Secure data exchange in smart cities: lessons from Arrowhead fPVN

Theodor Pintilie
BEIA Consult International, Bucharest, Romania
theodor.pintilie@beia.ro

Anzhelika Borbak
BEIA Consult International, Bucharest, Romania
anzhelika.borbak@beia.eu

George Suciu
BEIA Consult International, Bucharest, Romania
george@beia.eu

Abstract
Smart cities depend on the interaction of many heterogeneous systems, including IoT devices, mobility platforms, energy networks, environmental sensors, public services and administrative data systems. These systems are often developed by different providers, operated by different organisations and based on different data formats, interfaces and security requirements. As a result, cyber-resilience is not only a matter of protecting individual systems from attacks, but also of governing how information is exchanged, accessed and interpreted across complex digital environments. This paper explores how concepts from the Arrowhead fPVN project, which focuses on interoperability in production value networks, can provide useful lessons for secure data exchange in smart cities. The paper builds on published project directions related to microservice-based architecture, major industrial data models, semantic analysis and translation mechanisms between different data representations. The approach is conceptual and comparative: it maps selected Arrowhead fPVN principles to typical smart city challenges such as fragmented platforms, incompatible information models, cross-domain coordination and the need for controlled interaction between independent systems. The paper discusses how microservices, controlled service interaction and semantic translation can help reduce integration problems between heterogeneous systems and support safer information exchange, more transparent coordination and improved cyber management. The expected contribution is not to present Arrowhead fPVN as a complete cybersecurity solution for smart cities, but to show how its interoperability-oriented principles can inform the design of more structured, auditable and semantically clear digital public infrastructures. The results are relevant for researchers, practitioners and public administrations interested in cyber-resilient urban services, gradual integration of legacy systems and improved governance of data exchange.

Keywords: Interoperability, Data exchange, Smart city systems; Microservices, Data integration

1. Introduction
Smart cities depend on the interaction of many digital systems, including Internet of Things (IoT) devices, mobility platforms, energy networks, environmental sensors, public services and administrative data systems. These systems are often developed by different providers and operated by different organisations. As a result, the smart city can be understood as a system of systems, where independent components must exchange information to support public services, infrastructure management and decision-making.

Recent studies from the SCRD Digital Library highlight similar challenges in smart city development. Maulana et al. identify data silos, data integration deficiencies, interoperability, cyber management and data security as important issues for local-

government digital transformation [1]. Radchenko shows that smart city initiatives are shaped by organisational and institutional factors, including governance, regulations, technological capacity and connectivity [2]. Schachtner discusses municipal digital strategies from a governance perspective, while later work on Business Continuity Management links public-sector resilience with information security management [3], [4]. Together, these studies suggest that smart city development requires not only digital tools, but also structured mechanisms for cooperation, secure data exchange, continuity and governance.

European interoperability frameworks show that interoperability is not only a technical issue, but also involves organisational, semantic, legal and governance aspects [5], [6]. This is important for smart cities because fragmented systems can create duplicated integrations, unclear responsibilities and weaker coordination. Cyber-resilience therefore also depends on how information is shared, controlled and interpreted across different organisations and platforms.

The Arrowhead fPVN project offers a useful reference case for this discussion. Although it focuses on industrial production value networks, it addresses similar problems: heterogeneous systems, different data models and controlled interaction between independent actors. Public project materials describe Arrowhead fPVN as being based on microservices, major industrial data models and automatic translation between data models [7], [8]. These ideas are relevant for smart cities, where urban systems also need modular integration, reliable data exchange and correct interpretation of information.

This paper does not present Arrowhead fPVN as a definitive cybersecurity solution for smart cities, but it uses the project as a reference case to identify lessons for secure data exchange in urban digital environments. The paper proposes a conceptual mapping between selected Arrowhead fPVN principles and smart city data exchange challenges.

The remainder of the paper is structured as follows. Section 2 presents Arrowhead fPVN as a reference case. Section 3 maps selected concepts to smart city systems. Section 4 discusses benefits, limitations and public administration relevance. Section 5 concludes the paper and outlines future work.

2. Arrowhead fPVN as a reference case

Arrowhead fPVN is used in this paper as a reference case because it addresses interoperability in complex production value networks, where several independent systems, organisations and data models must interact. The project is not focused on smart cities directly, but its technical direction is relevant for urban digital systems because both domains face similar integration problems. In both cases, data has to move between systems that were not necessarily designed together, while access, reliability and correct interpretation must still be maintained.

Public project material describes Arrowhead fPVN as being built around three main directions: the microservice paradigm, the use of major industrial data models and automatic translation between data models [7], [8]. These directions are important because

they separate the interoperability problem into several layers. Microservices support modular interaction between systems. Data models describe the structure and meaning of exchanged information. Translation mechanisms help bridge differences between models and formats.

Public project deliverables also provide a more technical view of this approach. D1.1 presents the project baseline and requirements related to common Arrowhead technology, microservices, major fPVN data models and automated data model translation [9]. D2.2 focuses on the second version of the fPVN microservice architecture and describes work related to communication interoperability, identification of data-model non-interoperability, dynamic translation services and policy or rule-based microservice management [10]. D4.1 further discusses translation technology, including ontology translation tools and translation between major data modelling languages [11].

These elements make Arrowhead fPVN useful for this paper not as a complete cybersecurity model, but as an example of how interoperability can be treated in a structured way. Its focus on modular services, controlled interaction, data-model alignment and translation can inform discussions about smart city systems, where public services, infrastructure operators, IoT platforms and administrative systems also need to exchange information securely and consistently.

3. Mapping Arrowhead fPVN concepts to smart city systems

The main contribution of this paper is a conceptual mapping between selected Arrowhead fPVN principles and typical smart city data exchange challenges. This mapping is not intended to transfer the industrial architecture directly into the urban domain. Instead, it identifies common problems and shows how interoperability concepts used in production value networks may inform the design of smart city systems. Previous work has already discussed the Arrowhead framework in relation to IoT and system-of-systems architectures for smart cities and smart agriculture [12]. Smart city platform research also shows that urban digital environments require architectures able to integrate heterogeneous applications, devices and data sources [13]. In this sense, the mapping proposed in this paper builds on the SCRD literature by treating interoperability as both a technical and organisational issue. The focus is not only on connecting platforms, but also on clarifying how services interact, how access is controlled and how exchanged data is interpreted across institutional boundaries [1], [2], [3].

In smart cities, fragmentation can appear at several levels. A municipality may use separate systems for mobility, energy, water management, environmental monitoring, public safety and administrative services. These systems may expose different interfaces, use different data models and apply different rules for access control. An Arrowhead-inspired view would treat these systems as independent services that need controlled interaction, rather than as components of one centralized platform. Figure 1 summarises this Arrowhead-inspired view of secure data exchange in smart city systems, showing how heterogeneous urban systems can be connected through controlled service interaction and semantic and data-model alignment.

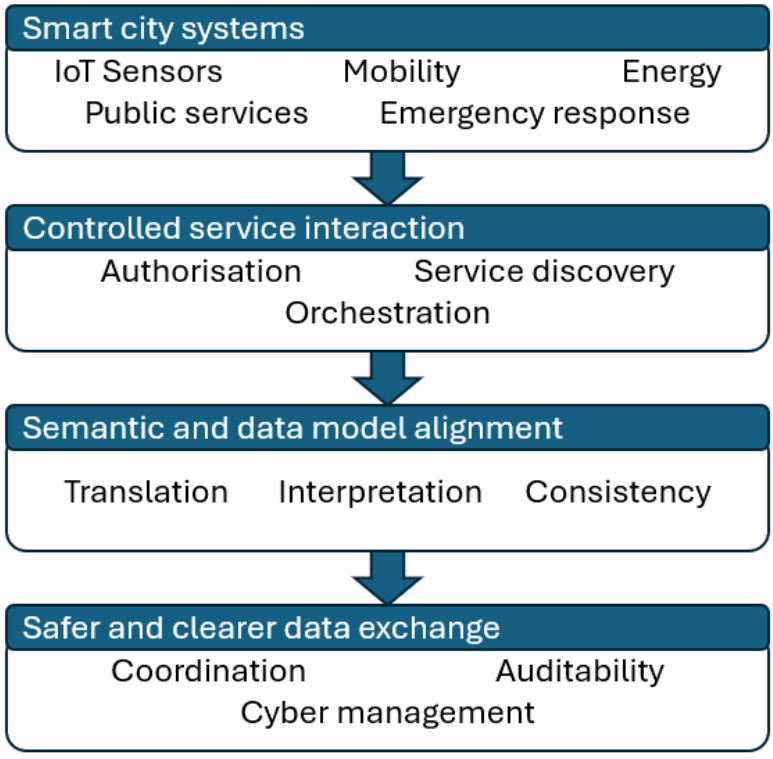


Fig. 1. Arrowhead-inspired secure data exchange model for smart city systems
Source: Author's representation based on Arrowhead fPVN public project concepts

Table 1 presents a simplified conceptual mapping between Arrowhead fPVN concepts and smart city data exchange needs.

Table 1. Conceptual mapping between Arrowhead fPVN and smart city systems

Arrowhead fPVN concept	**Smart city parallel**	**Possible relevance**
Microservice-based architecture	Modular urban services	Allows different city systems to interact without being merged into one platform
Controlled service interaction	Access between public, private and infrastructure systems	Supports clearer rules for who can access which data or service
Industrial data models	Urban domain data models	Helps structure information from mobility, energy, environment or emergency systems
Semantic analysis	Correct interpretation of data	Reduces misunderstandings caused by different formats, units or meanings
Translation mechanisms	Cross-domain data exchange	Helps connect systems that use different data structures or representations
Policy or rule-based management	Public administration governance	Helps connect systems that use different data structures or representations

Source: Authors' representation based on Arrowhead fPVN concepts

A simple example is flood response. A city may need to combine weather forecasts, rainfall sensors, water-level monitoring, road infrastructure data, energy-network status and emergency-response information. These data sources may belong to different organisations and may not use the same formats or terminology. A service-based approach could help authorised systems request and provide information in a controlled way, while semantic translation could support more consistent interpretation of the exchanged data.

This mapping shows that the value of Arrowhead fPVN for smart cities is not limited to technical integration. It also concerns coordination and governance. By separating service interaction, data modelling, translation and access rules, smart city systems can become easier to manage, extend and audit.

4. Benefits, limitations and public administration relevance

The main benefit of the proposed mapping is that it treats smart city data exchange as a governance problem, not only as a technical integration problem. This responds to challenges identified in SCRD literature, where smart city development is linked to data silos, interoperability, institutional capacity, cyber management and information security resilience in public institutions [1], [2], [4]. Instead of connecting systems through isolated and ad hoc interfaces, smart city platforms could be organised around clearer service interactions, access rules and data interpretation mechanisms. This can support more transparent coordination between municipal departments, infrastructure operators, technology providers and other stakeholders.

For public administrations, this approach may also help reduce dependence on single-vendor platforms. If urban services are organised as modular services with defined interfaces and data models, new systems can be added more gradually. This is important because many cities already operate legacy systems that cannot be replaced immediately. An interoperability-oriented approach can therefore support gradual digital transformation while keeping existing services functional, in line with the need for stronger municipal digital strategies and continuity planning [3], [4].

However, the concepts discussed in this paper should not be presented as a complete cybersecurity solution. Microservices, semantic translation and controlled service interaction can improve the structure of data exchange, but they do not replace security measures such as encryption, identity and access management, monitoring, incident response, vulnerability management and privacy protection. Smart city cybersecurity studies also emphasise the need for good practices adapted to city operators, public authorities and maturity levels [14].

The value of the Arrowhead fPVN perspective is therefore more specific: it offers ideas for making data exchange more controlled, understandable and auditable. A structured interoperability layer can help public organisations manage cooperation across institutions, platforms and service providers more clearly, especially in scenarios such as flood response, traffic disruption, energy incidents or environmental monitoring.

5. Conclusions and future work

Secure data exchange is an important requirement for smart city systems, where many public, private and infrastructure-related platforms need to interact. As cities become more digital, the main challenge is not only to collect more data, but also to ensure that information can be accessed, exchanged and interpreted correctly across heterogeneous systems.

This paper used Arrowhead fPVN as a reference case for discussing how interoperability concepts from industrial production value networks can inform smart city data exchange. The proposed mapping shows that microservice-based interaction, controlled service access, data-model alignment and semantic translation can be relevant beyond the industrial domain. These concepts can help smart city systems move away from isolated integrations and toward more structured, auditable and understandable forms of cooperation.

At the same time, the paper does not present Arrowhead fPVN as a complete cybersecurity solution for smart cities. The discussed concepts should be combined with established security measures, including identity management, encryption, monitoring, incident response, privacy protection and regulatory compliance. Their main contribution is to support the governance and organisation of data exchange between systems.

Future work could apply this mapping to a specific smart city scenario, such as flood response, traffic disruption, energy-network incidents or environmental monitoring. A more detailed case study could examine which services, data models, access rules and translation mechanisms would be required in practice. This would help assess how industrial interoperability principles can support real-world public administration and infrastructure coordination.

Acknowledgements

This work was partially supported by the Arrowhead fPVN project, funded by the Chips Joint Undertaking (Chips JU) and its member states, as well as by national funding authorities from the participating countries under grant agreement No. 101111977.

References

[1] R. Y. Maulana, U. Marjamat, D. Subekti and A. Wicaksono, "Catalyzing digital transformation through Smart Cities initiatives in Indonesian local government," Smart Cities and Regional Development Journal, vol. 9, no. 1, pp. 35-46, 2025, doi: 10.25019/59kh3t06.

[2] K. Radchenko, "Factors influencing the content of Smart City initiatives (particularly based on institutional theories of organization)," Smart Cities and Regional Development Journal, vol. 8, no. 3, pp. 55-64, 2024, doi: 10.25019/yxf9wh55.

[3] C. Schachtner, "Wise Governance – Elements of the digital strategies of municipalities," Smart Cities and Regional Development Journal, vol. 6, no. 2, pp. 23-29, 2022, doi: 10.25019/scrd.v6i2.126.

[4] C. Schachtner, "On the way to resilient information security management: Business Continuity Management (BCM) for public institutions," Smart Cities and Regional Development Journal, vol. 9, no. 1, pp. 7-15, 2025, doi: 10.25019/dq18x683.

[5] European Commission, "European Interoperability Framework for Smart Cities and Communities (EIF4SCC)," European Commission, 2022. [Online]. Available: https://living-in.eu/sites/default/files/files/eif4scc-en.pdf

[6] European Commission, "Levels of interoperability," Interoperable Europe Portal. [Online]. Available: https://interoperable-europe.ec.europa.eu/collection/iopeu-monitoring/solution/european-interoperability-framework-eif-toolbox/levels-interoperability

[7] European Commission, "Arrowhead Flexible Production Value Networks," CORDIS, Project ID 101111977. [Online]. Available: https://cordis.europa.eu/project/id/101111977

[8] Arrowhead fPVN Consortium, "Arrowhead fPVN – About," Arrowhead fPVN Project Website. [Online]. Available: https://fpvn.arrowhead.eu/about/

[9] Arrowhead fPVN Consortium, "Deliverable D1.1: Requirements, state of the art and base line," Arrowhead fPVN, 2023. [Online]. Available: https://fpvn.arrowhead.eu/wp-content/uploads/sites/3/2024/10/Arrowhead_fPVN_D1.1_v1.0-1.pdf

[10] P. Varga and K.-J. Gramner, "Deliverable D2.2: Second version of fPVN microservice architecture – Arrowhead v5.0," Arrowhead fPVN, 2025. [Online]. Available: https://fpvn.arrowhead.eu/wp-content/uploads/sites/3/2025/11/Arrowhead_fPVN_D2.2_v1.0.pdf

[11] Arrowhead fPVN Consortium, "Deliverable D4.1: First generation of translation technology," Arrowhead fPVN, 2024. [Online]. Available: https://fpvn.arrowhead.eu/wp-content/uploads/sites/3/2024/10/Arrowhead-fPVN-D4.1-1.pdf

[12] I. Marcu, G. Suciu, C. Bălăceanu, A. Vulpe and A.-M. Drăgulinescu, "Arrowhead Technology for Digitalization and Automation Solution: Smart Cities and Smart Agriculture," Sensors, vol. 20, no. 5, article 1464, 2020, doi: 10.3390/s20051464.

[13] E. F. Z. Santana, A. P. Chaves, M. A. Gerosa, F. Kon and D. S. Milojicic, "Software Platforms for Smart Cities: Concepts, Requirements, Challenges, and a Unified Reference Architecture," ACM Computing Surveys, vol. 50, no. 6, article 78, 2018, doi: 10.1145/3124391.

[14] ENISA, "Cyber Security for Smart Cities: An Architecture Model for Public Transport," European Union Agency for Cybersecurity, 2015. [Online]. Available: https://www.enisa.europa.eu/publications/smart-cities-architecture-model