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*Comprehensive Modelling for Advanced Systems of Systems*

# An Introductory Comparison of COMPASS Case Studies

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# Abstract:

This white paper is intended as a basic introduction to the four COMPASS industrial SoS case studies. The four case studies are compared side by side, in terms of their architectures, SoS classification and various SoS-relevant properties, such as how independence or autonomy are exhibited by the constituents, the distribution experienced by the constituents, the nature of emergent behaviour and whether dynamic reconfiguration is employed, the interdependence of the systems, and how they are affected by evolution.

# 1 Introduction

COMPASS works with four SoS case studies, supplied by the project's industrial partners: two major case studies, and two mini "challenge problems". The case studies are drawn from very different domains and contexts. In this white paper we provide some side-by-side comparisons of the case studies, intended to serve as a quick reference and introduction to the case studies that drive requirements for the COMPASS project.

The four case studies are:

- An emergency response system, provided by Insiel (described fully in COMPASS D41.1). This SoS co-ordinates different specialised services (fire brigade, ambulance service, police, etc.) situated in northern Italy to deliver cross-service responses to emergency situations.
- A distributed audio/visual system, provided by Bang & Olufsen (described fully in COMPASS D42.1). This SoS allows audio-visual content to be streamed and managed in real time by a variety of devices in line with rules stipulated by DRM.
- An energy management system, provided by GridManager (described fully in COMPASS D43.2). This SoS ensures that customers' energy requirements are fully met in line with pre-determined criteria.
- A traffic management system, provided by West Consulting (described fully in COMPASS D43.2). This SoS manages flows of traffic on an inter-urban road network.

## 1.1 SoS classification

Classifying an SoS into one of the four well-known categories is not a straightforward task, and in fact each of the case studies adopted by COMPASS categorize themselves using two categories. The categories are supplied in Table 1.

**Table 1 Summary of case study classifications**

| Case study | Classification |
|---|---|
| **Emergency response** | The SoS is generally closest to an **acknowledged** SoS, because the constituent components retain considerable autonomy and independence, although there is a resourced central manager. During a major emergency that cross-cuts the different emergency services, however, the SoS may behave in a **directed** way, with the manager able to directly allocate work and responsibilities to constituent systems. |
| **Distributed audio-visual system** | The SoS can be considered a **virtual** SoS, since there is no central management authority or agreed-upon purpose. However, at times the system enters a state where a designated manager is selected and constituent systems recognise some global objectives, which we regard as **collaborative**. |

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| **Energy management** | The system generally operates in a **collaborative** way, with all constituents choosing to participate but not accepting a central manager. |
| **Traffic management** | Parts of the system behave in a **directed** way. The constituents can and often do operate independently but for many functions they accept central management. For example, at certain times the Traffic Control Centre (TCC) may override ramp meters (traffic lights that control vehicles joining a highway) to implement a regional strategy. However, some parts of the SoS functions may behave in an **acknowledged** manner, with the presence of a resourced manager acknowledged, but with constituents retaining individual ownership and autonomy. For example, ramp meters mostly operate in an independent mode. |

## 1.2 Architecture

We compare here the dominant architectural patterns exhibited by the case study SoSs. Initial descriptions of the architectural patterns can be found in COMPASS D22.3. Table 2 presents a summary.

**Table 2 Summary of case study architectural patterns**

| Case study | Architectural pattern exhibited |
|---|---|
| **Emergency response** | **Centralised**. There is a central constituent system that communicates with all other constituent systems. |
| **Distributed audio-visual** | **Service-oriented architecture** (at the application layer). Constituent systems may offer services, consume services or act as a broker for discovering services available within the system and the policies that are attached to them. |
| **Energy management** | **Centralised** - a central constituent system communicates with all others. However, the system also implements a **service-oriented** pattern, collecting many data and services together for consumption by a variety of constituent systems. |
| **Traffic management** | **Centralised**. There is a central constituent system that communicates with all other constituent systems. This is for the most part a fully-centralised system, however a few functions may be delivered by subsets of constituents collaborate without central control. |

In COMPASS D22.3 it is observed that an SoS with a fully centralised architecture can be thought of as an acknowledged or directed SoS. This is because typically the central constituent system has been consciously developed to create an SoS. Two of our industrial case studies/challenge problems exhibit a fully centralised architectural pattern and also describe themselves as either (or both) acknowledged or directed.

## 1.3 SoS properties

Here we consider the various case studies in relation to the eight properties of SoS (which are explained in Nielsen et al 2013). Table 3 and Table 4 present summaries.

**Table 3 Summary of SoS properties for the emergency response and distributed audio-visual case studies**

| | Emergency response | Distributed audio-visual |
|---|---|---|
| Autonomy | **High autonomy**. Separate constituent systems can and do take decisions regarding their own future direction. The central management unit can also take such decisions; for example, it could elect to subscribe new emergency services to the current set. | **High autonomy**. Some constituents are supplied by third party manufacturers or are standalone products produced by individual teams at Bang & Olufsen. |
| Independence | **High independence**. This does not apply to the central constituent (the CUS), which relies on the co-operation of constituents to deliver meaningful service and therefore exhibits **low independence**. | **High independence**. The components each have a purpose (e.g., a television set, a speaker) which means it can continue to have a meaningful existence if the SoS is removed. |
| Distribution | **High**. Constituents are distributed across a region. | **High**. Constituents are distributed within a building. |
| Evolution | **Slow and long-term.** The services offered by the separate units have changed dramatically over a number of decades, as new technologies become available (mobile telecommunications, helicopters, GPS, medical equipment etc). The goal of the SoS also evolves long-term, from separate units into a coherent and "joined-up" service | **Swift.** The SoS evolves substantially over a short number of years as new technologies make it possible to stream new types of data to new types of device. |
| Emergence | The SoS does exhibit **some emergence**. The emergent behaviour centres on:<br>• delivering an appropriate response to an emergency that incorporates all necessary emergency services; | **Considerable emergence.** The emergent behaviour is the ability to stream and manage content between distributed devices, associated with a user account. Users can uncover new emergent behaviour, by finding new combinations of content server and playback |

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| | • region-wide planning and logistics<br>• providing a central point of contact to the end user<br>However, much of the time the constituent systems operate independently without needing to collaborate. Unpredicted emergent behaviour is considered to be highly undesirable. | device. Unexpected emergent behaviour must still conform to brand expectations. |
| Dynamicity | **Limited dynamicity**. The SoS does have the capability to change the architectural structure dynamically – e.g., if radios are unavailable then alternatives are used. Dynamic reconfiguration is not widely employed however: it has the potential to confuse command structures and impedes accurate logging of events. | **High dynamicity**. New, unexpected devices and/or content may be added to the system or removed from it at any time, requiring the system to incorporate a new constituent into the architecture or cope with the loss of a former constituent. |
| Interdependence | **Limited interdependence.** Only the central constituent system accepts any notion of interdependence and a need to consider sacrificing functionality for other constituents; other constituents are politically independent and do not consider the possibility of sacrificing functionality in favour of another constituent. | **Strong interdependence.** All constituents recognise the need to make sacrifices where necessary to abide by DRM regulations. Many constituents have a dependency on others – for example, devices for rendering content have a dependency on devices that store, stream and manage content and the relevant policies. |
| Interoperability | **Some interoperability**. Many constituent systems employ radically different types of data (e.g., medical records, GPS co-ordinates) but there are standard data types employed for many of these. Much data needs to be extracted from free text or human speech and cross-domain misunderstandings are possible. | **Some interoperability.** A third party protocol for data exchange is employed and understood by many devices. There are many different standards, however, and not all products are capable of interoperating freely. |

**Table 4 Summary of SoS properties for the energy management and traffic management challenge problems**

| | Energy management | Traffic management |
|---|---|---|
| Autonomy | **High autonomy.** Many constituents are supplied by 3rd party manufacturers and have commercial motivations to evolve the future of their product. A central constituent produced by Grid Manager does have the ability to make decisions that affect future direction and functionality. | Some constituent systems (including the central "manager") retain **high autonomy**. Some constituents make great use of components and systems sourced from third-party suppliers. Such suppliers may have commercial reasons to make decisions regarding future direction of the system. The central constituent system has the ability to include or exclude constituents and incorporate new functionality into the SoS. It's possible, however, that other constituent systems in the TMS may have lesser autonomy and their future direction may be dictated largely by the needs of the SoS itself and not by individual needs. |
| Independence | **High independence** for many constituents. However, the central "hub" constituent relies on the collaboration of other constituents to deliver meaningful functionality, with resulting **low independence**. | **High independence for most constituents**. However, the central "hub" constituent relies on the collaboration of other constituents to deliver meaningful functionality, with resulting **low independence for the central "hub" constituent**. |
| Distribution | **High**. Constituents are distributed across a large region. | **High**. Constituents are distributed nationally. |
| Evolution | **Slow and long-term.** New types of devices (such as metering devices) have become available over time and must be adapted to. | **Slow and long-term.** The functionality of the TMS has changed dramatically over a number of decades, as new technologies become available. The goal of the SoS has also evolved long-term, from a system that reacts to local problems into a system that implements proactive regional or national strategies. |

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| Emergence | **Considerable emergence.** The emergent behaviour is the ability to deliver energy based on a complex series of requirements specified by the customer, matched against data supplied by e.g., timestamps and energy tariffs. | **Considerable emergence**. The emergent behaviour is the ability to monitor roads regionally or nationally and proactively manage the flows of traffic according to predefined priorities. SoS does not operate in this mode continuously, however; some constituents operate individually much of the time. |
| Dynamicity | **Limited dynamicity.** Dynamic reconfiguration currently is limited to adaptations for new devices which may be added over time. | **Limited dynamicity.** New constituents may be added to the system as technologies become available, but this does not happen on a dynamic basis. The system can cope with a constituent system unexpectedly removed, e.g. by making predictions about missing data. However, architectural dynamic reconfiguration is not widely employed, partly because of the time and effort required to install redundant hardware devices. |
| Interdependence | **Some interdependence.** Many constituents are dependent on the availability of rules and data for making decisions (e.g., tariffs). Some constituents have a dependency on others – for example, many constituents depend on the accuracy of metering devices. Interdependence is exhibited more strongly for some constituents than for others, however. | **Some interdependence.** Constituent systems that can influence traffic behaviour have a strong dependency on either some traffic monitoring devices (such as induction loops or cameras) or on the availability of predicted data generated by the Traffic Control Centre for making decisions. Interdependence is exhibited more strongly for some constituents than for others, however. |
| Interoperability | **Problematic interoperability.** There is a wide variety of metering devices, for example, and they do not employ standard data types. | **High degree of interoperability.** Although the different devices employed by the SoS utilise very different data (e.g., video pictures, radar, weather readings), standard data types are employed to enable easy data exchange. |

There are many caveats when attempting to classify an SoS. Many of the properties are exhibited strongly by some constituent systems within an SoS, and less strongly by the peers in the same SoS. Many SoSs appear to have multiple modes of operation, such that the SoS global emergent behaviour is not in operation constantly. Some of the time constituents may be operating in isolation or non-co-operative mode, and the SoS is not operating as such unless environmental circumstances dictate that this is necessary (e.g., in the Insiel study, ambulances can be dispatched in isolation if no other emergency services are required; in the West Consulting challenge problem, ramp metering devices (traffic lights) can operate in an isolated mode without the rest of the SoS). Environmental conditions are therefore important for reasoning about emergent behaviour.

In a centralised architecture, the central hub constituent exhibits different properties to those of its peers. E.g., in two of our case studies/challenge problems (Insiel, West Consulting), the constituents mostly exhibit a high degree of autonomy or independence which may not be shared at all by the central hub constituent system.

## 1.4 Case study comparison summary

Although drawn from widely divergent domains there are some similarities between some of the COMPASS case studies. Most obviously, there are a number of similarities between the West Consulting traffic management system and the Insiel emergency response system, in terms of the acceptability of dynamic reconfiguration, the classification of the SoS and features of the domain in which SoS operates. For example, both of these systems are cautious about dynamic reconfiguration possibilities. The directed type of SoS allows for an easy implementation of a chain of command in situations where a swift response and a global oversight of the system is needed. The acknowledged mode of operation allows some devolution of command, where constituents are permitted to operate on a localised, independent level. The choice of a centralised architecture affects approach to dynamic reconfiguration, because there is a central hub which is a single point of failure. This is perhaps an appropriate choice for domains which do not intend to rely heavily on dynamic reconfiguration. For example, a safety-critical system may be cautious about implementing architectural changes which have not been planned carefully in advance.

Comparing our case studies makes clear that the domain of the SoS is of key importance in determining some key challenges and difficulties. For example, we find that interoperability is still a challenge in some domains but less so in others. The domain of the case study requires us to take into account:

- the environment of the SoS
- the independence and autonomy of its constituent systems
- the data formats and standards in use
- the potential for cross-domain misunderstanding
- the prevalence of black box, white box or grey box constituent systems (see COMPASS D21.2 for descriptions of black, white and grey boxes), and any trust issues

- the non-functional requirements demanded (e.g., high availability, fault tolerance, resilience, etc.)
- the classification of the SoS

For both a centralised SoS (like the emergency response system or the traffic management system) or a non-centralised SoS (like the audio-visual entertainment system) there is a need to develop a method of reasoning about the SoS-level requirements and the SoS performance, separately to the requirements and performance of the constituent systems, so that bottlenecks and risk factors that may damage the SoS performance may be proactively identified and modelled.

# References

COMPASS. Initial Report on Guidelines for Architectural Level SoS Modelling: D21.2. Technical report, http://www.compass-research.eu, 2013

COMPASS. Report on Modelling Patterns for SoS Architectures: D22.3. Technical report, http://www.compass-research.eu, 2013

COMPASS. Accident Response Case Study Engineering Analysis Report Using Current Methods & Tools. Document Number: D41.1. Technical report: http://www.compass-research.eu, 2013.

COMPASS. A/V/HA Ecosystem Prototype Using Current Methods and Tools. Document Number: D42.1. Technical report: http://www.compass-research.eu, 2013.

COMPASS. Challenge Problem Analysis Using Existing Methods and Tools. Document Number: D43.2. Technical report: http://www.compass-research.eu, 2013.