Approaches for Integration in System of Systems: A Systematic Review

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Summary

1. Introduction
2. Planning
3. Execution
4. Data Mapping
5. Results
6. Conclusions
1. Introduction

- System of Systems – SoS;
- System of Systems Integration – SoSI;
- Series of new challenges

SoS is a collection of independent entities and their assembled relationships to form a whole, greater than the sum of the parts (Boardman e Sauser, 2006).
1. Introduction/Motivation

- **SoS:**
  - Under the control of different organizations
  - Different geographic locations
  - Emergent behavior

- Difficulties: integration and adaptation to various emergent behaviors;

- Interoperability: sharing information semantically compatible and then process or manage this information.

- Goal of this Systematic Review (SR): to gather primary studies that propose techniques/approaches/tools for systems integration on the SoS context.
2. Planning

Research questions:

RQ1. How has the integration between CS's of a SoS been investigated?
- Evidence forms of integration in the SoS context, identifying for example: problems, approaches, techniques, solutions and advantages for integrating CS's of a SoS.

RQ2. In this type of study, which kind of tool has been used to aid in the integration of the constituent systems?
- Characterize when possible, tools that aid in the integration of the CS'S of a SoS.
2. Planning (cont.)

- We used the following data extraction form
  - F1- What is the purpose of the study regarding the integration of SoS?
    - F1.1- What SoS integration contribution was addressed?
  - F2- What is the application domain that has been targeted on the integration of SoS?
    - F2.1- What kind of SoS was used?
      - F2.1.1- Which features of the SoS were detailed?
    - F2.2- Which problems related to the integration of SoS were addressed?
    - F2.3- What are the advantages of using the concepts of SoS to integrate systems?
  - F3- Does the study mention any integration tool?
2. Planning (cont.)

- Search string:

\[((system of system) OR (systems of systems) OR (System-of-systems) OR (systems-of-systems)) AND (integration OR collaboration OR composition OR interoperability))\]
3. Execution

![Diagram showing search string and study selection process]

- Search String
- Excluding repeated: 1398 studies
  - Excluding repeated: 552 duplicated
  - Including: 846 studies
  - Inclusion and Exclusion Criteria (Title + summary): 53 studies
    - 5 unavailable and 4 not relevant
    - Including: 44 studies
      - Inclusion and Exclusion Criteria (Full Read): 29 studies
## 4. Data Mapping

<table>
<thead>
<tr>
<th>CQ</th>
<th>Answers</th>
<th>ID Papers</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
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<td></td>
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<tr>
<td></td>
<td>No</td>
<td>0</td>
<td></td>
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<tr>
<td>F1.1</td>
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<tr>
<td></td>
<td>Partly</td>
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<td>7</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>S1, S5, S9, S17, S18, S19</td>
<td>6</td>
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<tr>
<td>F2</td>
<td>Yes</td>
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<tr>
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<td>Partly</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>S6, S8, S10, S11, S13, S15, S16, S17, S18, S19, S21, S22, S23, S25, S26, S27, S28, S29</td>
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<td>F2.1</td>
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<td>S24</td>
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</tr>
<tr>
<td>F3</td>
<td>Yes</td>
<td>S3, S4, S8, S10, S12, S15, S21</td>
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</tr>
<tr>
<td></td>
<td>Partly</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>S1, S2, S5, S6, S7, S9, S11, S13, S14, S16, S17, S18, S19, S20, S22, S23, S24, S25, S26, S27, S28, S29</td>
<td>22</td>
</tr>
</tbody>
</table>
4. Data Mapping (cont.)
5. Results – SR SoSI

- Answer to F1 - What is the purpose of the study regarding the integration of SoS?

<table>
<thead>
<tr>
<th>ID Paper</th>
<th>Study proposal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Modeling</td>
</tr>
<tr>
<td>Total</td>
<td>13</td>
</tr>
<tr>
<td>S1, S2, S6, S7, S8, S11, S12, S14, S15, S18, S21, S22, S29</td>
<td>S20, S23, S26</td>
</tr>
</tbody>
</table>
Answer to F1.1 - What SoS integration contribution was addressed?

- S4 (Naqvi et al., 2010): show the importance of learning about the CS's and external influences that each one of them can present. To achieve a successful integration, it is necessary to have knowledge about the features that the CS offers.

- S16 (Kazman et al., 2013): proposed an architectural pattern to support the software architects in the integration process.
  - Greenfield (there are no restrictions for deployment);
  - Brownfield (changes/adjustments can be made to the CS's to achieve the goal of integration);
  - Closed Source (there is no access to the CS's);
5. Results – SR SoSI (cont.)

- S24 (Madni e Sievers, 2004): presented important concepts for the integration of SoS, such as interoperability, systems integration, type and characteristics of SoS, SOA, SoSI and reuse of CS's.

- Integration should be part of the overall SoS development lifecycle;
- Legay Systems: increases the complexity of integration, documentation about them can be not readily available;
- The form and rigor of Sosi is directly related to the type of SoS;
  - The unmanaged (Virtual) is inherently more difficult to integrate than a managed SoS (Directed).
Answer to F2 - What is the application domain that has been targeted in the SoS integration context?

<table>
<thead>
<tr>
<th>Application Domain</th>
<th>Number of Studies</th>
<th>ID Paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Specific Application Domain</td>
<td>16</td>
<td>S6, S8, S10, S11, S13, S15, S16, S17, S18, S19, S21, S22, S23, S26, S27, S29</td>
</tr>
<tr>
<td>Defence and National Security</td>
<td>4</td>
<td>S3, S4, S14, S20, S28</td>
</tr>
<tr>
<td>Military</td>
<td>1</td>
<td>S2</td>
</tr>
<tr>
<td>Industrial Automation</td>
<td>1</td>
<td>S5</td>
</tr>
<tr>
<td>Aerospace</td>
<td>1</td>
<td>S9</td>
</tr>
<tr>
<td>Quality Management</td>
<td>1</td>
<td>S1, S25</td>
</tr>
<tr>
<td>Earth Observation System</td>
<td>1</td>
<td>S24</td>
</tr>
<tr>
<td>Simulation</td>
<td>1</td>
<td>S7</td>
</tr>
<tr>
<td>Auto Adaptation</td>
<td>1</td>
<td>S12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>29</strong></td>
<td></td>
</tr>
</tbody>
</table>
5. Results – SR SoSI (cont.)

- Answer to F2.1 - What kind of SoS was used?
- Of the 29 papers selected for data extraction, only one defined the type of SoS to be used for system integration.

  - According to Madni e Sievers (2014), Directed or Acknowledge SoS are pre-specified, which makes them predictable and consistent with traditional validation and verification methods.
  
  - Virtual or Collaborative SoS are not pre-specified, which makes them more challenging to integrate.
5. Results – SR SoSI (cont.)

- Answer to F2.1.1 -Which features of the SoS were detailed?

- Operational and managerial independence, evolutionary development, emergent behavior and geographic distribution;

  - Analyzing the 29 papers:
    - only four of them signaled such evaluation, which corresponds to only 13.79% of the studies;

  - Specifically, the papers S5, S6, S19, S24 demonstrated greater caution in relation to the characteristics to propose any integration solution.

- There are some other characteristics that have not been mentioned by others, such as: adaptive development, connectivity, autonomy, diversity, reconfiguration, and principles of modularity.
5. Results – SR SoSI (cont.)

- Answer to F2.2 - Which problems related to the integration of SoS were addressed?

- It was observed that 58.33% of the papers cited some problem/difficulty of integration, seven papers responded completely, which corresponds to 24.13% (S4, S9, S14, S17, S20, S24);

- Managerial;
- Single Modeling;
- Complexity of interations;
- Complexity of CS’s;
- Collaboration;
- Incompatibility of interfaces;
- Evolution;
- Frequence updates;
- Documentation;
- Scripts;
5. Results – SR SoSI (cont.)

- Answer to F2.3 - What are the advantages of using the concepts of SoS to integrate systems?
  - It was observed that 16.66% of the papers cited one advantage when using SoS to integrate and two articles responded completely, which corresponds to 6.89\% of articles.

<table>
<thead>
<tr>
<th>ID</th>
<th>Advantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Broader involvement of all stakeholders.</td>
</tr>
<tr>
<td>2</td>
<td>Reduced use of multiple resources.</td>
</tr>
<tr>
<td>3</td>
<td>Development of coherent systems.</td>
</tr>
<tr>
<td>4</td>
<td>Unified harmonized standard to solve problems.</td>
</tr>
<tr>
<td>5</td>
<td>Improving the cost benefit.</td>
</tr>
<tr>
<td>6</td>
<td>It increases flexibility and possibility to include other systems.</td>
</tr>
<tr>
<td>7</td>
<td>Improved operational performance together.</td>
</tr>
<tr>
<td>8</td>
<td>Increased motivation of staff.</td>
</tr>
<tr>
<td>9</td>
<td>Cost reduction and reengineering more efficient.</td>
</tr>
<tr>
<td>10</td>
<td>Maintaining the original characteristics of the constituent system.</td>
</tr>
<tr>
<td>11</td>
<td>Operational and managerial independence.</td>
</tr>
<tr>
<td>12</td>
<td>better scalability.</td>
</tr>
<tr>
<td>13</td>
<td>better interoperability.</td>
</tr>
<tr>
<td>14</td>
<td>Serviceability.</td>
</tr>
</tbody>
</table>
5. Results – SR SoSI (cont.)

- Answer to F3 - Does the study mention any integration tool?
- It was observed that 29.16\% of the papers cited a tool to integrate CS's of SoS.
  - FireScrum;
  - Mind mapping tool;
  - RDL – Requirements Description Language;
  - Tool chain;
  - SENSE;
  - UPPAAL;
  - DEVS;
  - M-Model;
6. Conclusions

Answer to RQ1:

- There are several fields of research regarding SoS that are still incomplete and require more researches;
  - For example: SoSI;
- SoSI has high demand and many challenges;
- There have been significant contributions that provided relevant information to the SoSI state of the art;
- The integration between CS's of a SoS has been investigated through the use of SOA (Service-Oriented Architecture);
  - Promising architectural style for SoSI;
  - Approximately 51.72% of the works have explored the use of SOA;
6. Conclusions (cont.)

- **Answer to RQ2:**
  - No system integration tools found in the surrounding context of SoS;
  - Detailed tools before, support any phase of development of SoS;
  - Are not necessarily tools to support integration;
  - Thus, it can be seen that there is a lack of tools to assist in the integration of systems in the context of SoS.
6. Conclusions (cont.)

- Research in System of System Integration (SoSI);
- Individuals and teams working in isolation;
  - It is necessary to develop more general procedures, techniques and tools;
- Finally, we noted in this review that there are domains, such as reuse environments, that are poorly explored in the research community of SoS → ongoing work
Thank you for your attention!!!

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