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Implementation Aspects of Management Models for Network and Services in Smart Street Lighting

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Value-added services in recent networks are provided with smart grid technology and particularly smart street lighting. The effective management of services and networks, structured as smart, imposes development of management information model, which meets the requirements of network operator, service provider, and subscribers. Paradigm of smart grid defines only management framework without specification of architecture model and functions. The bright deployment of smart grid is based on development of management models. To this moment they are short specialized, cover only some of management functional areas, and reflect partially the actors' requirements. This paper represents implementation aspects of models for service management and network management in smart street lighting. Object-oriented method is used by models' design. Management functions for services and network are considered in installation, provision, configuration, maintenance, security, accounting, and performance. The focus is on problems regarding optimization of developed models and their reducing to Boyce-Codd Normal Form. The procedures for Service Installation and Service Provision are demonstrated with different methods: direct method and method with decomposition. The paper is intended to business developers, university professors, and students.

Keywords: value-added services, smart grid, management information model, smart street lighting, Boyce-Codd Normal Form

Introduction

The concept of network for smart street lighting ensures value-added services (for service subscribers—municipalities), by which the network operator could be distinguished among competition. The whole infrastructure (processing nodes, data bases, services, and applications) supports and manages business benefit. Key factor is the effective network management, which minimizes the emergency of faults and interruptions in service provision. Paradigm of smart street lighting (InteliLIGHT, 2020) defines only management framework without specification of architecture model and functions. This led to development of myriad diverse methods and products for network management (Higuera, Hertog, Perálvarez, Polo, & Carreras, 2015; Guo, Wu, G. L.

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Li, J. H. Li, & Wu, 2017; Mahoor, Hosseini, Khodaei, Paaso, & Kushner, 2020). Network optimization (Olson, 2003; Srinidhi, Dilip Kumar, & Venugopal, 2019), devices monitoring (Breunig, Stock, & Bauernhansl, 2020; Forma, Boutin, Wilkie-Chancellier, Le Conte, & Jossic, 2025; Rajendran, Singh, Moudgil, Turukmane, Umadevi, & Glory, 2022), automated service configuration (Ponomarev & Mustafin, 2021; García-Galán, Trinidad, Rana, & Ruiz-Cortés, 2016), applications performance management (Souifi, Boulanger, Zolghadri, Barkallah, & Haddar, 2021; Sturm, Pollard, & Craig, 2017), intelligence optimization (Mohammadi & Sheikholeslam, 2023) are only a small part of the proposed management approaches. The recent types of solutions cover only separate management functional areas or satisfy management requirements only for network operator or only for service provider. A successful management practice must cover all stages of life cycle of network and services and must consider requirements of all actors: network operator, service provider, subscribers, and users.

The paper represents management information models for services and network in smart street lighting, which integrate all functional areas—from installation and deployment of network and services through their configuration, maintenance, and performance to security and accounting. The focus is on specific aspects of models' implementation, which considers their optimization. A procedure avoiding data dependency is described. The term "data dependency" (Garcia-Molina, Ullman, & Widom, 2002) means restriction on possible relationships, which could be the recent set of exemplars in an entity relationship. This could lead to following problems:

(1) Data redundancy. An attribute is written always for functionally fixed attribute.

(2) Update anomalies (potential inconsistency). Due to data redundancy an attribute in a record could be updated and, in another record, could stay undated. In this case there is not a unique value for the functionally fixing attribute.

(3) Insert anomalies. An attribute could not be written, if it is not functionally fixed from another attribute. A null value could be set on the place of fixing attribute and by insert of such attribute the record with null value always must be deleted. Moreover, the fixing attribute is the key for the relationship and if the key field contains null, the query on primary index could be impossible.

(4) Delete anomalies. The reverse problem on those of point 3 is that if all attributes, fixing another attribute, must be deleted, the fixed attribute would be lost.

The data dependency is eliminated by reducing the entity relationship representing managed objects to normal form—generally five normal forms (DataCamp, 2024). In this paper we demonstrate the routine to the Third Normal Form (3NF), which eliminates the transitive dependences. A transitive dependency occurs when a non-key attribute depends on another non-key attribute, which itself depends on the primary key. It basically takes its value by the transitive law. We will consider also functional dependences, which contain all candidate-keys in a relation. We will apply Boyce-Codd normal form, which is a stronger condition than 3NF. It ensures that every determinant (set of attributes, which uniquely fix a relation) in an entity relationship is a candidate-key (minimum set of attributes, which uniquely fixes a relation). The essence of this is that all determinants could serve as primary keys. The Fourth and Fifth Normal Forms will not be considered in this paper. They examine multi-valued dependences and join dependences.

Brief descriptions of developed management information models for network and services are represented in following section. The next step is the data base normalization procedure avoiding dependences.

Management Information Models for Network and Services in Smart Street Lighting

Object-oriented method under requirements in standards (ITU-T, 2011) is applied to design of management information. Each resource—physical or logical, interesting of management viewpoint, is constituted by Managed Object (MO). The actors in service management model are: service provider—MO ServiceProvider, service subscriber—MO MOfficer (Municipality Officer), and service user—MO BusinessUser (Head of Department in Munisipality). Objects of management are: smart street lighting service—MO SmartService, service subscriber, and service user. Objects of management are administrated by profile—MO Profile. Management elements are explained by functional areas: MO Configuration, MO Maintenance, MO Security, MO Accounting, and MO Performance (ISO/IEC/IS, 1989). Figure 1 (Ilieva-Obretenova & Pipev, 2023) depicts MOs for service management. Similarly, the actors in network management model are: network operator—MO Operator, network subscriber (service provider)—MO NetworkSubscriber, network user (service subscriber)—MO NetworkUser. Objects of management are: network for smart street lighting—MO SmartNetwork, network subscriber, and network user. Objects of management are headed by profile—MO NetworkProfile. Management elements are explicated by five functional areas: MO NetworkConfiguration, MO NetworkMaintenance, MO NetworkSecurity, MO NetworkAccounting, and MO NetworkPerformance (ISO/IEC/IS, 1989). Figure 2 illustrates MOs for the network management. By defining of MOs, connected with management areas, in each model are taken into account management requirements of each actor: network operator, service provider, service subscriber, service user. For example, MOs included in Service Installation, are: SmartService, ServiceProvider, ServiceFeature, ServiceProfile, ServiceConfiguration, ServiceMaintenance, ServiceSecurity, ServiceAccounting, ServicePerformance. Figure 3 shows relations between MOs, participating in Service Installation in Smart Street Lighting. MOs, included in Service Provision, are the following: SmartService, ServiceProvider, ServiceFeature, ServiceProfile, ServiceConfiguration, ServiceMaintenance, ServiceSecurity, ServiceAccounting, ServicePerformance, MOfficer, OfficerContract, OfficerProfile, OfficerConfiguration, OfficerMaintenance, OfficerSecurity, OfficerAccounting, OfficerPerformance, BusinessUser, BusinessProfile, BusinessAccounting, BusinessPerformance. Figure 4 depicts dependences between MOs, incorporated in Service Provision in smart street lighting.

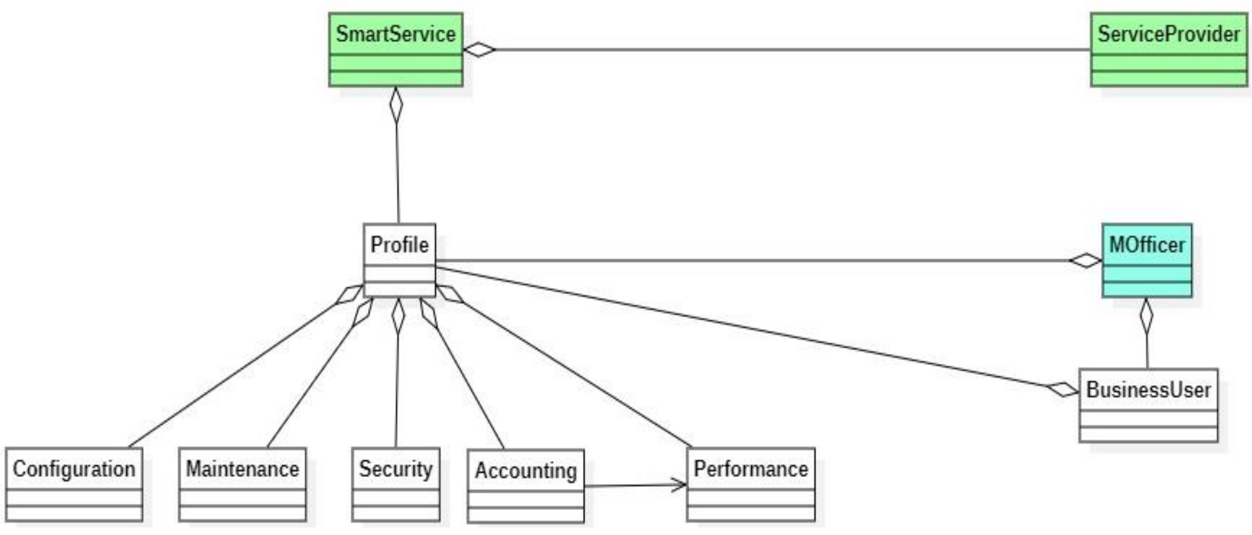

Figure 1. Managed objects for service management.

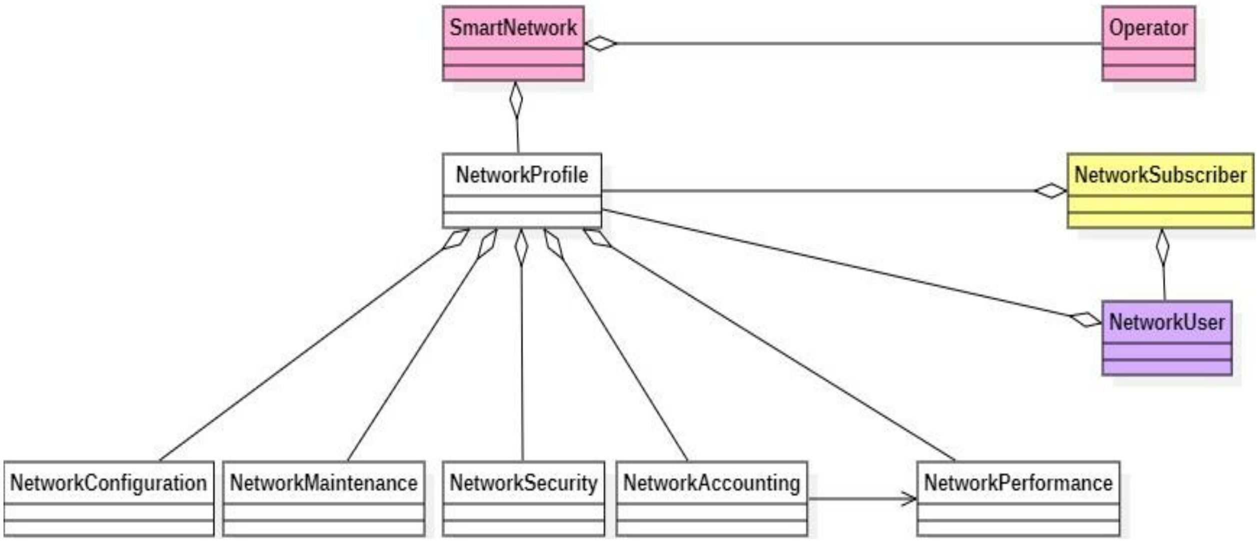

Figure 2. Managed objects for network management.

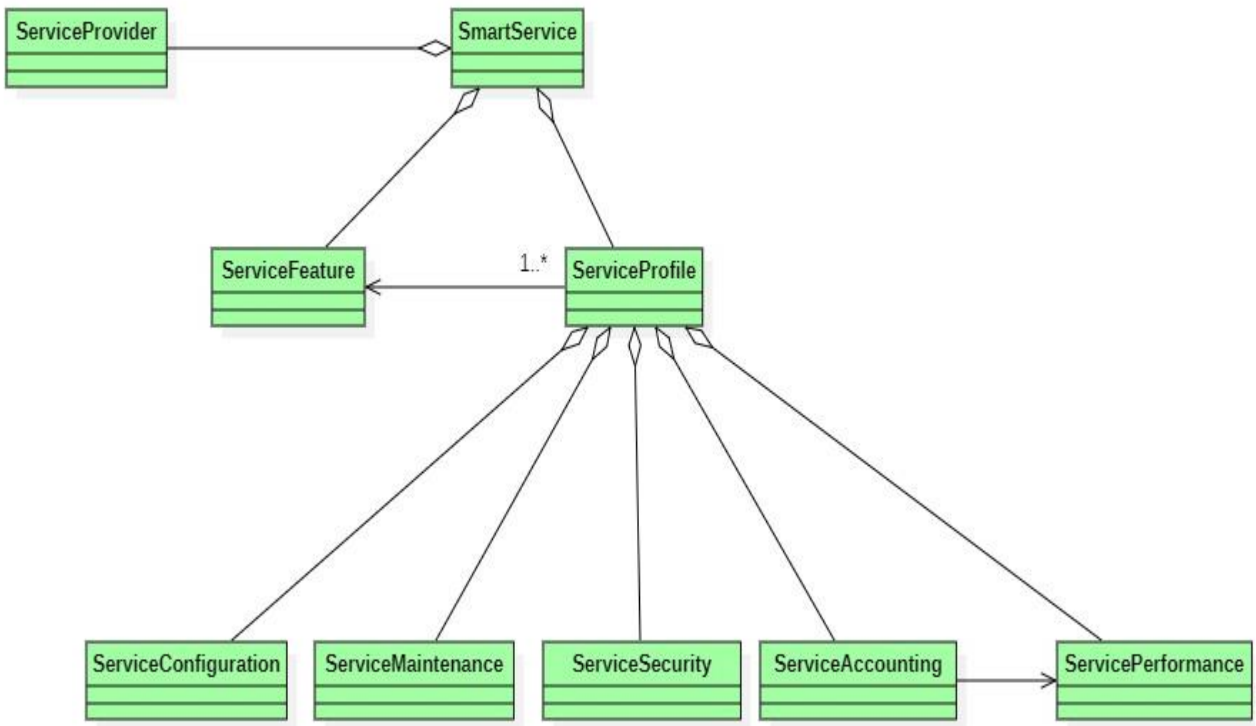

Figure 3. Managed objects for service installation.

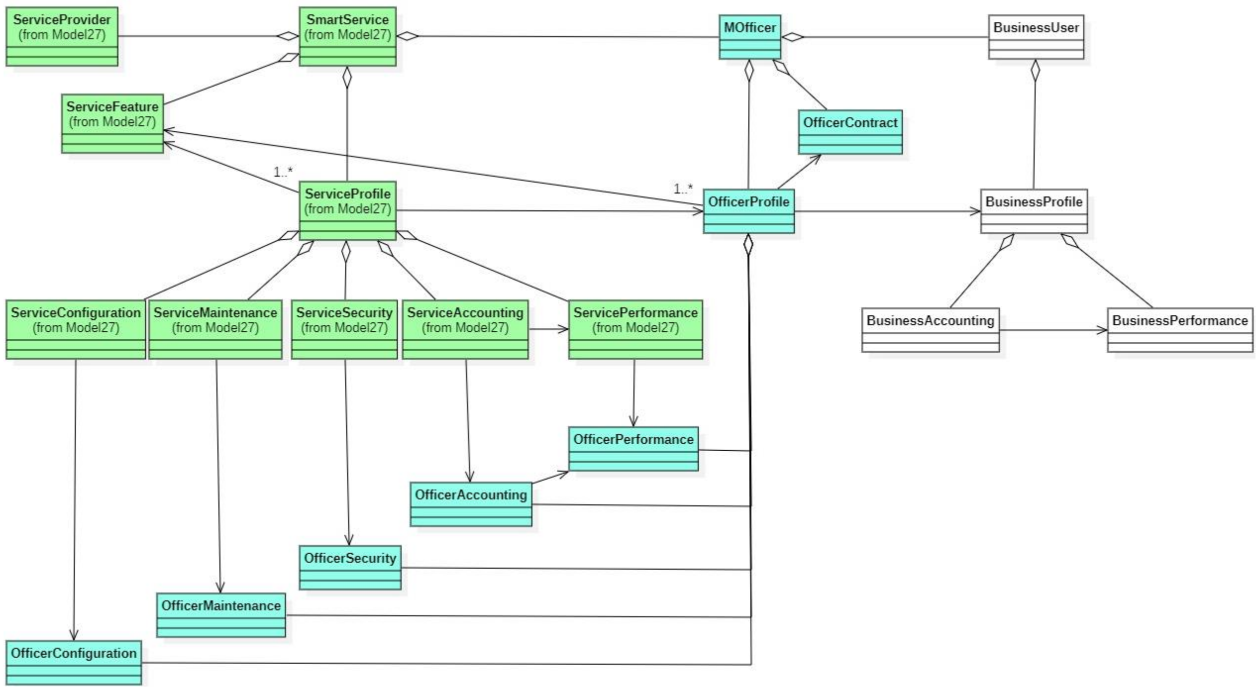

Figure 4. Managed objects for service provision.

Normalization of Entity Relationships, Representing Managed Objects

Two methods for reducing entity relationships to normal form find application, depending on the objects' number and the actor's number: direct method and method with decomposition.

The direct method is concerned for reducing to normal form for entity relationships with less MOs and more than one actor or for these with more MOs and one actor. The method contains only Test algorithm whether a given attribute is a key. The method with decomposition is applied for reducing to normal form for entity relationships with more MOs and more than one actor. The procedure contains a decomposition to smaller entity relationships, application of Test algorithm whether a given attribute is a key for each scheme and pointing the super-key for the whole design. The MOs play the role of attributes by the normalization. Examples of developed information models for Service Installation and Service Provision illustrate the applicability of these methods.

Reducing to Boyce-Codd Normal Form of Entity Relationship for Service Installation

Information model for Service Installation is reduced to Boyce-Codd Normal Form with the direct method, because the entity relationship contains less MOs and one actor. Attributes, participating in information model, are taken from Figure 3.

Let SmartService = A; ServiceProvider = A`; ServiceFeature = B; ServiceProfile = C; ServiceConfiguration = D; ServiceMaintenance = E; ServiceSecurity = F; ServiceAccounting = G; ServiceAccounting = H.

The entity relationship is R = AA`BCDEFGH.

We must prove, that by given functional dependences the entity relationship has key. For this purpose, we use Test algorithm whether a given attribute is a key. Figure 5 shows functional dependences in the scheme.

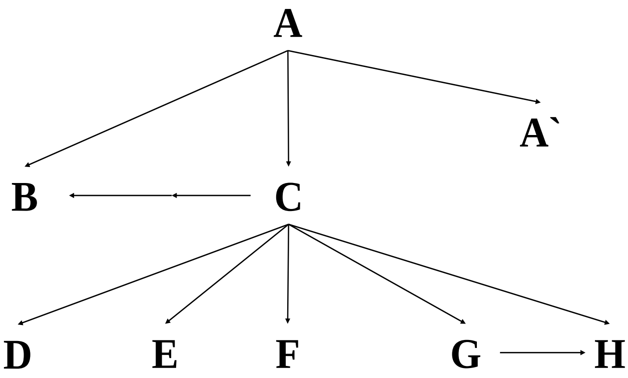

Figure 5. Functional dependences for Service Installation.

The set of functional dependences F is the following:

$$A \to A`, A \to B, A \to C, C \to\to B, C \to D, C \to E, C \to F, C \to G, C \to H, G \to H.$$

The set F+ contains functions, consequence of these in F:

(1) From $A \to B$ and $A \to C \Rightarrow A \to BC \in F+$ (Distribution lemma)

(2) From $C \to D, C \to E, C \to F, C \to G, C \to H \Rightarrow C \to DEFGH \in F+$ (Distribution lemma)

(3) From $C \to\to B \Rightarrow C \to\to (ABCDEFGH – C - B) \Rightarrow C \to\to ADEFGH$

We choose $DEFGH = Z \subseteq ADEFGH$. $C \to\to Z$.

W exists, for which is in force: $W \to DEFGH$. $W \to Z \Rightarrow C \to Z \in F+$. $C \to DEFGH \in F+$.

(4) From $A \to C$ and $C \to DEFGH \Rightarrow A \to DEFGH \in F+$ (Transitivity lemma)

We suppose that key of the relation is ABC. We must prove that:

- ABC is a key, because A, B, C, AB, AC, and BC do not fix functionally all attributes or;
- ABC is not a key, because A or B or C or AB or AC or BC fixes functionally all attributes (minimality condition).

Proof:

Whether A fixes functionally all attributes or whether $A \to A`ABCDEFGH \in F+$?

We set $Z = DEFGH \subset A`ABCDEFGH$.

Due to decomposition lemma the following is in force: $A \to DEFGH$.

We proved yet, that $A \to DEFGH \in F+$.

- ABC is not a key.
- A is a key.
- Attribute SmartService is a key of the entity relationship.
- The entity relationship Service Installation is in Boyce-Codd Normal form.

Reducing to Boyce-Codd Normal Form of Entity Relationship for Service Provision

Information model for Service Provision is reduced to Boyce-Codd Normal Form by the decomposition method, because entity relationship contains more MOs and two actors. Attributes, participating in management information model are taken from Figure 4 (Ilieva-Obretenova & Pipev, 2023). We set SmartService = A; ServiceProvider = A`; ServiceFeature = B; ServiceProfile = C; ServiceConfiguration = D; ServiceMaintenance = E; ServiceSecurity = F; ServiceAccounting = G; ServicePerformance = H; MOfficer = I; OfficerContract = J; OfficerProfile = K; OfficerConfiguration = L; OfficerMaintenance = M; OfficerSecurity = N; OfficerAccounting

= O; OfficerPerformance = P; BusinessUser = Q; BusinessProfile = R; BusinessAccounting = S; BusinessPerformance = T.

The resulting entity relationship is R = A`ABCDEFGHIJKLMNOPQRST.

We must prove that by given functional dependences the scheme has a key. For this purpose we use Test algorithm whether a given attribute is a key.

The functional dependences in set F are:

$$A \to A`, A \to B, A \to C, C \to\to B, C \to D, C \to E, C \to F, C \to G, C \to H, G \to H,$$
$$A \to I, I \to K, I \to J, K \to J, K \to\to B, C \to K, K \to L, K \to M, K \to N, K \to O, K \to P,$$
$$O \to P, D \to L, E \to M, F \to N, G \to O, H \to P, I \to Q, Q \to R, K \to R, R \to S, R \to T, S \to T.$$

Figure 6 illustrates the entity relationship for Service Provision.

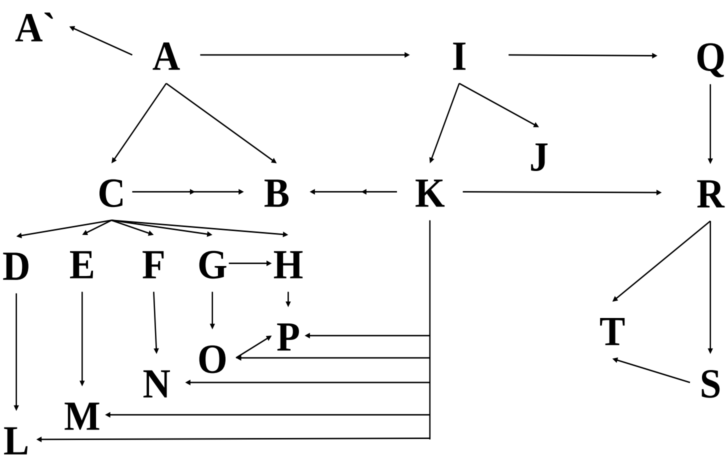

Figure 6. Functional dependences for Service Provision.

In contrast with Service Installation entity relationship for Service Provision is bigger and therefore we make a decomposition into three smaller relations R_1, R_2, and R_3.

$R = R_1 \cup R_2 \cup R_3$

R_1 = ABCDEFGH

R_2 = AIJKLMNOP

R_3 = IQRST

We must prove that this decomposition has join without loss.

We apply a Test algorithm for verification of join without loss (Date, 2000). A table with 20 columns and 3 rows is built. Column j corresponds to attribute A_j, and row i corresponds to entity relationship R_i. In the crosspoint of row i and column j the symbol a_j is placed, if A_j is in R_i. If not, on the same place the symbol b_{ij} is set. In the next step we seek rows which match in column for attribute X, e.g. a_1 and a_1, a_9 and a_9. If we find such two rows, their symbols for attribute Y are equated. By equation of two symbols, if the one is a_j, the other also gets a value of a_j. If, after the change of rows according to the above condition, we find that a row has the form $a_1 \dots a_n$, the join is without loss. If not, the join is with loss (not without loss). Table 1 illustrates the primary data. Table 2 depicts join without loss.

Table 1

Primary Data for Normalization with Decomposition

J i	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
R_1	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	b_{19}	b_{110}	b_{111}	b_{112}	b_{113}	b_{114}	b_{115}	b_{116}	b_{117}	b_{118}	b_{119}	b_{120}
R_2	a_1	b_{22}	b_{23}	b_{24}	b_{25}	b_{26}	b_{27}	b_{28}	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	b_{217}	b_{218}	b_{219}	b_{220}
R_3	b_{31}	b_{32}	b_{33}	b_{34}	b_{35}	b_{36}	b_{37}	b_{38}	a_9	b_{310}	b_{311}	b_{312}	b_{313}	b_{314}	b_{315}	b_{316}	a_{17}	a_{18}	a_{19}	a_{20}

Table 2

Join without loss in Normalization with Decomposition

j i	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
R_1	$\underline{a_1}$	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	a_{20}
R_2	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	a_{20}
R_3	b_{31}	b_{32}	b_{33}	b_{34}	b_{35}	b_{36}	b_{37}	b_{38}	a_9	b_{310}	b_{311}	b_{312}	b_{313}	b_{314}	b_{315}	b_{316}	a_{17}	a_{18}	a_{19}	a_{20}

In the next step we must find the keys of every entity relationship in the decomposition.

The key to entity relationship R_1 is A (a_1) or attribute SmartService.

Attribute SmartService (a_1) is a key to entity relationship R_2 too.

Attribute MOfficer (I, a_9) is a key to entity relationship R_3.

- The split entity relationship Service Provision has keys A and I or SmartService and MOfficer. The functional dependency between them is A $\rightarrow$ I.
- A is a super key.
- Attribute SmartService is a super key of entity relationship R.
- The entity relationship Service Provision is in Boyce-Codd Normal Form.

Conclusion

This paper investigates aspects, connected to database implementation, representing management models for services and network, structured as smart. Approaches for reducing of entity relationships with managed objects to Boyce-Codd Normal Form are applied. By this way the data base is optimized, avoiding data dependency. Direct method for reducing to Boyce-Codd Normal Form is illustrated with entity relationship Service Installation. It would be useful to Service Configuration, Network Installation, Service Maintenance, Network Security, Network Accounting, Network Performance, and physical nodes in project for smart street lighting. Approach with decomposition for reducing to Boyce-Codd Normal Form is illustrated with entity relationship Service Provision. It would be useful for Network Provision, Network Configuration, and Subscriber Control on Network from the same project. Deployment of developed models would significantly increase efficiency of management activities, covering all life cycle stages of the whole infrastructure for provision of value-added services, oriented to requirements of end users.

References

Breunig, D. A., Stock, D., & Bauernhansl, T. (2020). Requirements and concept for a modular and state-oriented control device architecture. *Procedia Manufacturing, 42*, 281-287. Retrieved from https://doi.org/10.1016/j.promfg.2020.02.096

DataCamp. (2024). *Normalization in SQL (1NF-5NF): A beginner's guide*. New York: DataCamp.

Date, C. J. (2000). *An introduction to database systems.* Toronto: Addison Wesley Longman, Inc.

Forma, L., Boutin, H., Wilkie-Chancellier, N., Le Conte, S., & Jossic, M. (2025). An innovative method for the objective comparison of the performance of active control devices. *Journal of Sound and Vibration, 596*, 118688. https://doi.org/10.1016/j.jsv.2024.118688

García-Galán, J., Trinidad, P., Rana, O. F., & Ruiz-Cortés, A. (2016). Automated configuration support for infrastructure migration to the cloud. *Future Generation Computer Systems, 55*, 200-212. Retrieved from https://doi.org/10.1016/j.future.2015.03.006

Garcia-Molina, H., Ullman, J. D., & Widom, J. (2002). *Database system: The complete book.* Wilmington: Prentice Hall, Inc.

Guo, L. G., Wu, J., Li, G. L., Li, J. H., & Wu, J. (2017). Software-defined networking model for smart transformers with ISO/IEC/IEEE 21451 sensors. *ICT Express, 3*(2), 67-71. Retrieved from https://doi.org/10.1016/j.icte.2017.05.004

Higuera, J., Hertog, W., Perálvarez, M., Polo, J., & Carreras, J. (2015). Smart lighting system ISO/IEC/IEEE 21451 compatible. *IEEE Sensors Journal, 15*(5), 2595-2602. doi:10.1109/JSEN.2015.2390262

Ilieva-Obretenova, M., & Pipev, R. (2023). IoT management for street lighting—Information model—Part II. *Management Studies, 11*(5), 253-261. doi:10.17265/2328-2185/2023.05.002

InteliLIGHT. (2020). City-centric smart street lighting, 26.06.2020. Everything you need to know about smart street lighting. Washington, D.C.: InteliLIGHT®.

ISO/IEC/IS 7498-4 CCITT Recommendation X.700. (1989). Information processing—Open systems interconnection—Basic reference model—Part 4: Management framework.

ITU-T. (2011). M.Imp3100: Implementers' guide for recommendations ITU-T M.3100-series, generic network information model.

Mahoor, M., Hosseini, Z. S., Khodaei, A., Paaso, A., & Kushner, D. (2020). State-of-the-art in smart streetlight systems: A review. *The Institution of Engineering and Technology IET, 2*(1), 24-33. Retrieved from https://doi.org/10.1049/iet-smc.2019.0029

Mohammadi, A., & Sheikholeslam, F. (2023). Intelligent optimization: Literature review and state-of-the-art algorithms (1965-2022). *Engineering Applications of Artificial Intelligence, 126*, 106959. Retrieved from https://doi.org/10.1016/j.engappai.2023.106959

Olson, D. L. (2003). Optimization models. In H. Bidgoli (ed.), *Encyclopedia of information systems* (pp. 403-411). New York: Elsevier. Retrieved from https://doi.org/10.1016/B0-12-227240-4/00128-3

Ponomarev, A., & Mustafin, N. (2021). Decision support systems configuration based on knowledge-driven automated service composition: Requirements and conceptual model. *Procedia Computer Science, 186*, 654-660. Retrieved from https://doi.org/10.1016/j.procs.2021.04.213

Rajendran, N., Singh, R., Moudgil, M. R., Turukmane, A. V., Umadevi, M., & Glory, K. B. (2022). Secured control systems through integrated IoT devices and control systems. *Measurement: Sensors, 24*, 100487. Retrieved from https://doi.org/10.1016/j.measen.2022.100487

Souifi, A., Boulanger, Z. C., Zolghadri, M., Barkallah, M., & Haddar, M. (2021). From big data to smart data: Application to performance management. *IFAC-PapersOnLine, 54*(2), 857-862. Retrieved from https://doi.org/10.1016/j.ifacol.2021.08.100

Srinidhi, N. N., Dilip Kumar, S. M., & Venugopal, K. R. (2019). Network optimizations in the Internet of Things: A review. *Engineering Science and Technology, an International Journal, 22*(1), 1-21. Retrieved from https://doi.org/10.1016/j.jestch.2018.09.003

Sturm, R., Pollard, C., & Craig, J. (2017). *Application performance management (APM) in the digital enterprise.* New York: Elsevier.