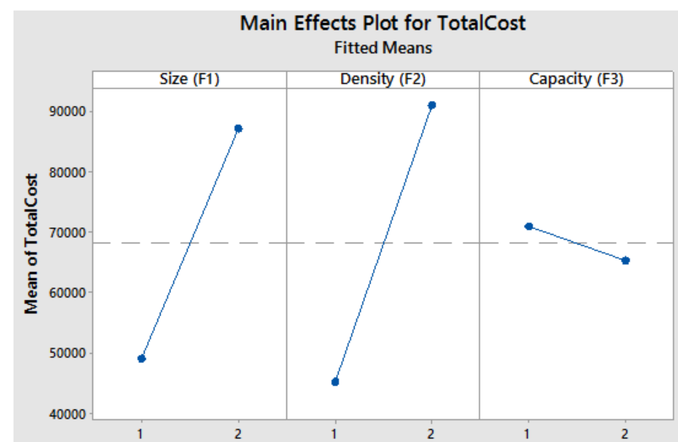
No. LINKS
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Size (F1)	1	1114925	1114925	3809.26	0.000
Density (F2)	1	2646478	2646478	9041.98	0.000
Capacity (F3)	1	655	655	2.24	0.135
Size (F1)*Density (F2)	1	16953082	16953082	57922.01	0.000
Size (F1)*Capacity (F3)	1	373	373	1.27	0.260
Density (F2)*Capacity (F3)	1	40927	40927	139.83	0.000
Size (F1)*Density (F2)*Capacity (F3)	1	252004	252004	861.00	0.000
Error	392	114734	293		
Total	399	154533675			

TOTAL COST
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Size (F1)	1	8759567287	8759567287	342.27	0.000
Density (F2)	1	21798992873	21798992873	851.77	0.000
Capacity (F3)	1	15706716	15706716	0.61	0.434
Size (F1)*Density (F2)	1	22096470158	22096470158	863.39	0.000
Size (F1)*Capacity (F3)	1	1134214	1134214	0.04	0.833
Density (F2)*Capacity (F3)	1	540455140	540455140	21.12	0.000
Size (F1)*Density (F2)* (F3)	1	236185413	236185413	9.23	0.003
Error	392	10032275538	25592540		
Total	399	4.08071E+11			





F1. NODES COMPLEXITY
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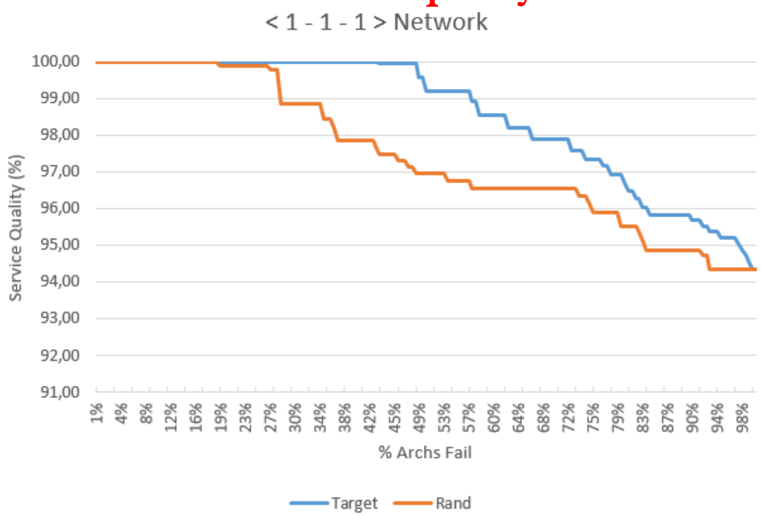
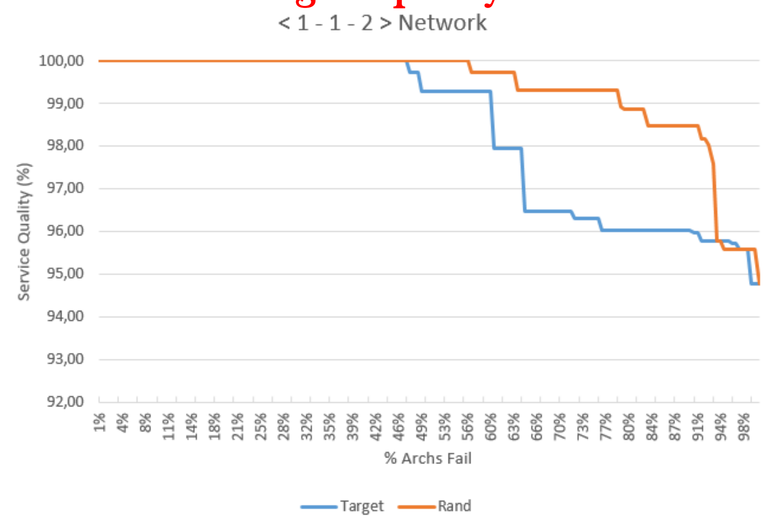
4.EXPERIMENTAL FRAMEWORK AND RE

SOME CURVES (Low No. Nodes)

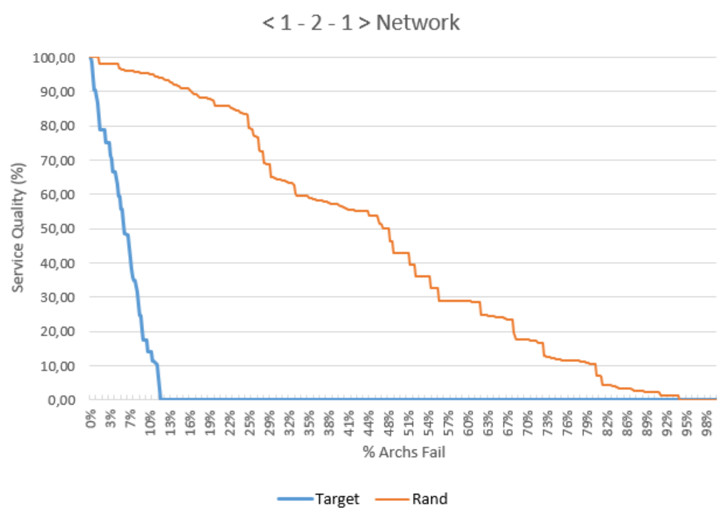
low capacity | high capacity

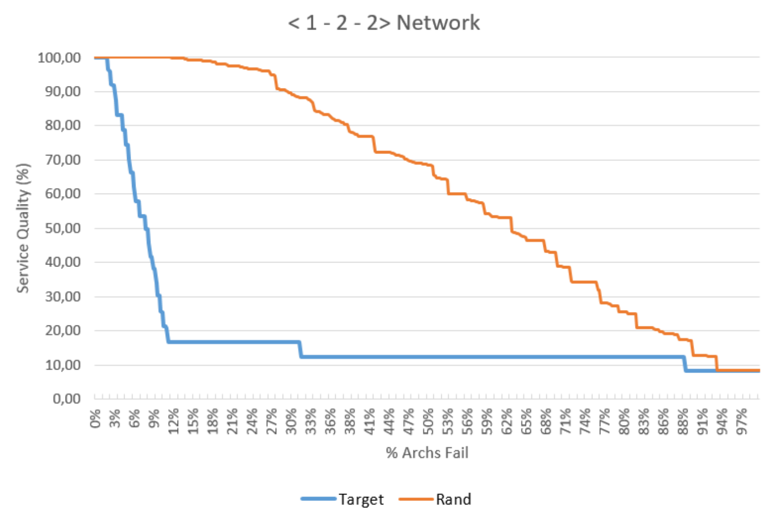
70% links





100% links





F1. NODES COMPLEXITY
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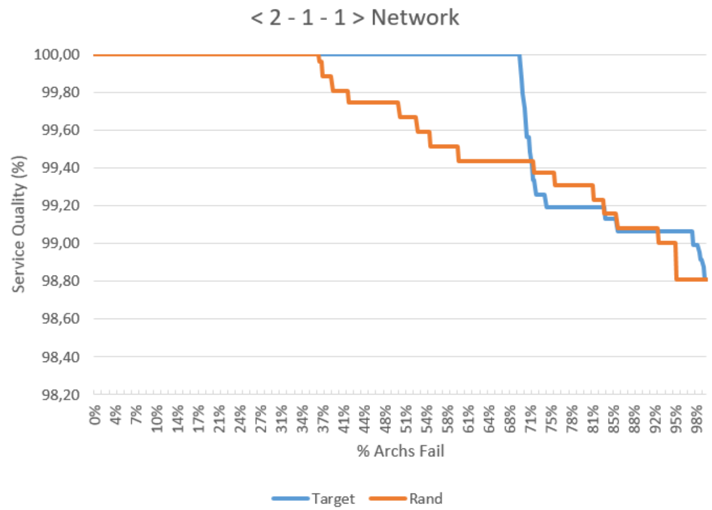
4.EXPERIMENTAL FRAMEWORK AND RE

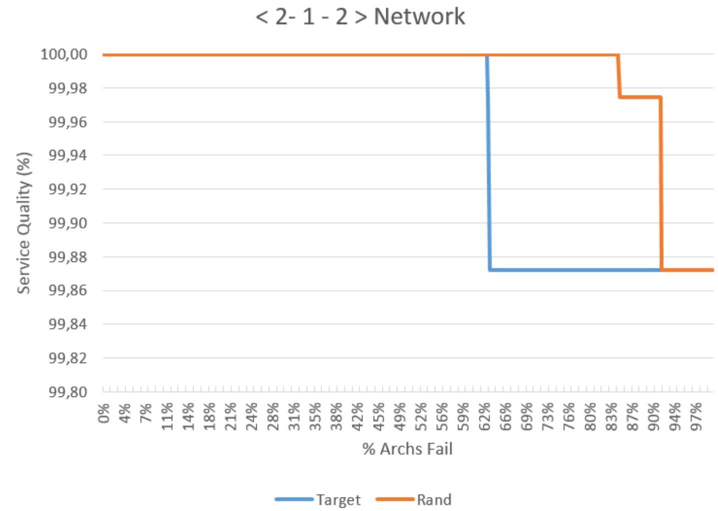
SOME CURVES (High No. Nodes)

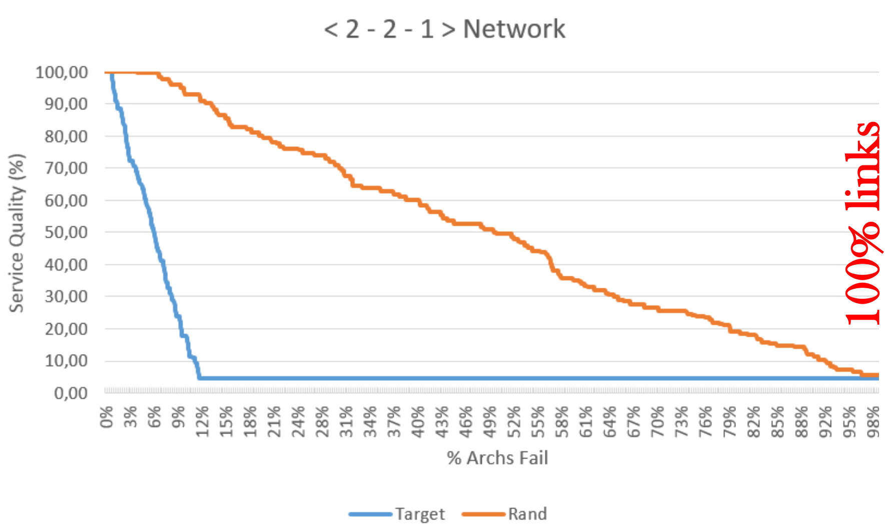
low capacity

high capacity

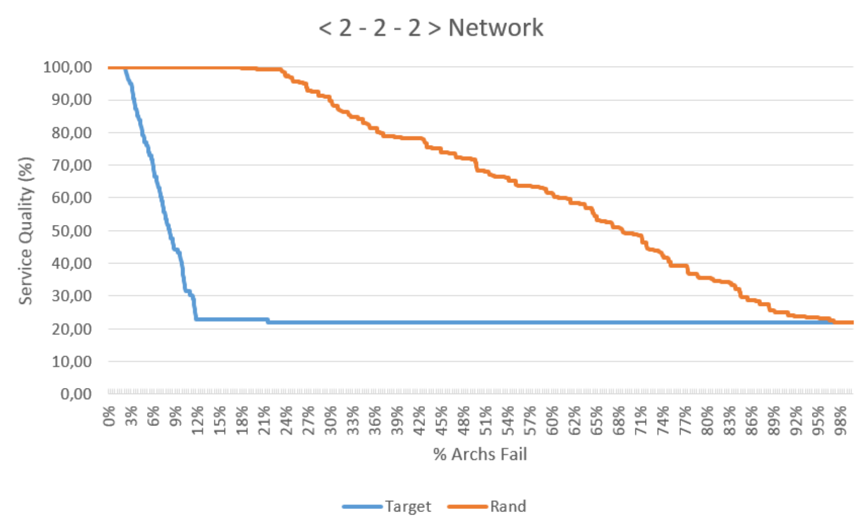


70% links





100% links



F1. NODES COMPLEXITY
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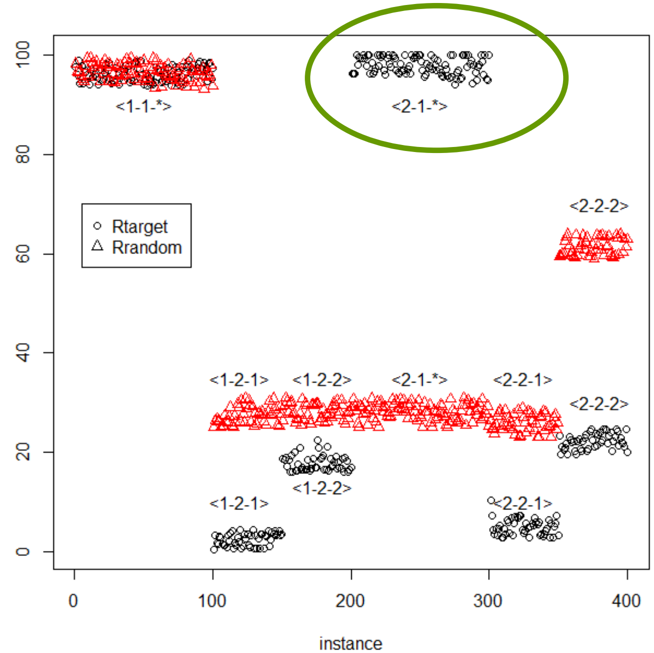
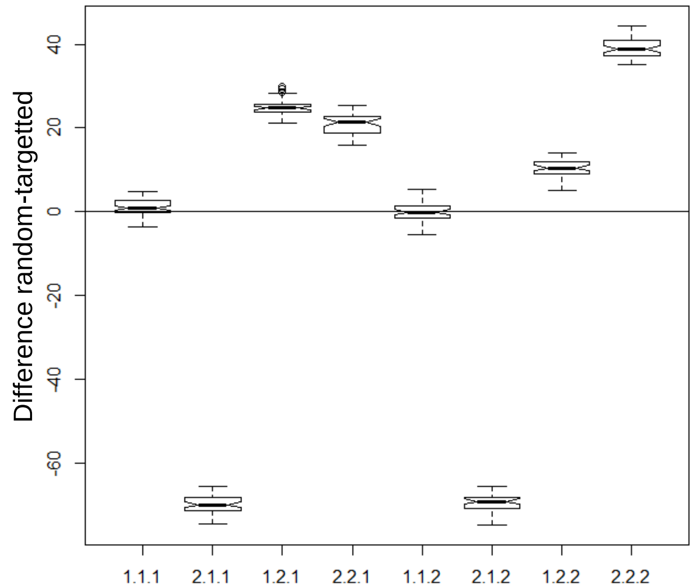
4.EXPERIMENTAL FRAMEWORK AND RE

SOME PRELIMINARY RESULTS

Larger robustness is found under
targeted attack than under random failure!!





- For high “link complexity” networks ⟨*-2-*⟩, R^{targ} and R^{rand} behave as expected
- …and the most complex cases ⟨2-2-2⟩, with clear effects of targeted attacks
- For low “link complexity” AND “high node complexity”, unexpected behaviour is observed

5. SUMMARY AND CONCLUSIONS

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5. SUMMARY AND CONCLUSIONS

- We propose a measure of robustness as resilience under successive collapse of links, measured as the area of service level
- Some experiments have been carried out, considering random and targeted attacks
- First results show unexpected behaviour when the network is complex in nodes and links
- Over-capacity of the chain seems not having much influence in network characteristics and robustness

5. SUMMARY AND CONCLUSIONS

FURTHER QUESTIONS

- Introduce the other two resilience factors (density and node criticality) described by Craighead et al (2007)
- Sorting links according to their impact when collapsing, instead of flow
- So far the impact on service level has been assessed but cost impact may also be important
- Ways of increasing resilience can be devised
- In this study only the arcs can collapse but, in practice, supply chain nodes can also fail