CSC8701 – Model-Based Systems Engineering

Assessment 1 – Report - 230302626

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Abstract

The Urban Observatory within Air Quality Surveillance System of Systems (SoS) represents an integrated network designed to monitor and analyse air quality, specifically focusing on PM2.5 particulate matter in urban environments. This SoS combines independent systems—sensor networks, data processing units, and decision-support tools—that collaboratively function to provide comprehensive insights into urban air quality. The unique architecture of the SoS affords managerial and operational independence to its component systems, enabling a flexible, resilient, and scalable network that can adapt to evolving technological landscapes and urban needs. Emergent behaviours arising from system interoperations enhance the SoS's capability to provide real-time data and actionable intelligence, pivotal for informed policy-making and public health initiatives. Geographical distribution of the system's components allows for localized data collection and tailored responses, vital for addressing the spatial variability of urban pollution. This report delves into the SoS's design, operational dynamics, and the interplay of its distributed yet interdependent components, revealing the complexity and potential of this modern approach to environmental surveillance.

1 Introduction

In recent years, air quality surveillance has become a cornerstone of urban environmental management, driven by the growing recognition of air pollution's impact on public health and the urban ecosystem. The Urban Observatory within Air Quality Surveillance SoS is at the forefront of this effort, employing advanced technologies and methodologies to monitor, analyse, and report on particulate matter, with a particular emphasis on PM2.5. This SoS is not merely a collection of technical solutions but a carefully orchestrated ensemble of independent yet interlinked systems that collectively enhance urban life quality.

The SoS approach provides a multifaceted view of the urban air quality landscape, with each system contributing its unique capabilities to a larger, more comprehensive understanding. This report undertakes a rigorous exploration of the engineering complexities and the intricate systemic interdependencies that characterize the System of Systems (SoS). It is supported by an analytical exposition of three distinct diagrams, each elucidating critical aspects of the SoS architecture. These diagrams serve as foundational tools in dissecting the operational frameworks, data flow mechanisms, and stakeholder roles within the SoS, thereby providing a comprehensive understanding of its functional dynamics.

The selection of this System of Systems (SoS) was predicated on its perceived utility and intrinsic interest, coupled with its pertinence to real-world scenarios, particularly within the context of Newcastle City. The city's deployment of over 5,000 sensors, which serve to enhance urban living standards by monitoring environmental parameters, presents a compelling case study for examining the impact of technological interventions on life quality for urban inhabitants. Through this exploration, we aim to uncover the capabilities and potential of the SoS, setting the stage for future advancements in the realm of urban air quality surveillance

2 SysML Diagrams

2.1 Use Case Diagram (UC)

The Use Case (UC) diagram included in this report provides a detailed visualization of the operational interactions within the Urban Observatory's Air Quality Surveillance System of Systems (SoS). This UC diagram is instrumental in elucidating the role-specific activities and their subsequent contributions to the overarching objective of air quality management in an urban context. The diagram identifies five principal actors—IT Technician, System Administrator, Developer, Analyst, and Authorized Expert—and their interactions with the system's components, reflecting a structured approach to air quality surveillance.

The IT Technician initiates the operational sequence by responding to sensor deployment requests, which involves the tactical placement, configuration, and secure installation of IoT sensors. This groundwork is pivotal for capturing accurate environmental data. The System Administrator's role is crucial in maintaining the system's integrity, as they oversee the addition of devices to the network and continuously monitor sensor signal states to ensure data reliability.

Developers are tasked with the critical role of creating a reliable data pipeline, which is the backbone of the system, facilitating the flow and preprocessing of data. This refined data is then channelled to Analysts who scrutinize the data, distil insights, and formulate strategic summaries and recommendations that drive the system's value.

Culminating the process, the Authorized Expert at the City Council platform assesses these analytical reports. Their role embodies the decision-making apex of the SoS, where they interpret data-driven conclusions and orchestrate requisite interventions or policy actions. This Use Case diagram captures the essence of the SoS's functionality, showcasing a complex yet coherent network of roles and processes that underpin the efficient surveillance of air quality, demonstrating a sophisticated interplay between technological assets and human expertise, pivotal for sustaining urban environmental health.

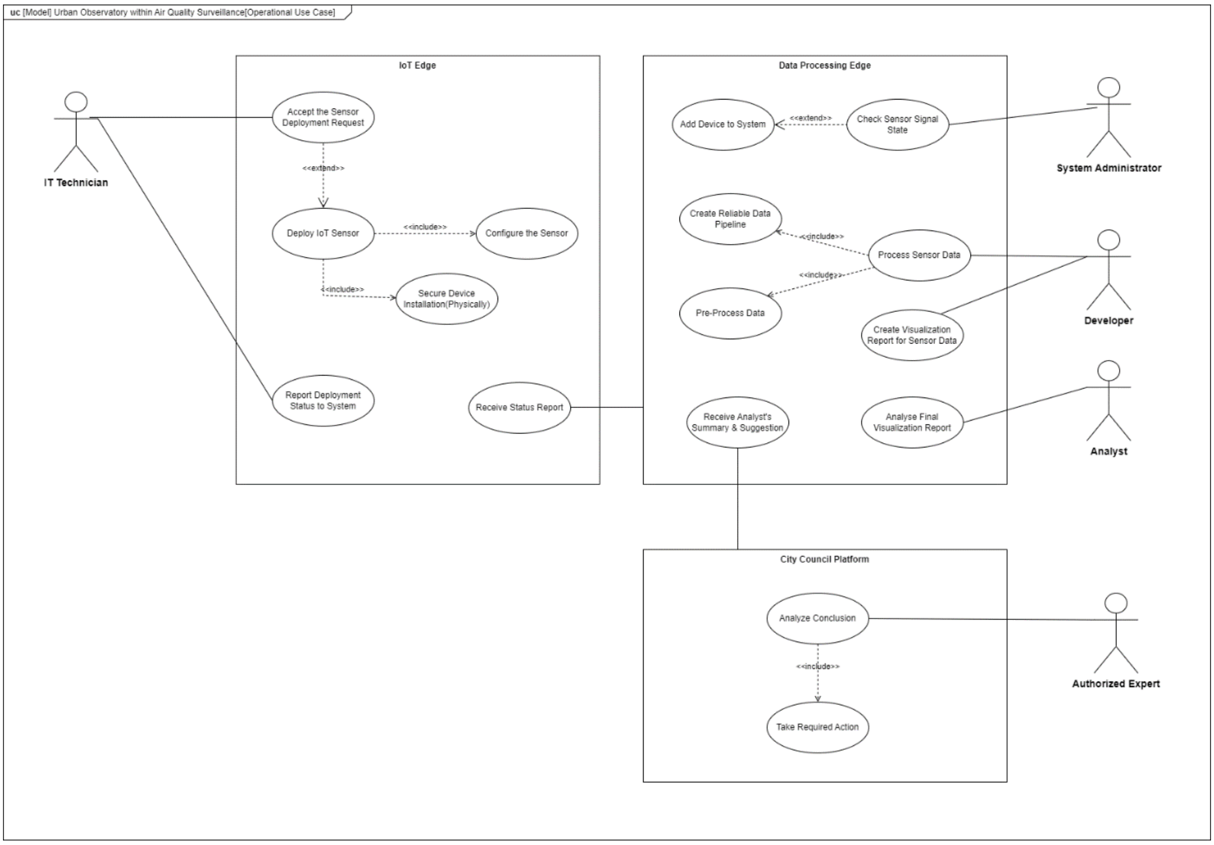

Figure 1 - Use Case Diagram

2.2 Block Definition Diagram (BDD)

The Block Definition Diagram (BDD) (Figure 2) depicted represents a fundamental component of the Urban Observatory within Air Quality Surveillance System of Systems (SoS). This diagram provides a schematic overview of the system architecture, illustrating the interconnections and hierarchies between the various subsystems and their interfaces. Central to the SoS are the IoT Edge and Data Processing blocks, which are integral in collecting and refining environmental data. The IoT Edge is equipped with sensors and toolkits for deployment, configuration, and security, ensuring the reliable acquisition of PM2.5 air quality measurements.

The Data Processing block is composed of several key elements: Device Manager Tool, Servers, Data Pipeline Software, and interfaces for MQTT and RabbitMQ Brokers, culminating in a PostgreSQL Database. This setup is tasked with the critical functions of data ingestion, filtration, preprocessing, and storage. The data is subsequently channelled through Visualization and Report Generator Software, transforming raw data into intelligible reports and visual outputs.

Anchoring the system's functionality is the City Council Platform, where the synthesized data is analysed using Data Analysis Software, supported by a Decision Support System and an underlying Machine Learning (ML) Engine. This advanced analytical suite informs the decisions made by Authorized Experts, ultimately guiding urban air quality management policies.

This BDD serves not just as a technical reference but also as a roadmap guiding the implementation and integration of the SoS components. It encapsulates the structural complexity of the SoS, highlighting the synergy between its technical infrastructure and the specialized roles of stakeholders involved in the multifaceted domain of urban air quality surveillance.

2.3 Internal Block Diagram (IBD)

The Internal Block Diagram (IBD) (Figure 3) provided offers a comprehensive illustration of the data processing module within the Urban Observatory's Air Quality Surveillance System of Systems (SoS). The IBD meticulously outlines the flow and transformation of data from initial capture to the delivery of actionable insights. The journey begins at the IoT Edge, where PM2.5 sensors detect particulate matter, sending raw signal and data through to the Device Manager Tool. This initial step is crucial, as it represents the point of data genesis, upon which the integrity of the entire system depends.

Following this, the raw data traverses to the Sensor Data Injector, which serves a pivotal role in filtering and preparing the data for subsequent stages. The processed data is then channelled via the RabbitMQ Broker, an intermediary ensuring data integrity and channel-based transfer, facilitating a seamless flow to the Data Pipeline Software. This software acts as the analytical engine of the system, further refining data and preparing it for dissemination.

The processed data is then distributed, employing the MQTT & RabbitMQ Broker to publish the data, making it accessible for reporting and visualization. The Report Generator Software transforms the data into structured reports, while the Visualization Generator Software creates visual representations of the data, enhancing interpretability. These outputs are then directed to the City Council Platform, where they are ingested by a PostgreSQL Database, informing the Decision Support System. This system is pivotal for extracting refined documents and visual outputs, providing the critical decision-making support necessary for city officials to take informed actions for air quality management.

The IBD encapsulates the intricate data pathways and processing mechanisms, providing a clear visual guide to the inner workings of the SoS, and highlighting the essential role of data transformation in informing urban air quality strategies.

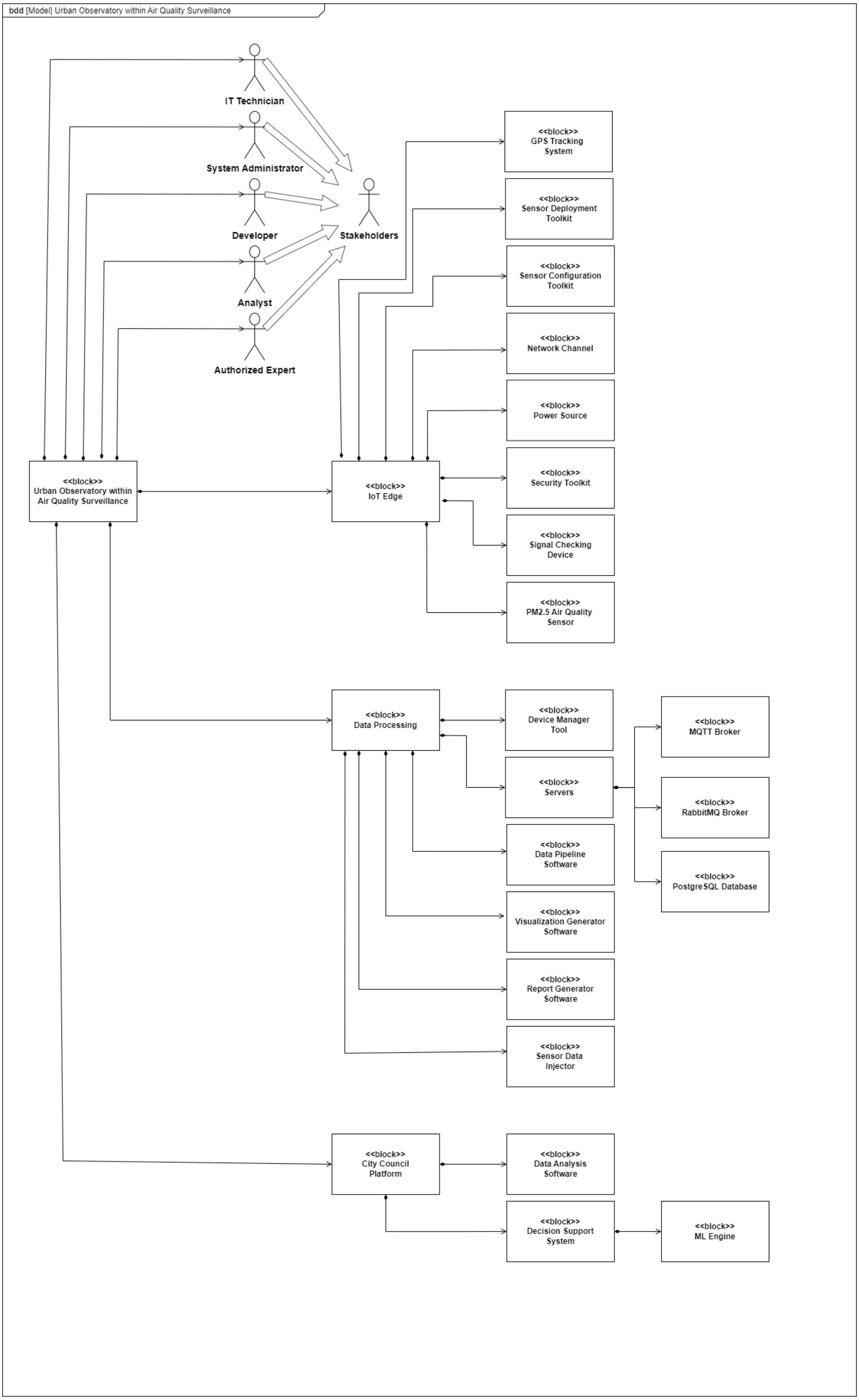

Figure 2 - Block Definition Diagram

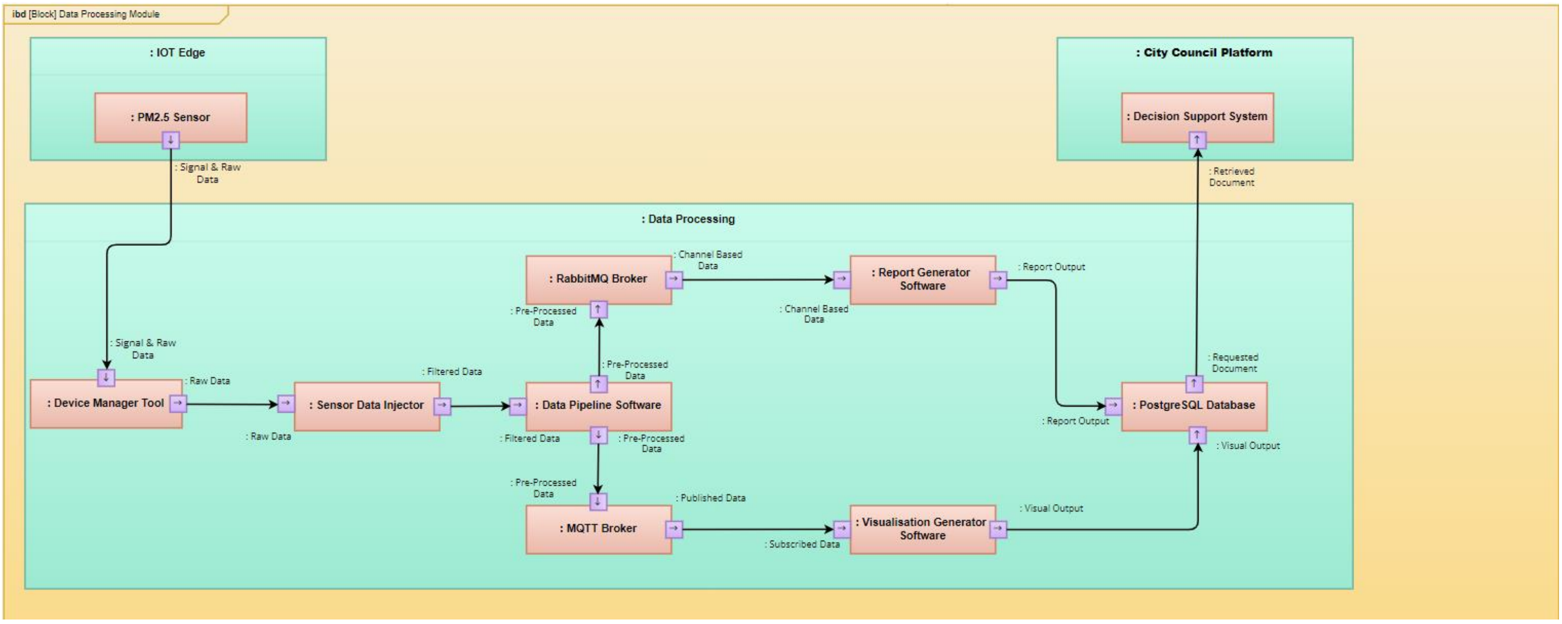

Figure 3 - Internal Block Diagram

3 Analytical Discussion of Particular SoS

3.1 Alternative Choices of System Boundaries

One alternative boundary choice could involve the integration of external environmental data sources. Incorporating data such as weather patterns, traffic flow, and industrial emissions could significantly enhance the predictive analytics capabilities of the SoS, leading to more accurate and proactive air quality management strategies. This expanded boundary would facilitate a more holistic view of the factors affecting urban air quality, enabling a more nuanced response to pollution events.

Conversely, another choice might be to narrow the system boundary to focus on the internal efficiency and optimization of the data processing pipeline. Concentrating on the heart of data transformation processes could lead to improvements in data quality, processing speed, and overall system reliability. This more focused approach could prove beneficial in achieving high-performance standards in data handling and analysis, ensuring that the SoS operates at peak efficiency.

A further alternative would be to extend the system boundary to encompass end-user engagement platforms, such as mobile applications or public information displays. This extension would bring the SoS directly into the public domain, facilitating real-time air quality updates and enhancing public awareness and engagement with environmental issues.

Each of these alternative boundary choices carries with it distinct advantages and challenges, reflecting the diverse pathways available for the SoS's development. The selection of system boundaries thus remains a critical strategic decision that can shape the system's current functionality and future evolution.

3.2 Key Issues in Engineering the System

One of the primary conflicts arises from the necessity to balance the granularity of data collected by PM2.5 sensors with the imperative to protect individual privacy. While detailed data enables comprehensive analysis, it also raises concerns about the potential for misuse or unintended disclosure of sensitive information, necessitating stringent data protection protocols.

Another significant issue is the juxtaposition of the need for real-time data processing to facilitate prompt decision-making and the requirement for meticulous data analysis to ensure the accuracy and reliability of insights. This often results in a trade-off between the speed of data availability and the quality of the analytical output, with implications for the responsiveness and efficacy of the system.

Additionally, the engineering process must address the robustness of the SoS, ensuring it is resilient to technical failures and data bottlenecks, while also maintaining a user-friendly interface for the various stakeholders interacting with the system. This involves a delicate balance between creating a technically sound system and one that is accessible and practical for everyday use.

The resolution of these conflicting requirements is critical to the successful deployment and operation of the SoS. It requires a multi-faceted approach that includes stakeholder engagement, iterative design processes, and the application of adaptive technological solutions.

3.3 System of Systems (SoS) Aspects

In the context of the project, managerial independence is exemplified by the autonomous operation of individual sensor networks managed by separate entities within Newcastle. Each network decides on sensor placements and data protocols independently, allowing for flexibility and specialization .Whereas, the operational independence is observed in the system's ability to maintain air quality data collection through individual sensors even when parts of the network communication are disrupted, ensuring continuous operation.

The SoS displays emergent behavior through its comprehensive data analytics capabilities. When individual data points from over 5,000 sensors are synthesized, the system can predict pollution hotspots—insights that are not discernible from isolated data sets. Also, project demonstrates evolutionary development through the progressive integration of advanced algorithms and machine learning techniques that improve the predictive accuracy of the system over time, adapting to the city's changing environmental conditions.

The widespread deployment of sensors across Newcastle facilitates a detailed geographical mapping of air quality, allowing for targeted policy interventions in pollution-prone areas, showcasing the advantage of the system's extensive geographical coverage.

These aspects, as evidenced in the project, underscore the SoS's ability to operate beyond the sum of its parts, delivering a robust and adaptive solution for urban air quality monitoring, contributing significantly to the health and well-being of city inhabitants.

4 References

Renkeer. (n.d.). What is PM2.5 and how to measure? Retrieved from https://www.renkeer.com/what-is-pm2-5-and-how-measure/

Wikipedia contributors. (2021). System of systems. In Wikipedia, The Free Encyclopedia. Retrieved from https://en.wikipedia.org/wiki/System_of_systems

Urban Observatory. (n.d.). Graphs PM2.5. Newcastle Urban Observatory. Retrieved from https://newcastle.urbanobservatory.ac.uk/graphs/PM2.5/

Sustainability Methods. (n.d.). System Boundaries. Retrieved from https://sustainabilitymethods.org/index.php/System_Boundaries

SysML Forum. (n.d.). What is an internal block diagram? Retrieved from https://sysml.org/sysml-faq/what-is-internal-block-diagram.html

SysML Forum. (n.d.). What is the difference between a BDD and an IBD? Retrieved from https://sysmlforum.com/sysml-faq/what-is-diff-between-BDD-and-IBD.html

SysML Forum. (n.d.). What is a block definition diagram? Retrieved from https://sysml.org/sysml-faq/what-is-block-definition-diagram.html

Systems Engineering Body of Knowledge (SEBoK). (n.d.). Systems of Systems (SoS). Retrieved from https://sebokwiki.org/wiki/Systems_of_Systems_(SoS)