1ST SCANDINAVIAN WORKSHOP ON
THE ENGINEERING OF
SYSTEMS-OF-SYSTEMS
SWESOS 2015
SWESOS 2015

Purpose:
• Create a meeting place for researchers and practitioners interested in SoS
• Informal event, focusing on presentation of results and ongoing research
• Stimulate interaction among the researchers

Submissions:
• 16 papers submitted, 13 accepted (3 out of scope)
PROGRAM OVERVIEW

09.00-09.30  Introduction & SoS Agenda project
09.30-10.30  Session 1: Business aspects
10.30-11.00  Coffee
11.00-12.20  Session 2: Architecture
12.20-13.20  Lunch
13.20-14.20  Session 3: Principles & properties
14.20-14.50  Coffee
14.50-15.50  Session 4: Applications & tools
15.50-16.30  Plenary discussion
THE SYSTEM-OF-SYSTEMS AGENDA PROJECT
SOS AGENDA PROJECT

• Objective: Formulate a strategic research and innovation agenda for the area SoS
• Duration: Jan-June 2015
• Funding: Vinnova
• Expected outcomes:
  • An agenda document, with the preliminary title "System-av-system för gränsöverskridande innovation i det digitala samhället: En strategisk forsknings- och innovationsagenda"
  • Side effect: creation of an expert network
PARTNERS

- SICS (project leader)
- Saab Aeronautics
- FOI
- Volvo Cars
- Volvo Technology
- Volvo Construction Equipment
- Syntell
- Decisionware
- INCOSE Sweden
- And everyone who is interested in joining!
PROJECT PARTS

• Actors
  • Current status
  • Potential and future challenges
  • Common concerns
  • Mainly executed as a series of workshops
• Research
  • Current status in Sweden and Internationally
• Synthesis
  • Identify actions
  • Document in agenda
WORKSHOPS/FOCUS GROUPS WITH (MAINLY) PRACTITIONERS

- **WS1 (February):**
  - Characteristics of SoS
  - Presentation of example SoS and archetypes
- **WS2 (March):**
  - Lifecycle aspects of SoS
  - Relation to Systems Engineering methods
- **WS3 (April):**
  - Joint work on SoS examples
  - Contents of agenda document

(Material available on project homepage)
SOS CHARACTERISTICS

<table>
<thead>
<tr>
<th>Maier, 1996</th>
<th>Boardman &amp; Sauser, 2005</th>
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<tbody>
<tr>
<td>Operational independence</td>
<td>≈ Autonomy</td>
</tr>
<tr>
<td>Managerial independence</td>
<td>≈ Belonging</td>
</tr>
<tr>
<td>Evolutionary development</td>
<td>≈ Connectivity</td>
</tr>
<tr>
<td>Emergent behavior</td>
<td>≈ Emergence</td>
</tr>
<tr>
<td>Geographical distribution</td>
<td>Diversity</td>
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</table>

- Two definitions from literature, with a large overlap
- The first four are core, the other two maybe not?
- A given SoS may exhibit these characteristics in various degrees, no strict definition
- For example, some constituent systems may be more independent than others
STATUS OF RESEARCH

• What is the current status of international SoS research?
  • Conduct a systematic literature mapping!
• What is the current status of Swedish SoS research?
  • Conduct a survey!
RESEARCH QUESTIONS

Community:
1. When – Development over time?
2. Where – Geographical distribution?
3. Who – Leading researchers?
4. What – Key papers?
5. Where – Publication sources?

Topics:
6. What – Application areas?
7. What – Research topics?
SYSTEMATIC LITERATURE MAPPING

Process Steps
- Definition of Research Question
- Conduct Search
- Screening of Papers
- Only papers in English; remove proceedings, etc.
- Keywording using Abstracts
- Classification Scheme
- Data Extraction and Mapping Process
- Systematic Map

Outcomes
- Result: 3274 papers
- Removed 252 papers, total 3022

What are the topics in SoS research?
What does the community look like?

RQ1: PUBLICATIONS PER YEAR
RQ2: PUBLICATIONS PER COUNTRY

All years

Last 5 years

United States
United Kingdom
Italy
China
France
Germany
Canada
Japan
Australia
Netherlands
Spain
Austria
Norway
Switzerland
Sweden
# RQ3: LEADING RESEARCHERS

<table>
<thead>
<tr>
<th>Author</th>
<th>No. papers</th>
</tr>
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<tbody>
<tr>
<td>DeLaurentis, D</td>
<td>67</td>
</tr>
<tr>
<td>Mavris, D</td>
<td>53</td>
</tr>
<tr>
<td>Jamshidi, M</td>
<td>38</td>
</tr>
<tr>
<td>Keating, C</td>
<td>32</td>
</tr>
<tr>
<td>Sauser, B</td>
<td>28</td>
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<tr>
<td>Lane, J</td>
<td>27</td>
</tr>
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<td>Dagli, C</td>
<td>26</td>
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<tr>
<td>Michael, J</td>
<td>26</td>
</tr>
<tr>
<td>Boardman, J</td>
<td>23</td>
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<tr>
<td>Gorod, A</td>
<td>22</td>
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</table>

<table>
<thead>
<tr>
<th>Author</th>
<th>No. citations</th>
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<tbody>
<tr>
<td>Keating, C</td>
<td>307</td>
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<tr>
<td>Jackson, M</td>
<td>288</td>
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<tr>
<td>Keys, P</td>
<td>223</td>
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<tr>
<td>Sauser, B</td>
<td>210</td>
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<td>Sousa-poza, A</td>
<td>210</td>
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<tr>
<td>Boardman, J</td>
<td>198</td>
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<tr>
<td>DeLaurentis, D</td>
<td>181</td>
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<tr>
<td>Rabadi, G</td>
<td>166</td>
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<td>Boehm, B</td>
<td>165</td>
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<td>Unal, R</td>
<td>162</td>
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h-index = 7
h-index = 6
## RQ4: KEY PAPERS

<table>
<thead>
<tr>
<th>Authors</th>
<th>Title</th>
<th>Year</th>
<th>No. cit.</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. C. Jackson, P. Keys</td>
<td>Towards a system of systems methodologies</td>
<td>1984</td>
<td>223</td>
</tr>
<tr>
<td>S. Karapetrovic, W. Willborn</td>
<td>Integration of quality and environmental management systems</td>
<td>1998</td>
<td>98</td>
</tr>
<tr>
<td>P. G. Carlock, R. E. Fenton</td>
<td>System of systems (SoS) enterprise systems engineering for information-intensive organizations</td>
<td>2001</td>
<td>92</td>
</tr>
<tr>
<td>D. DeLaurentis, R. K. Callaway</td>
<td>A system-of-systems perspective for public policy decisions</td>
<td>2004</td>
<td>84</td>
</tr>
<tr>
<td>B. Boehm</td>
<td>Some future trends and implications for systems and software engineering processes</td>
<td>2006</td>
<td>74</td>
</tr>
<tr>
<td>A. Gorod, B. J. Sauser, J. T. Boardman</td>
<td>System-of-systems engineering management: A review of modern history and a path forward</td>
<td>2008</td>
<td>70</td>
</tr>
<tr>
<td>W. Kröger</td>
<td>Critical infrastructures at risk: A need for a new conceptual approach and extended analytical tools</td>
<td>2008</td>
<td>69</td>
</tr>
<tr>
<td>W. B. Rouse</td>
<td>A theory of enterprise transformation</td>
<td>2005</td>
<td>66</td>
</tr>
<tr>
<td>W. H. Manthorpe</td>
<td>The emerging joint system of systems: A systems engineering challenge and opportunity for APL</td>
<td>1992</td>
<td>57</td>
</tr>
</tbody>
</table>
RQ5: PUBLICATION SOURCES

- IEEE Int. Conf. Syst. Syst. Eng., SOSE
- IEEE Int. Syst. Conf. Proc. SysCon
- Proc SPIE Int Soc Opt Eng
- Annu. Int. Symp. Int. Counc. Syst. Eng.,...
- IEEE Syst. J.
- Procedia Comput. Sci.
- Conf. Proc. IEEE Int. Conf. Syst. Man...
- Syst. Eng.
- Proc IEEE Mil Commun Conf MILCOM
- Jane's Def. Weekly
- CrossTalk

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RQ6: APPLICATION AREAS

Military; 21%

Space; 11%

Disaster management; 5%

Health care; 5%

Aircraft; 4%

Earth observation; 3%

Critical infrastructure; 4%

Transportation; 3%

Cities; 2%

Manufacturing; 2%

Telecommunication; 2%

Power systems; 2%

Agriculture; 1%

Construction; 1%

Education; 1%

Intelligence; 1%

IT services; 1%

Terrorism prevention; 1%

None; 27%
RQ7: RESEARCH TOPICS

- Modeling – 22%
- Integration – 17%
- Risk management – 9%
- Requirements – 7%
- Design – 7%

- Sustainability – 8%
- Interoperability – 7%
- Cost – 6%
- Effectiveness – 6%
- Safety – 6%
- Security – 6%
- Efficiency – 5%
- Reliability – 5%

- Architecture – 23%
- Communication – 14%
- Sensors – 7%
- Interconnections – 7%
- Simulation – 12%

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SUMMARY – INTERNATIONAL RESEARCH

- Overall status of the research field
  - Good connection to practitioners (44% of authors), many applications
  - US dominance, although improving... But what is going on in China?
- Application areas
  - Focus on Military, Space applications (government driven)
  - Where are “hot” topics such as cyber-physical systems, Internet of Things, software ecosystems? (commercially driven)
- Immature research area
  - Few researchers with SOSE as core area, many “visitors”
  - Low citation counts, researchers not building on each other’s result
  - Little use of systematic empirical research methods, mostly anecdotal evidence
- Core principles
  - What is different in SOSE?
STATUS OF RESEARCH

- What is the current status of international SoS research?
  - Conduct a systematic literature mapping!
- What is the current status of Swedish SoS research?
  - Conduct a survey!
METHODOLOGY

Are you **funding** research in SoS? If so, what projects?

Step 1: Are you **conducting** research in SoS? If so, who is doing it?

Step 2: What do you (as an individual) do research on?

Are you **publishing** research in SoS? Derived from literature mapping!

Funding agencies

Universities & institutes

Research results
FUNDING AGENCIES

After a scanning of all major agencies, 6 were identified as potential SoS funders.

General funding for SoS:
• Vinnova
• SSF Stiftelsen för strategisk forskning
• VR Vetenskapsrådet

Conditional funding for SoS:
• Energimyndigheten – Not as a general area, but SoS in energy applications is funded
• KKS – Do not fund specific topics, but if the new universities apply they can get funding for SoS

Not funding SoS:
• Knut och Alice Wallenbergs stiftelse

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UNIVERSITIES

Have SoS related research:
• Blekinge tekniska högskola
• Chalmers tekniska högskola
• Försvarshögskolan
• Göteborgs universitet
• Handelshögskolan i Stockholm
• Högskolan i Halmstad
• Högskolan i Jönköping
• Högskolan i Skövde
• Karolinska institutet
• Kungl. Tekniska högskolan (KTH)
• Linköpings universitet
• Linnéuniversitetet
• Luleå tekniska universitet
• Lunds universitet
• Malmö högskola

Have SoS related research (cont’d):
• Mittuniversitetet
• Mälardalens högskola
• Stockholms universitet
• Sveriges lantbruksuniversitet
• Umeå universitet
• Örebro universitet

Do not have SoS related research:
• Högskolan i Gävle

No reply:
• Högskolan Dalarna
• Karlstads universitet
• Uppsala universitet

In total, there are ~50 universities/similar in Sweden. 25 were filtered out as potentially interested in SoS.
RESEARCH INSTITUTES ETC.

Have SoS research:
- FMV Försvarets materialverk
- FOI Totalförsvarets forskningsinstitut
- VTI Statens Väg- och Transportforskningsinstitut
- SICS
- Viktoriainstitutet

Do not have SoS research:
- Swerea IVF

No reply:
- Acreo AB
- IVA Kungl. Ingenjörsvetenskapsakademin
- Skogforsk
- SP Sveriges Tekniska Forskningsinstitut
RESEARCH PUBLICATIONS

Based on literature study, the following Swedish actors appear as author affiliations:

- KTH – 3 paper
- SICS – 3 paper
- Blekinge Tekniska Högskola – 2 paper
- Lunds Universitet – 1 paper
- Luleå Tekniska Universitet – 1 paper
- FOI – 1 paper
- Linköpings Universitet – 1 paper
- SP – 1 paper
- TeliaSonera – 1 paper
- Volvo Technology – 1 paper
- Mecel AB – 1 paper
- Mentor Graphics – 1 paper
SUMMARY – SWEDISH RESEARCH

Funding agencies

Are you **funding** research in SoS? If so, what projects?

Yes: 5(6)  
No: 1(6)

Step 1: Are you **conducting** research in SoS? If so, who is doing it?

Step 2: What do you (as an individual) do research on?

Yes: 38(51)  
No: 3(51)  
No reply: 10(51)

Universities & institutes

Yes: 23(35)  
No: 4(35)  
No reply: 8(35)

Research results

Are you publishing research in SoS? Derived from literature mapping!

Yes: 8(35)  
No: 27(35)

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TECHNICAL SESSIONS
SESSION 1: BUSINESS ASPECTS

• The ‘Three Layer Ecosystem Strategy Model’ (TeLESM). Helena Holmström Olsson (Malmö University) and Jan Bosch (Chalmers).

• Openness in the interplay between technical and business aspects – a system of systems. Per Runeson (Lund University).

• Frameworks for innovation – studies of technology innovation and systems for energy, defence and security. Bengt Mölleryd (KTH).
SESSION 2: ARCHITECTURE

• Enterprise architecture analysis with production functions. Ulrik Franke (FOI).
• Enterprise architecture with executable modelling rules: A case study at the Swedish Defence Materiel Administration. Daniel Oskarsson (FOI).
• Architectural concepts for federated embedded systems. Jakob Axelsson and Avenir Kobetski (SICS).
SESSION 3: PRINCIPLES & PROPERTIES

• Systems-of-systems reliance on emergent properties. Patrizio Pelliccione (Gothenburg University).

• The notion of ‘systems of systems’ should be abandoned. Darek Haftor (Linnaeus University).

• The role of human factors in systems engineering, mutual interest and effective co-existence. Lars-Ola Bligård (Chalmers) and Robert Nilsson (Volvo Cars).
SESSION 4: APPLICATIONS & TOOLS

• From conventional to adaptable manufacturing paradigms – a systems perspective. Afifa Rahatulain (SenseAir), Harold Lawson (Lawson Konsult).

• Towards standards-based healthcare ecosystems of systems. Konstantinos Manikas (University of Copenhagen).

• Modeling and simulation of evolvable production systems using Simulink/SimEvents. Afifa Rahatulain (SenseAir), Tahir Naseer Quereshi (Hiab), and Mauro Onori (KTH).
PLENARY DISCUSSION

• Main takeaways?
• Key research challenges related to system-of-systems?