An Ontology Based Approach for Data Model Construction Supporting the Management and Planning of the Integrated Water Service

Michele Grimaldi[1], Monica Sebillo[1(✉)], Giuliana Vitiello[1], and Vincenzo Pellecchia[2]

[1] University of Salerno, 84084 Fisciano, SA, Italy
{migrimaldi,msebillo,gvitiello}@unisa.it
[2] Water Management Authority AATO-1, Campania, Italy
vpellecchia@enteidricocampano.it

Abstract. The Italian Ministry of Infrastructures and Transport has started the implementation of SINFI, the National Federated Infrastructure Information Service, whose goal is both to share information about infrastructures and underground utilities, and offer a single dashboard that efficiently manages and monitors all interventions. Although the data model underlying SINFI has been designed with a general-purpose approach, it doesn't result in line with the actual needs of the operators of the Integrated Water Service that instead has to be compliant with the updating of the plans of intervention according to the macro-indicators of technical quality referred to in the ARERA resolution.

The aim of this paper is to propose a data model that allows measuring such macro-indicators and generating interoperable datasets. An ontological approach has been used that has produced a data storage model as implemented in the Semantic Web.

Keywords: Integrated Water Service · Ontology · SINFI · Indicators RQTI

1 Introduction

The Authorities responsible for the regulation and control of the Integrated Water Service (Servizio Idrico Integrato - SII) have matured the awareness of the need to significantly improve the level of knowledge about the infrastructures distributed on the Italian territory. This attentiveness has both stimulated further investigation conceived to define methodologies capable to support data modelling, and motivated new actions addressed to put into practice such metodologies.

The initial analysis, already underway for several years, has highlighted a series of critical issues. Italian water services are suffering from a significant infrastructural deficit, in terms of both quality and quantity of supply, and of sewerage systems and water treatments. Even in the field of management, measurement systems and controlling computer systems require urgent investments needed for both the recovery of operational efficiency and saving of water and energy in systems and networks to combine safety, quality, and continuity of service, environmental protection, and sustainable use of the resource itself [1].

S. Misra et al. (Eds.): ICCSA 2019, LNCS 11624, pp. 243–252, 2019.
https://doi.org/10.1007/978-3-030-24311-1_17

At international level, the attention to the knowledge of infrastructures is recognized by the recently published *Underground Infrastructure Concept Development Study (UICDS) Engineering Report*, which has examined the state of information of the American underground infrastructure, costs and benefits, as well as future opportunities for an improvement of the current status. The report describes a number of candidate models for describing information, and recommends a series of related activities, including the development of an integration model prototype for information related to underground infrastructures, namely "Model for Underground Data Definition and Integration" (MUDDI) [2, 3].

The study presented in the report demonstrates that the development of interoperable underground infrastructure data standards is extremely important to support a series of essential business processes for the economy and society, now and in the future. In particular, the geospatial community and the wider one of engineers and property developers have long understood the value of standardized and interoperable infrastructure data. However, there have been important obstacles to the creation of this data, among the others, the absence of standardized models useful for guiding the storage and development of existing databases.

A factor that inhibits the development of standardized infrastructure data is the perception, by both public and private utilities, that development costs are too high and far outweigh the benefits that could be brought to the system. However, it emerged from the report that there are strong indications on the possibility of being able to derive significant benefits from achieving the standardization and interoperability of infrastructure data.

In Italy, the Ministry of Infrastructures and Transport (Ministero delle Infrastrutture e dei Trasporti) has started implementing the National Federated Infrastructure Information Service (Sistema Informativo Nazionale Federato delle Infrastrutture - SINFI) [4–7]. However, the data model proposed in SINFI is not fully responsive to the needs of today companies that manage SII. As a matter of fact, the update of the "investment plan", developed according to the macro indicators of the technical quality referred to the Regulation of the technical quality of the Integrated Water Service (RQTI) resolution by ARERA [8], is one of the mandatory activities requested by the Service Operators, which would benefit from a standardization of the database of water infrastructure.

In summary, the picture that emerges highlights the presence of two needs by public and private utilities, as follows:

- the need to comply with the obligation to populate the SINFI database, and
- the need to monitor the infrastructures of the water system according to the technical quality requirements by implementing the performance indicators.

The research carried out along this line is meant to define models and develop methods for an effective monitoring of the existing infrastructures and of plan investment for SII. In particular, the present paper describes how the basic specifications provided by SINFI can be adopted and adapted for this system by expanding the parameters to measure the macro indicators of performance. A set of schemas is then described to embed a catalog of spatial reference metadata addressed to the SII census and empowerment.

The rest of the paper is organized as follows. Section 2 briefly describes the SINFI specifications and the regulation of technical quality for SII and for each service within it (RQTI). In Sect. 3, the spatial catalog is built starting from a (non) functional requirements analysis. Conclusions are drawn in Sect. 4.

2 Method and Material

In order to define the data model underlying SII monitoring activities, a case-based approach has been followed, aimed at characterizing in a more representative manner the different categories in which SII has been broken down. The general purpose being to simulate its operating characteristics and evaluate results in terms of decision-making support.

In the following Subsections, specifications underlying SINFI are summarized and an excerpt of RQTI is presented.

2.1 National Federated Infrastructure Information Service

SINFI was established by a Decreto 11 maggio 2016 (GU Serie Generale n.139 del 16-06-2016). It represents the instrument identified for coordination and transparency for the new broadband and ultra-broadband strategy. Its general purpose is to share information about infrastructures and underground utilities, and offer a single dashboard that efficiently manages and monitors all interventions.

The SINFI case studies represent the first application examples of the coordination action carried out by AgID in order to convey the competent administrations to the use and sharing of thematic data models compliant with the national Database Geotopografici (DBGT – Topographic geodatabases) specifications [9].

The SINFI technical specifications represent an extension of the contents of the "07 - underground networks" layer of the DBGT specifications shown in Fig. 1.

Fig. 1. Contents of the DBGT specific to SINFI

2.2 Regulation of the Technical Quality of the Integrated Water Service

By the Resolution 917/2017/R/IDR, the Regulatory Authority for Electricity, Gas and Water defines the SII technical quality with an asymmetric and innovative approach. The regulation model especially develops the selectivity, correlation, effectiveness, reward, progression and stability in order to identify correct and effective incentives to promote benefits for users of the different services in specific contexts.

This model results from an extensive consultation (dco 562/2017/R/IDR and 748/2017/R/IDR) and is based on the following indicators:

- prerequisites - the conditions necessary for admission to the incentive mechanism associated with the general standards;
- specific standards - performance parameters to be guaranteed for services provided to individual users where non-compliance requires automatic indemnities;
- general standards - these parameters are broken down into macro-indicators and simple indicators that describe technical conditions for providing a service with an incentive mechanism. The macro-indicators are:

  M1 – "Water losses" (to minimise losses, with effective monitoring of water infrastructure), taking into account both actual and percentage water losses;
  M2 – "Service interruptions" (to maintain service continuity, also through a suitable configuration of supply sources). It represents the ratio between the total length of interruptions in a year and the number of end users served by the supplier;
  M3 – "Quality of water supplied" (to ensure adequate quality of the resource for human consumption). It uses multi-stage logic, considering: (i) the incidence of non-potability orders; (ii) the rate of non-compliant internal samples; (iii) the level of parameters from non-compliant internal controls;
  M4 – "Adequacy of the sewage system" (to minimise environmental impact from waste water). It uses multi-stage logic - considering: (i) the frequency of flooding and/or spills from sewers; (ii) the legal adequacy of flood drains; (iii) the control of flood drains;
  M5 – "Landfill sludge disposal" (to minimise the environmental impact of wastewater treatment, for sludge). It represents the ratio between the amount of sewage sludge measured dry that is disposed of in landfills and the total quantity of sewage sludge measured dry;
  M6 – "Quality of purified water" (to minimise the environmental impact of wastewater treatment, for the water line). This is the rate wastewater discharge samples exceed limits.

3 Building the Data Model: From the Analysis of Requirements to the Catalog

In order to define the standard data storage model, an ontology-based architecture has been used, according to the Semantic Web approach [10–16]. In order to simulate the operational features and test the reliability of the model, a case study has been developed concerning the water system of the Municipality of Solofra (Southern Italy), as part of the "Programma degli Interventi" ranging (2016–2019). Figure 2 shows the water network of this town.

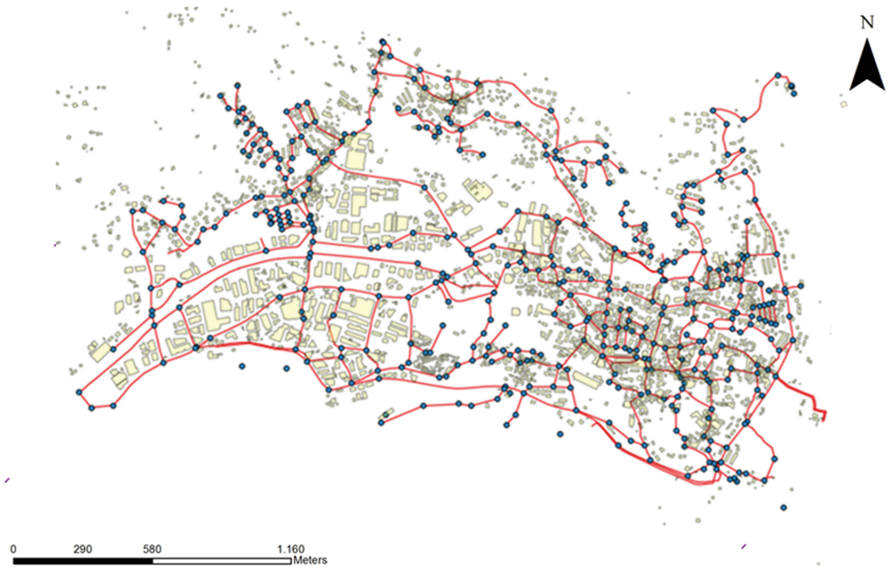

Fig. 2. Water network of municipality of Solofra (Italy)

By adopting a multistep methodology, the identification of the ontology elements has been first performed. Starting from the content specifications of the SINFI tables, SII has been associated to the information layer "07", which is divided into two themes (macro-classes), namely water supply network and water disposal network. Each theme consists of 3 classes as shown in Table 1, namely line, node and network. The first two refer to the geographic elementary units that schematize the network, the network class is related to concepts referring to the network as a whole.

Table 1. Classes: line, node and network

theme 01: Water supply network (0701)	class 01: Section of the water supply network (TR_AAC-070101)
	class 02: Node of the water supply network (TR_AAC-070102)
	class 03: Water supply network (TR_AAC-070103)
theme 02: Water disposal network (0702)	class 01: Section of the water disposal network (TR_AAC-070201)
	class 02: Node of the water disposal network (TR_AAC-070202)
	class 03: Water disposal network (TR_AAC-070203)

Subsequently, for each class, the attributes able to characterize the SII structure have been identified by analyzing the reference manuals of water infrastructure engineering. In conformity with SINFI, each attribute has been assigned an alphanumeric coding that represents its unique and distinctive semantic number, such as ND_AAC_TY that indicates the type of water supply network node, and TR_SAC_TY indicating the type of section of the disposal network of water (Fig. 3).

In addition to the geometric aspects, specific attributes have been introduced in accordance with the performance indexes and with the 6 macro indicators of th technical quality:

- responsible for the operation of the network,
- position and localization,
- typology and function of nodes and traits,
- environmental conditions,
- year of construction,
- operating status and physical conditions,
- survey date,
- type of user connected to the network,
- state of the elements to be maintained or replaced,
- length and working pressure of the pipes.

07010106	TR_AAC_MAT	**Materiale [1…n]**	Enum (Materiale)	aTratti su	Tracciato
		Tipologia di materiale			
07010108	TR_AAC_PRO	**Profondità [0..1]**	Enum (Range di profondità)	aTratti su	Tracciato
		Range di profondità cui è posato l'oggetto			
07010104	TR_AAC_DIA	**Diametro**	Integer	aTratti su	Tracciato
		Diametro nominale/diagonale della sezione [mm]			
07010131	TR_AAC_LUN	**Lunghezza tratto**	Real		
		Indica la lunghezza del tratto in km			
07010132	TR_AAC_ABI	**N°abitanti**	String(50)		
	Indica il numero di abitanti servito dal tratto				

Fig. 3. Example of alphanumeric coding for attributes according to SINFI content specifications

The basic ontological model depicted in Fig. 4 has been created by using Protégé [17, 18] program. For both the water supply network and the water disposal network, the model has been further expanded with a new class named "Technical Quality". In these new classes, the concepts related to all parameters necessary for computing the macro indicators have been transferred.

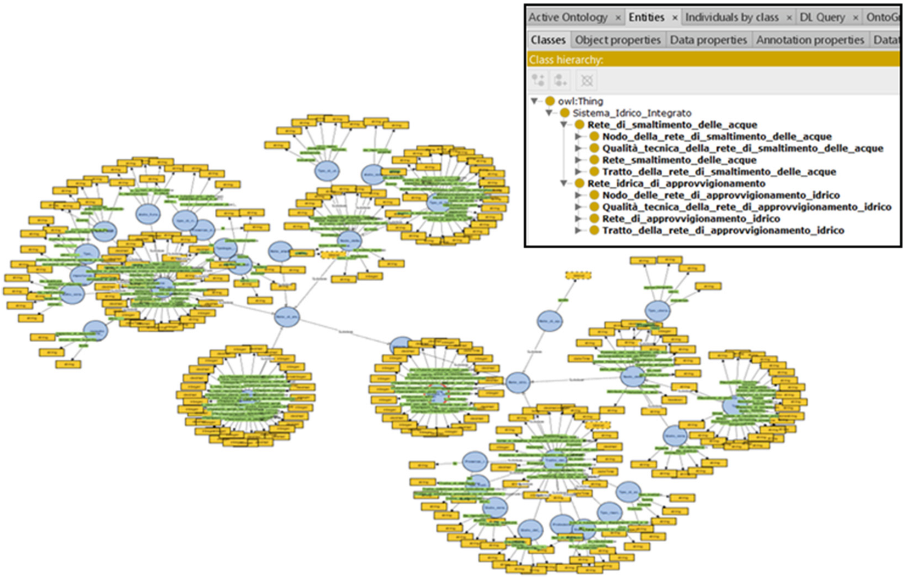

Fig. 4. Data model visualization and Class hierarchy

The cognitive map shown in Fig. 4 has been generated in order to verify the consistency of the concepts. The result has been translated into a catalog expressed in terms of a data storage model organized in compliance with SINFI. In particular, the additional classes shown in Figs. 5 and 6 are:

- Class 04: Technical quality of the water supply network (QT_AAC-070104)
- Class 04: Technical quality of the water disposal network (QT_SAC_070204).

CLASSE: **Qualità tecnica della rete di approvvigionamento idrico** (QT_AAC - 070104)

	SINFI
Popolamento della classe	

Definizione
Individua tutti i parametri per il calcolo degli indici di performance e dei macro indicatori come disposto dal programma degli interventi e dal programma di controllo per la Qualità tecnica della rete e delle acque. Per ogni caratteristica è prima riportato l' ID del tratto corrispondente, richiamato dal nome e tipo della rispettiva classe del tratto.

Attributi				
Attributi della classe				SINFI
07010401	QT_AAC_DAT	Anno di riferimento dati	Date	P

Fig. 5. Technical quality of the water supply network (QT_AAC-070104)

CLASSE: **Qualità tecnica della rete di smaltimento delle acque** (QT_SAC - 070204)

	SINFI
Popolamento della classe	

Definizione

Individua tutti i parametri per il calcolo degli indici di performance e dei macro indicatori come disposto dal programma degli interventi e dal programma di controllo per la Qualità tecnica della rete e delle acque. Per ogni caratteristica è prima riportato l' ID del tratto corrispondente, richiamato dal nome e tipo della rispettiva classe del tratto.

Attributi				
Attributi della classe				SINFI
07010401	QT_SAC_DAT	Anno di riferimento dati	Date	P

Fig. 6. Technical quality of the water disposal network (QT_SAC_070204)

4 Discussion

According to the logic of interoperability envisaged for spatial data by the INSPIRE directive, most of data used by the proposed model is shared with the SINFI information system. This assumption simplifies, by reducing time and cost of implementation, the development, population and updating of the two systems, also through both the reuse of IT components already implemented by Infratel Italia for SINFI, and the shared use (without duplication) of spatial data common to the two systems. In particular, as regards the implementation phase, the model produces significant effects both on the operator side and on the controller side.

In the first case, it allows the monitoring of all the critical issues related to SII management, the optimization of the planning of interventions and the operational support for the preparation of the investment plan, globally improving the performance of the service.

In the second case, the system will allow ARERA to implement the incentive mechanism, which provides for the application of bonuses and penalties for system operators through a multi-criteria comparative system in accordance with the TOPSIS methodology, on a homogeneous and comparable data base among the various operators. In fact, to date, since such a method is not envisaged and the evaluation criteria are codified, the different operators measure the macro-indicators according to their own modalities, strongly influenced by the degree of knowledge of their own system. This will inevitably produce measures that are not perfectly comparable and will influence the outcome of the evaluation. The outcome of the assessment, in fact, if negative, will lead to an increase in the level of investments with consequential rises in the service tariff for the user. In particular, as for the implementation phase, the model produces significant effects, both for to face various critical issues related to the SII management, creating the prerequisites for the provision of other types of value-added services.

5 Conclusions

The present paper intends to underline the need of extending the field of application of DBGTs to the different themes that imply in-depth knowledge of the territory, in order to produce innovative services for the improvement of the SII efficiency and effectiveness.

The proposed model responds to the SINFI specifications in terms of interoperability and then it allows ARERA implementing the bonus-penalty mechanism envisaged by the abovementioned determination.

It should be pointed out that, according to the logic of interoperability envisaged for spatial data by the INSPIRE directive, most of data used by the proposed model is shared with the SINFI information system. This assumption simplifies, by reducing time and cost of implementation, the development, population and updating of the two systems, also through both the reuse of IT components already implemented by Infratel Italia for SINFI, and the shared use (without duplication) of spatial data common to the two systems. In particular, as for the implementation phase, the model could produce significant effects to face various critical issues related to the SII management, creating the prerequisites for the provision of other types of value-added services [19, 20].

However, the emerged limits reside in the lack of capability of intervention by the managers of the service, in structural way on the knowledge of the networks. In fact, the lack of data and tools invalidates the calculation of macro-indicators, making technical quality a mere bureaucratic exercise and not an effective tool for orienting the contents of the “investment plan” towards excellent and performing solutions.

References

1. Grimaldi, M., Fasolino, F., Pellecchia, V.: Urban plan and water infrastructures planning: a methodology based on spatial ANP. Sustainability **9**(5), 1–23 (2017)
2. Lieberman, J.: Introduction to MUDDI: Model for Underground Data Definition and Integration, OGC (2018)
3. Model for Underground Data Definition Integration (MUDDI), Engineering Report (2018)
4. Agenzia per l’italia Digitale: Specifiche di contenuto di riferimento per i DataBase delle Reti di sottoservizi e per il SINFI - Versione 3.0 (2016)
5. Agenzia per l’italia Digitale: Specifiche di contenuto di riferimento per i DataBase delle Reti di sottoservizi e per il SINFI - Versione 3.0 (2017)
6. Ministero dello sviluppo econominco: Manuale operativo di prima consegna dei dati per il SINFI, https://www.sinfi.it/portal/index.php/conferimento-dati-sinfi/documentazione. Accessed 21 Feb 2019
7. INFRATEL, AgID, Linee guida per la produzione dati del SINFI. http://www.infratelitalia.it/piani-nazionali-e-regionali/catasto-delle-infrastrutture. Accessed 21 Feb 2019
8. 917/2017/R/IDR: Regulation of the technical quality of the Integrated Water Service or of each of the individual services that compose it (RQTI) (2017)
9. Agenzia per l’italia Digitale: Modifiche introdotte nella versione 3.0 delle Specifiche di contenuto di riferimento per i DataBase delle Reti di sottoservizi e per il SINFI (2017)
10. Hitzler, P., Krotzsch, M., Rudolph, S.: Foundations of Semantic Web Technologies. Chapman & HALL/CRC, Boca Raton (2009)

11. Métral, C., Falquet, G., Vonlanthen, M.: An Ontology-based Model for Urban Planning Communication. In: Teller, J., Lee, J.R., Roussey, C. (eds.) Ontologies for Urban Development. SCI, vol. 61. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-71976-2_6
12. Fox, M.: A Foundation Ontology for Global City Indicators. Global Cities institute, University of Toronto, Toronto (2013)
13. Oulidi, H.J: Spatial Data on Water, Geospatial Technologies and Data Management. ISTE Press – Elsevier, London (2018). Loukis, E.: An ontology for G2G collaboration in public policy making, implementation and evaluation. Artif. Intell. Law **15**(1), 19–48 (2007)
14. Bouyerbou, H., Bechkoum, K., Lepage, R.: Geographic ontology for major disasters: methodology and implementation. Int. J. Disaster Risk Reduct. **34**, 232–242 (2019)
15. Gil, Y., Blythe, J.: PLANET: a shareable and reusable ontology for representing plans. In: AAAI Workshop on Representational Issues for Real-World Planning Systems (2000)
16. Pundt, H.: Domain ontologies for data sharing—an example from environmental monitoring using field GIS. Comput. Geosci. **28**(1), 95–102 (2002). https://doi.org/10.1016/S0098-3004(01)00018-8
17. Tudorache, T., Csongor, N., Natalya, F., Mark, A.: WebProtégé: a collaborative ontology editor and knowledge acquisition tool for the web.". Semant. Web **4**(1), 89–99 (2013)
18. Protégé 5.5.0. www.protege.stanford.edu. Accessed 10 Mar 2019
19. Ginige, A., Paolino, L., Romano, M., Sebillo, M., Tortora, G., Vitiello, G.: Information sharing among disaster responders - an interactive spreadsheet-based collaboration approach. Comput. Supported Coop. Work (CSCW) **23**(4–6), pp. 547–583 (2014). ISSN 0925-9724
20. Sebillo, M., Vitiello, G., Paolino, L., Ginige, A.: Training emergency responders through augmented reality mobile interfaces. Multimedia Tools Appl. **75**(16), 9609–9622 (2016). Springer, New York (2015). https://doi.org/10.1007/s11042-015-2955-0