Modelling Security of Critical Infrastructures: A Survivability Assessment

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Introduction (I)

Critical Infrastructures

- Provide essential services to the society
  - Power distribution, water treatment, telco, financial services...
- Discontinuity of service may lead to fatalities or injuries
  - Different nature, from unintended acts of nature to intentional attacks (e.g., sabotage, terrorism)





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Introduction (II)

Recent examples

2003 Northeast (U.S.) blackout

- Attributed to downed power line
- 11 deaths and an estimated $6B in economic damages, plus disrupted power over a wide area for two days

2013 Bowman Avenue Dam in NY was compromised, and control of the floodgates was gained

- Attributed to Iranian hackers

2015 Prykarpattyaoblenergo Control Center (PCC) in the Ivano-Frankivsk region of Western Ukraine

- Leaving 230K residents without power for up to 6 hours
- Presumed Russian cyberattacker

Not only safe, but also secure

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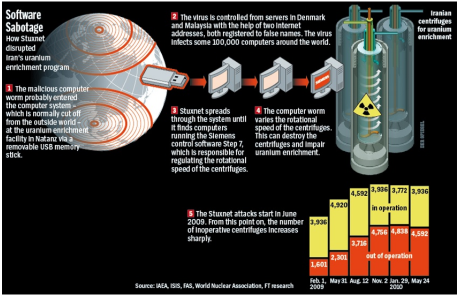
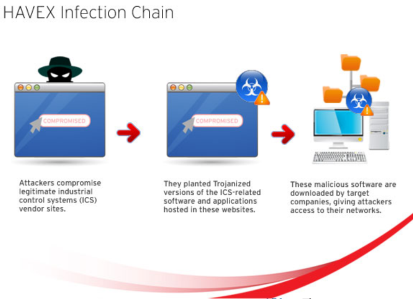
Introduction (III)

The *game* just begun...

- Cyberattacks against SCADA systems doubled in 2014: more than 160K (Dell's 2015 Annual Security Report)
- Malware targeting SCADA systems identified:
  - Examples: Stuxnet, Havex, and BlackEnergy3





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Introduction (IV)

Survivability

- *Capability of a system to fulfill its mission, in a timely manner, in the presence of attacks, failures, or accidents*
- Usually qualitative in nature; and not precise or detailed enough to facilitate measurable survivability requirements and evaluations
- Survivability strategies phases:
  1. Resistance
  2. Recognition
  3. Recovery

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Our proposal

- `SecAM` (Security Analysis and Modelling) UML profile
  - Enables survivability analysis for critical infrastructures to provide capabilities for assessing defence plans

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Introduction (V)

Advantages

- Specification, in a quantitatively and quantitatively manner, of security and survivability in early stages of development
- Specific models for infrastructures and attack patterns
- Survivability analysis through formal models (in particular, Generalized Stochastic Petri nets)
  - Model-checking techniques
  - Allows steady-state analysis
  - Efficient techniques, as linear algebra and linear programming-based techniques

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Disadvantages

- Model complexity increased
- Lack of CASE tools with automated translation

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Background (I): UML profile

UML profile

- UML tailored for specific purposes: profiling
- Stereotypes and tagged values
  - Extend model semantics
  - Allow to express non-functional properties (e.g., performance, reliability, security) within the model

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Background (I): UML profile

UML profile

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OMG example

- *Modelling and Analysis of RT Embedded systems* (MARTE)
  - Provides support for performance and schedulability analysis
  - Well-defined language to express NFPs (VSL, *Value Specification Language*)

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Background (II): GSPNs

UML profiling sounds cool, but. . .

- Express quantitative properties for analysis
  - Transformation to formal models (in particular, Generalized Stochastic Petri nets)
  - Good (and mature) analysis framework

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Background (II): GSPNs

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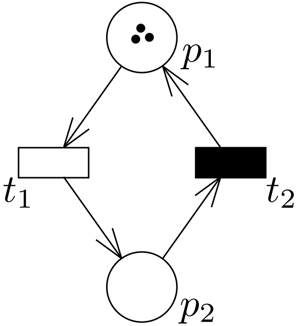
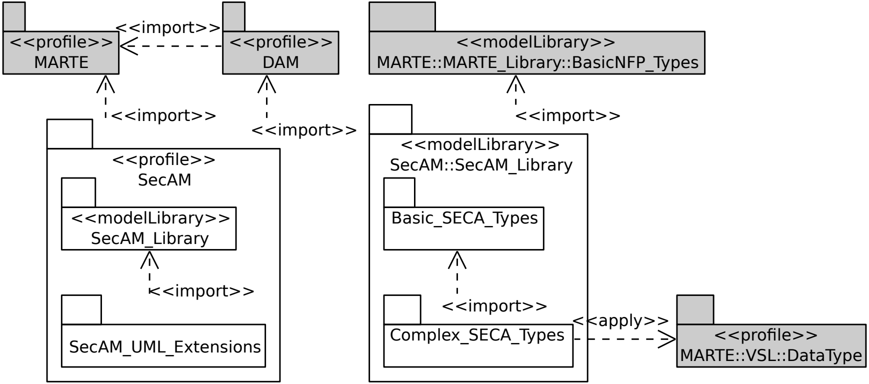


GSPN – explanation simplified

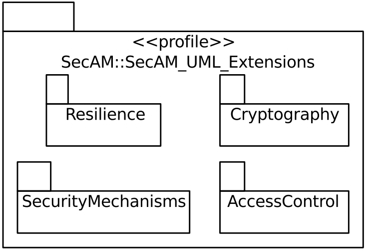
- Underlying Markov-chain
- Places (circles, p_X)
- Transitions (white/black bars, t_X)
- Time interpretation
  - Immediate transitions ($t = 0$)
  - Timed (allows different probabilistic distributions)
- Tokens (black dots)

SecAM Profile (I): a General Overview (1)



- `SecAM` relies on two profiles:
  - MARTE: analysis capabilities (among other features)
  - Dependability Analysis and Modeling (DAM): concepts shared by the dependability and security fields
- Set of stereotypes; and basic and complex types

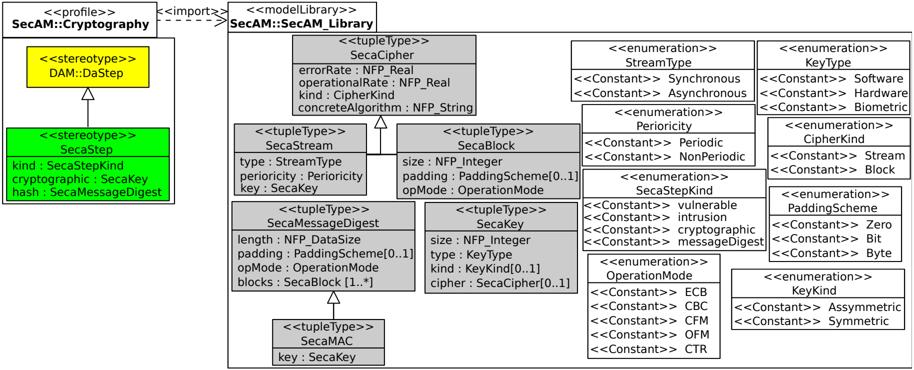
SecAM Profile (I): a General Overview (2)



Security attributes	`SecAM` **packages** (P1)	(P2)	(P3)	(P4)
Integrity	√	√		√
Availability		√	√	
Confidentiality	√	√		√
Authorisation				√
Non-repudiation	√			
Authenticity	√			

(P1): `Cryptographic`; (P2): `SecurityMechanisms`
(P3): `Resilience`; (P4): `AccessControl`

SecAM Profile (II): Cryptography package (1)



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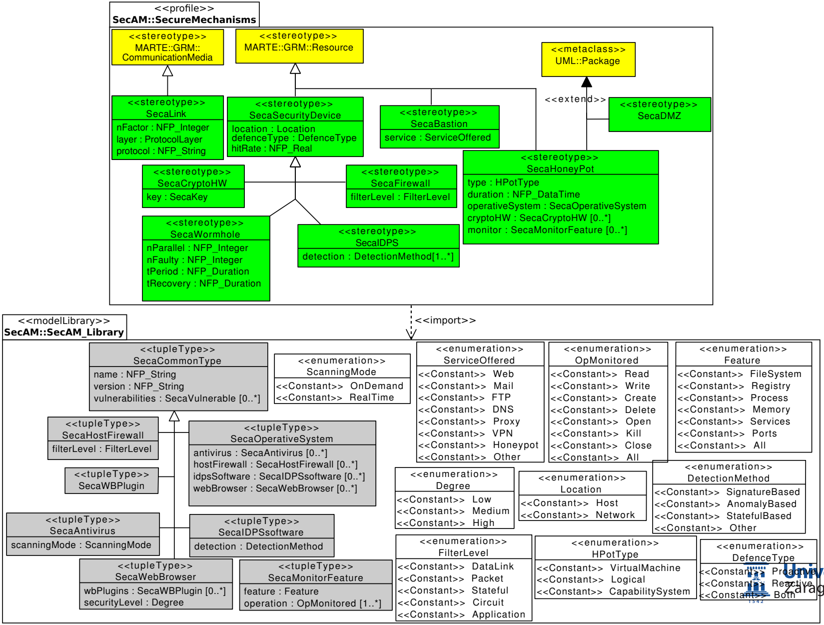
SecAM Profile (III): SecurityMechanisms package



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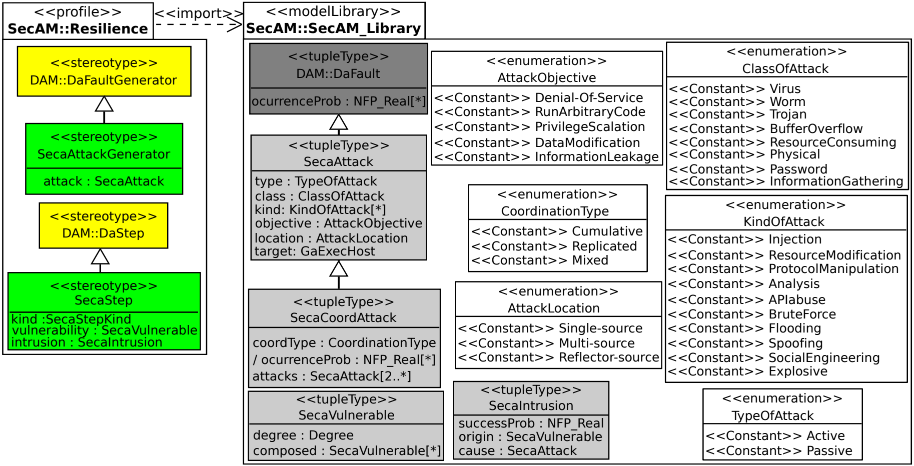
SecAM Profile (IV): Resilience package



SecAM Profile (V): AccessControl package

Proposal (draft)

- Subjects, operations and objects
- Operations: kind and granted/not granted (boolean)
  - Read
  - Write
  - Access
  - Execution?
- Subjects: self-association
  - Delegation of authorisation
  - Separation of duties
- Idea: access control policies specified by OCL (UML constraints)

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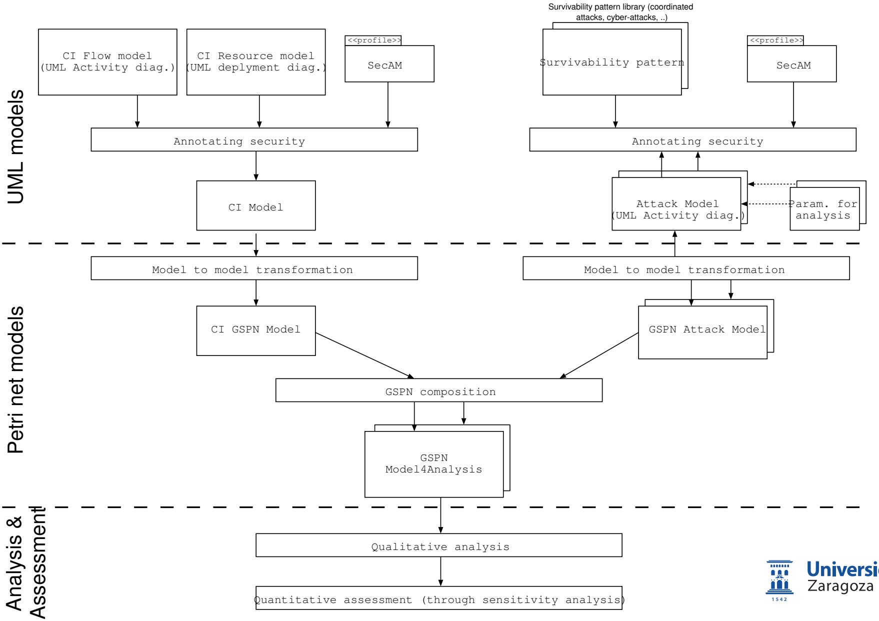
Model-based Methodology



Case Study (I)

Saudi Arabia crude-oil pipeline network (1)

Highlights

- World's largest
  - exporter of petroleum liquids
  - crude oil producer (8-10 mmbbl/day)
- National distribution network
  - $> 9,000$ miles long

Case Study (I)

Saudi Arabia crude-oil pipeline network (2)

- Terrorist target
  - physical attacks (Abqaiq oil facility, 2006)
  - cyberattacks (Shamoon malware, 2012)

[a] Chaney and Berner. *Global: oil price update: still higher and more uncertain.* Global Economic Forum. Morgan& Stanley. 2004

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Case Study (I)

Saudi Arabia crude-oil pipeline network (2)

- Terrorist target
  - physical attacks (Abqaiq oil facility, 2006)
  - cyberattacks (Shamoon malware, 2012)
- A 50% reduction of Saudi Arabia crude-oil output would lead to a global recession if the infrastructure could not be repaired within few months[a]

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Case Study (I)

Saudi Arabia crude-oil pipeline network (2)

- Terrorist target
  - physical attacks (Abqaiq oil facility, 2006)
  - cyberattacks (Shamoon malware, 2012)
- A 50% reduction of Saudi Arabia crude-oil output would lead to a global recession if the infrastructure could not be repaired within few months[a]
- Survivability strategies are a must to quickly recover -hours/days- the infrastructure

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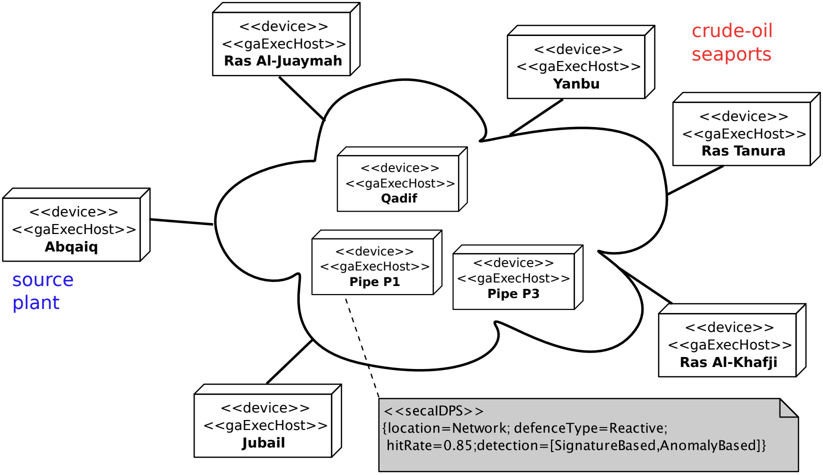
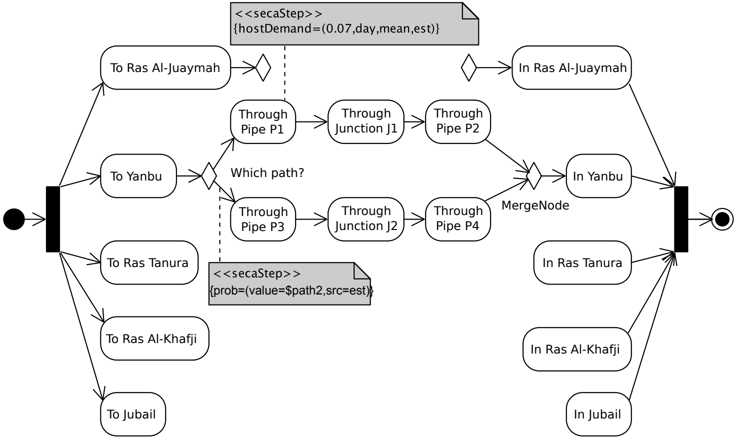
Case Study (II): Distribution network model



- MARTE: devices & exec. hosts
- `SecAM`: security mechs

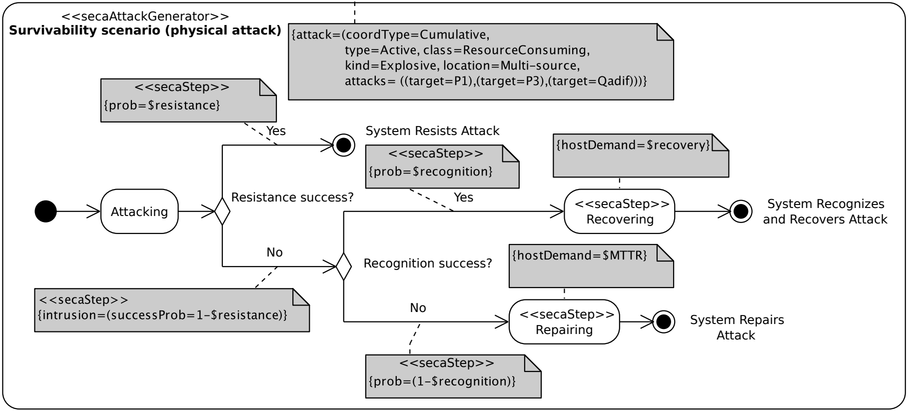
Case Study (III): Crude-oil system flow model



- `SecAM` annotations to specify
  - crude-oil traversal time in pipe, junctions
  - routing probabilities

Case Study (IV): Physical Attack (1)

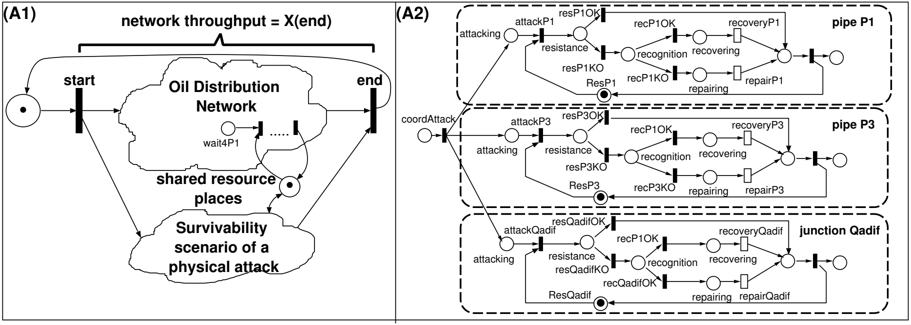
Survivability scenario



- SecAM annotations to specify:
  - Attack type and concrete target nodes in the network
  - Resistance & recognition probabilities
  - Time to recovery & repair

Case Study (IV): Physical Attack (2)

Analysis with GSPN

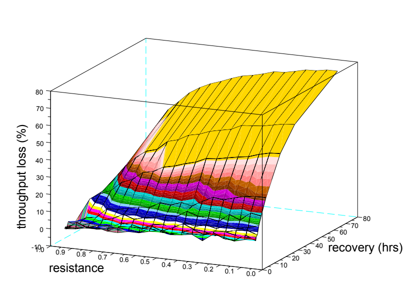


Parameters	Value(s)	GSPN transitions
resistance	[0.05-0.95]	recP1OK, recP3OK, recQadifOK
recognition	1	recP1OK, recP3OK, recQadifOK
recovery	[72-3] hrs	recoveryP1, recoveryP3, recoveryQadif
MTTR	6 months	repairP1, repairP2 repairQadif

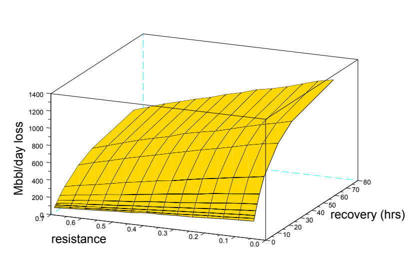
Case Study (IV): Physical Attack (3)

Analysis results

Throughput loss (%)



Mbbl/day loss



- rec < 6hrs → $X < 20\%$, $n < 240$ Mbbl/day

Case Study (IV): Physical Attack (3)

Analysis results

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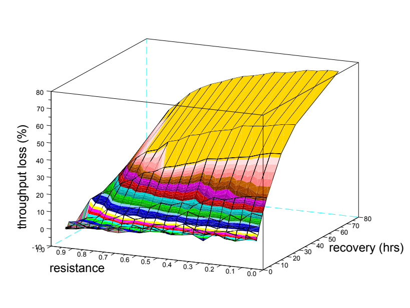

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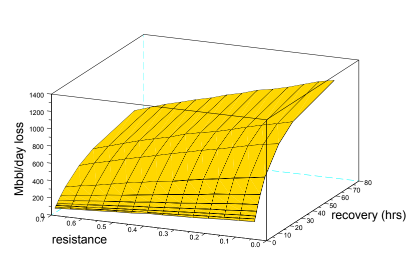
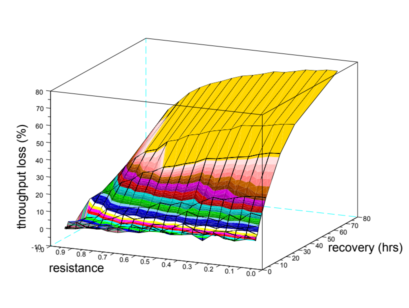


- rec $<$ 6hrs $\rightarrow X < 20\%$, $n < 240$ Mbbl/day
- res $<$ 50%, rec $\in [1-3]$days $\rightarrow X \in [40-77]\%$, $n \in [990K - 1.2M]$

Case Study (IV): Physical Attack (3)

Analysis results

Throughput loss (%)



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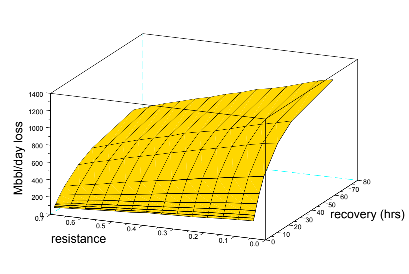
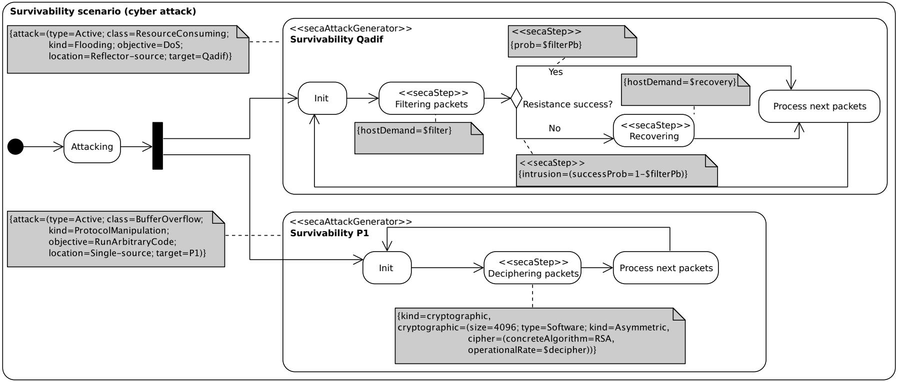


- rec < 6hrs → X < 20%, n < 240 Mbbl/day
- res < 50%, rec ∈ [1 – 3]days → $X \in [40 - 77]\%$, $n \in [990K - 1.2M]$
- Hard resistance solutions required to maintain $X < 50\%$
  - Example: surveillance combined with external perimeter security

Case Study (V): Cyber Attack (1)

Survivability scenario



- Coordinated attack to two computation nodes
  - DoS to Qadif node & run arbitrary code to P1 node
  - Resistance strategies: IPDS & cryptographic algorithm

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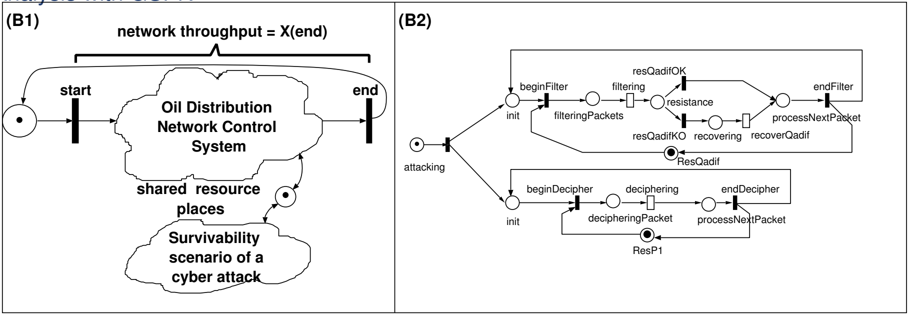
Case Study (V): Cyber Attack (2)

Analysis with GSPN



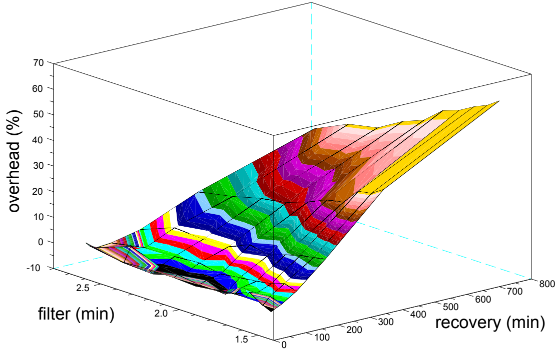
Parameters	Value(s)	GSPN transitions
filterPb	[0.50;..;0.95]	resQadifOK
filter	[1.44min;..;14.4min]	filtering
decipher	2.88 min	deciphering
recovery	[11min-12hrs]	recoveryQadif

- Overhead due filtering solution
  - `filter` and `filterPb` are in direct proportion

Case Study (V): Cyber Attack (3)

Analysis results

- rec $<$ 3hrs $\rightarrow$ $Ov < 16\%$



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Case Study (V): Cyber Attack (3)

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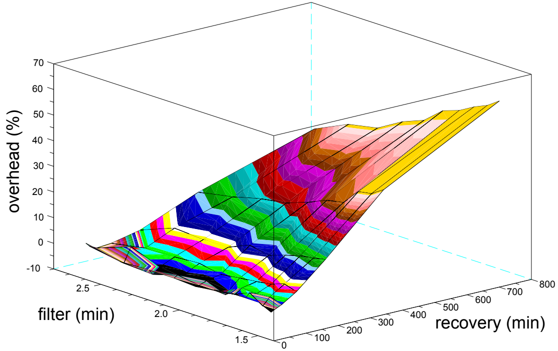
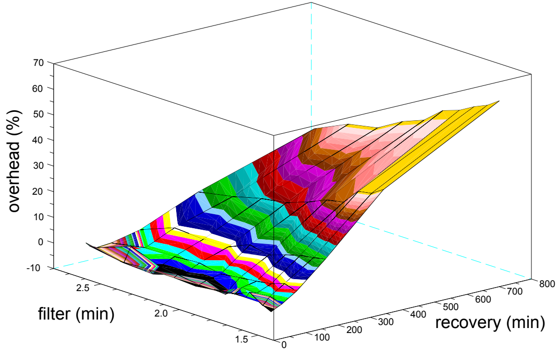
- rec < 3hrs $\rightarrow Ov < 16\%$
- rec $\in [6 - 12]$hrs $\rightarrow$



Case Study (V): Cyber Attack (3)

Analysis results

- rec < 3hrs $\rightarrow Ov < 16\%$
- rec $\in [6 - 12]$hrs $\rightarrow$
  - $Ov \sim 60\%$ for low quality filters



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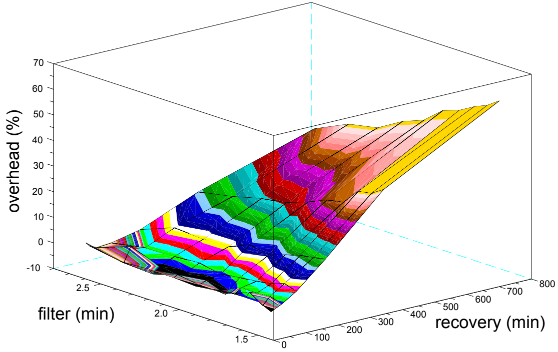
Case Study (V): Cyber Attack (3)

Analysis results

- rec < 3hrs → *Ov* < 16%
- rec ∈ [6 – 12]hrs →
  - *Ov* ∼ 60% for low quality filters
  - *Ov* ∼ 30% for high quality ones



Conclusions and Future Work

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- `SecAM` enables to express security parameters and requirements
- Formal models to perform survivability analysis
- Evaluate survivability strategies under different scenarios

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- SecAM enables to express security parameters and requirements
- Formal models to perform survivability analysis
- Evaluate survivability strategies under different scenarios

Future Work

- Automated tool to complete transformation (and feedback!)
- Combine SecAM with other formal methods (e.g., Fault Trees or Bayesian Networks)

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