Introducing an Information Logistics Approach to Support the Development of Future Energy Grid Management

Steffen Nienke, Oliver Zöllner, Violett Zeller and Günther Schuh
Institute for Industrial Management (FIR) at RWTH Aachen University, Campus-Boulevard 55, Aachen, Germany

Keywords: Information Management, Information Logistics, Energy Grid, Information Logistics Notation, Grid Stability.

Abstract: Due to the drastically increasing amount of data, decision making in companies heavily relies on having the right data available. Also because of an increasing complexity of structures and processes, quick and precise flows of information become more important. This paper introduces a new approach for modelling information flows, creating a basis for an efficient information management. It can be used to structure the information requirements and identify gaps within the information processing. To display its benefits, the proposed Information Logistics Notation (ILN) is applied to the information logistics of todays and future energy market and grid stability management, both processes of increasing complexity.

1 MOTIVATION

During recent years, the industry is trying to replace the currently prevailing experience-based decisions with data-driven decisions to improve the decision quality (pwc, 2016). However, due to the increasing amount of data that is available nowadays, the complexity of the decision-making processes increases, too. Decision makers face an overwhelming amount of data and information, which usually leads to a neglect of some parts of the available information (Saaty, 2008). In addition, the subjective need for information differs from the impartial need of information (Krcmar, 2015). Therefore, a lot of potential to improve decision quality remains unused. In order to reduce the complexity, a consistent use of IT must be set up. The IT system needs to collects the data, prepare information and generate decision recommendations. Such a system should be designed user-centred, so that the user can focus on decision making instead of searching for and preparing information. In other words, the user can actually focus on his actual task he was hired for.

To achieve such a system, many components on three levels have to be considered. On the bottom layer, there is a need for a fast and reliable data acquisition and storage solution. On the middle layer, it requires a data analytics software that is intelligent enough to create decision recommendations. Finally, on the top layer, the information needs to be presented to the right person at the right time. Today, a lot of research and development is carried out on all levels and also on combining these levels. However, to create such a holistic system, those developments and approaches need to work together smoothly. Consequently, it is essential to structure the whole system to derive the necessary components and determine where those components are required. However, many existing approaches only consider the business processes to structure the IT system. Since every industry is striving to increase the use of information, this is only half of the needed requirements. In addition to the sequence of performed tasks that are represented of a process, it is important to determine who needs what kind of information within each task. Therefore, an information logistic model is required to structure the flow of information and determine the impartial information for each user. A Method for visualizing the information logistics is the Information Logistics Notation (ILN) that is presented in this paper.

To demonstrate the benefits of the information logistics model, it will be applied in the context of energy grid monitoring and stability management, a subject most relevant with regard to rising renewable generation. As the Climate Change 2014 Synthesis Report points out, “Human influence on the climate system is clear, and recent anthropogenic emissions

Nienke, S., Zöllner, O., Zeller, V. and Schuh, G.
Introducing an Information Logistics Approach to Support the Development of Future Energy Grid Management.
DOI: 10.5220/0006673202390246
In *Proceedings of the 20th International Conference on Enterprise Information Systems (ICEIS 2018)*, pages 239-246
ISBN: 978-989-758-298-1

of green-house gases are the highest in history." (Pachauri and Mayer, 2015, p. 2).

However, renewable energy generation capacities are neither reliable, nor centralized the way conventional power plants are. Because of this, the currently existing infrastructure for energy distribution and information exchange is not prepared to integrate large amounts of renewables. "The next generation electricity grid, known as "smart grid" […], is expected to address the major shortcomings of the existing grid" (Farhangi, 2010). A fully developed smart grid continuously tries to balance itself locally. To achieve the best possible balance, consumers and other actors on the energy market are constantly communicating and reacting, for example reducing energy consumption to stabilize the grid. Considering the many different players that need to act interdependently on the energy market, the many different measures that may have to be taken within seconds, communication has to be extremely quick and precise.

In turn, the data exchange required by a smart grid needs to be carefully organized with regard to information flows which is a possible application area for the Information Logistics Notation (ILN) proposed in this paper. Thus, the logistics of information in this sector is a crucial subject and a suitable case to present the benefits of the ILN.

The paper is structured as follows: After describing the motivation in this chapter, Chapter 2 clarifies the necessity for the new approach for modelling information flows and describes the basics for electricity grid operation. In Chapter 3, details on the aim of the approach are given. Followed by a detailed description of the components of the ILN and how they are used. Afterwards, the ILN is exemplarily applied to today's and future electricity grid operation in chapter 4. Finally chapter 5 sums up the findings and provides an outlook on future work.

2 DEFINITIONS AND FUNDAMENTALS

2.1 Information Logistics

In general, logistic is defined as controlling and executing all processes within and outside a socio-economic system (e.g., a company) that serve to bridge time and space. These could be the primary purpose of the company (e.g. logistics companies such as DHL), but also the subsidiary tasks of a company (e.g., transporting or storing within a company, Koch, 1996). The definition of information logistics varies in literature. In particular older publications, information logistics is merely referred to as the information linked to the flow of goods (Immoor, 1998). However, with the increasing importance of data and information, a broader definition is used. In this definition, the information is treated as a separate logistical asset (Krcmar, 2015; Voß and Gutenschwager, 2001). This paper is following the modern approach. As a result, the information logic combines all the methods that deal with the modelling, storage, distribution and provision of information. Hence, information logistics covers planning, control and monitoring of information flows (Krämer, 2002). In short, the aim of information logistic is to achieve the 5 R's: get the right information, to the right person, at the right time, in the right amount and providing the right quality (Krcmar, 2015).

2.2 Modelling Information Flows

In Literature, there are quite a few approaches on how to model information and data itself. Notable examples are the tools TOGAF (The Open Group Architecture Framework), ArchiMate or DEMO (Design & Engineering Methodology for Organizations). These already offer possibilities to model the information logistics structure of a company. However, modelling of information flows is usually not covered to the required extend of many use cases. Especially the ability to model the time-related exchange of specific objects of information and distinguish between information push and information pull is missing in those tools. As described in Section 1, modelling the information flow is getting more important since it enables entities to analyse and coordinate the information movements as well identify redundant information (Durugbo *et al.*, 2013). Modelling Information flows can be complex, since an information exchange takes place between individuals in one or more companies, between departments or companies, and between companies and their environment. Therefore, a structured approach on modelling information flows is crucial. In general, two methods of information flow modelling can be distinguished: the diametric modelling and the mathematical modelling (Durugbo *et al.*, 2013). The Diametric modelling usually results in a human-readable representation and is thus usually easier to understand e.g. by employees. The mathematical modelling, on the other hand, corresponds more to a machine-readable representation of the information flows. However, the diametric and mathematical approach to information flow modelling do not necessarily exclude but could complement each other. Accordingly, combinations of both approaches are often used (Durugbo *et al.*, 2013). In this paper, a diametric graph approach is presented, which can easily be converted into a matrix visualization and thus be turned into a mathematical model.

2.3 Electric Grid Operation and Expected Changes

Within this chapter, relevant aspects of the energy market, power generation and power grid are introduced to understand the ILN application area of this paper.

2.3.1 Status Quo of Transmission and Distribution Grids

The currently existing grid infrastructure was "designed as a centralized system such that the electric power flows unidirectional through transmission and distribution lines from power plants to the customer premises" (Gungor *et al.*, 2013). The networks themselves are radial, the top down power flow is unidirectional and the security scheme simple (Celli *et al.*, 2004). This means that all distribution grids simply pass the shortage on to higher grid levels. This makes them relatively easy to maintain but also limits them to their present use.

Engineers from a central network control station manage the grid in real time. They have to foresee bottlenecks or overloads (Schneiders, 2014).

Due to the emergence of decentralized power generation in small, renewable power plants attached to the distribution network, the grid becomes harder to manage. The amount of information processed in control centres is strongly increasing (Schneiders, 2014).

2.3.2 Trends and Expected Changes

Until now, the centralized approach on grid planning and control allowed robust and scalable power systems. The number of prosumers – persons who consume and produce energy – will rise dramatically, leading to a strong increase in renewable, variable power generation. (Divan and Kandula, 2016)

Additionally, renewable power generation quantities can only roughly be predicted (Su *et al.*, 2014). Communicating with energy suppliers to adjust output to keep the grid balanced gets harder because instead of a few companies, communication would have to reach thousands or even millions of households where a quick reaction would also have to ensue.

Shifting to an inconsistent energy generation will result in both energy surpluses and shortages that will ultimately lead to a time-dependent energy price for consumers (Hirth, 2013). Energy is cheapest when renewable production is highest, thus increasing energy consumption when the price is low disburdens the grid.

As the power grid needs to be continuously balanced with regard to power generation and consumption, the fluctuating energy generation will require all participants of the energy market to become more flexible.

3 INFORMATION LOGISTICS NOTATION (ILN)

The aim of the Information Logistics Notation (ILN) is to visualize the information logistics within an entity or in between various entities. The result can also be described as information map that shows where what information comes from and where each information is directed. This notation will help to solve the tasks of structuring the information flows and therefore the whole information system. In fact, the structured information flows can be used to identify missing components or interfaces in information systems as well as roles that do not receive enough information to cover the objective information need. While using this notation, there are certain similarities to the use of conventional business processes. Thus, in both cases, an actual state can be recorded and compared with a desired state. However, instead of presenting sequences of tasks, the ILN displays information objects and their flows between sources and sinks. Thus, an IL-model does not replace the traditional recording of business processes, but rather forms a new level, closing the gap between modelling business processes and modelling databases

3.1 Notation – Display of Information Logistics Models

The following subchapter describe the components and use of ILN.

3.1.1 Components of the ILN

In an IL-model, roles (or stakeholders) are the central objects. These roles represent functions within companies. Thus, they can symbolise persons, departments or objects like sensors. As visible on the left side of Figure 1, a role is visualised by an oval form. A role is characterised by the information generated (source) and required (sink). Every role possesses a source as well as a sink; a vertical line visually separates the two sides of a role.

Decision-making roles (or target roles) are exceptional roles that have a certain demand for information to reach a particular decision (Figure 1, right side). The decision-making role is distinguished by a filled margin. Additionally, the questions to be answered are noted over the decision-making roles. It is initially assumed that humans embody decision-making roles, making decisions based on supplied information. In future, due to increasing automation, this assumption might change towards computer-based roles.

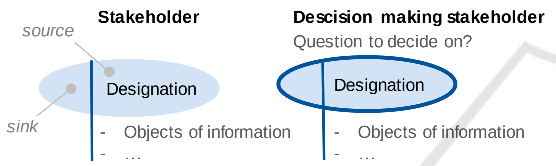

Figure 1: Symbols for stakeholders and decision-making stakeholders with target decision.

Some roles may not refer to single companies, divisions or stakeholders, but rather to a group of people. Taking the example of a power generation company, a role within the ILN could be customers. It is harder or sometimes impossible to exchange information with all individuals of such a role. Depending on how crucial the respective communication is, a special infrastructure may be required. Thus, roles that represent a big group are visually accentuated by a group-symbol on the left side of the vertical line (Figure 2).

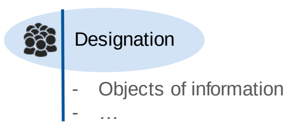

Figure 2: Symbol for a group of stakeholders.

Apart from roles, **systems** are an important element in mapping a flow of information. There are two kinds of systems: on the one hand, **database systems** are saving data and information (Figure 3, left side), and on the other hand, **processing systems** are aggregating, analysing and transforming incoming information to new objects of information (Figure 3, right side). Both kinds of system are visualised by rectangles, labelled with a name and tagged with a symbol to distinguish between databases (database symbol) and processing systems (gear wheels) as visible in Figure 3. Furthermore, systems can be sources and sinks of information; the object is divided by a vertical line analogue to stakeholders. In contrast to a role, databases can store series of data and can consequently give access to historical data. A processing system can execute complex analyses.

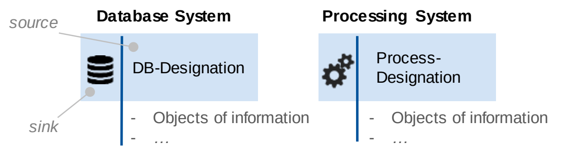

Figure 3: Symbols for database systems and processing systems.

The roles and systems exchange **objects of information** via **information flows**. As shown in Figure 4, objects of information are listed on the source side of a role. To increase lucidity and structure, datasets are pooled together in objects of information and then listed one below the other. Information flows connect objects of information from the source to the designated sink of a role or system. Each information is transmitted at a certain **transmission frequency** that is specified next to the respective information flow.

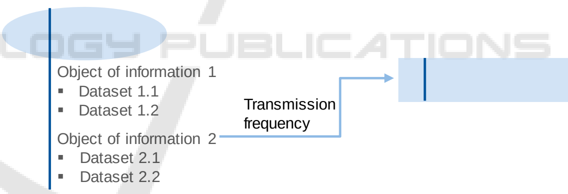

Figure 4: Visualization of objects of information and information flows.

There are two categories of transmission frequencies: On the one hand, information can be exchanged on a regular basis (for example each second or day), on the other hand the transmission can be actively triggered. The transmission can either be triggered from the side requiring information (information pull) or from the information source in case the information object changed (information push). For large information logistics displays to be more clearly arranged, the following shortcuts can be used to label information flows with transmission frequencies:

- s – every second;
- m – every minute;
- ¼ h – every quarter of an hour;

- h – every hour;
- d – daily;
- iC – if changed;
- oD – on demand.

Apart from the notations' basic elements that have been described to this point, there are other optional elements. They can display situations that are more complex. **Or-connections** can model alternative or redundant sources of information. As shown in Figure 5, such branches are pictured by a filled circle with an "X" in the middle. Only the information flow directed to the sink is labelled with the transmission frequency, because it shows the necessary availability of the respective information.

Additionally, it is possible to tag flows of information with a **weighting** and the **technology used for transmission**. Weighting flows of information makes sense if they require prioritization and the information system's available resources are possibly limited. Furthermore, priorities are the basis for mathematically optimizing an information logistics model.

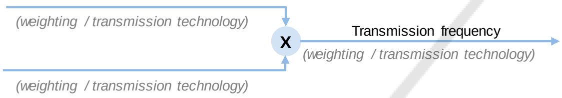

Figure 5: Visualization of OR-connections, weighting and transmission technology.

3.1.2 Rules and Approach for Modelling Flows of Information

To model a flow of information in ILN it is usually beneficial to go backwards along the information's flow. This means that the initial position is a requirement for specific information resulting from the need to make a certain decision within a period. Demand for information and the question to decide on are marked at the decision-making stakeholder. From this starting position, one can follow the flow of information along the stakeholders and systems to the original source. As shown in Figure 6, a processing system provides the required object of information. To model the flow of information, the arrow starts at the object of information and leads to the designated sink of the following stakeholder or system. Furthermore, systems or stakeholders that are not part of the current examination but still contribute information are coloured in grey.

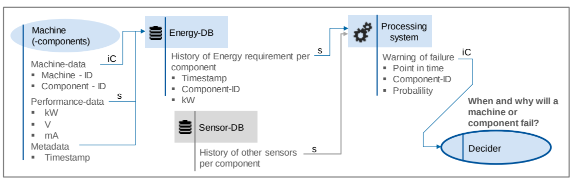

Figure 6: Exemplary presentation of logistics of information following the proposed notation.

3.2 Applying the ILN

To use the ILN for analysing the existing Information system or to start a greenfield development, three basic steps should be conducted:

3.2.1 Step 1: Situation Analysis and Target Definitions

As a first step, the current situation and the target dimension should be considered. To determine the current situation of information flows, the ILN can be used to describe the relationship of the required roles, systems and information. Therefore, the actual state is recorded on an information map that displays which role provides and requires what kind of information. The target situation should also be defined by using the ILN. One possibility to create such a target information map would be to use reference ILN-Models to derive the individual needs. The other possible solution is to create a target map from scratch. In both cases, first, the relevant use cases that should be covered by the information system need to be identified. They can usually be derived from the corporate strategy of a company. By deciding about the use cases that should be implemented, the involved roles and the decision that each role hast to take are determined. These decisions have to be made upon a solid and reliable information basis. For example, relevant information can be identified by interviewing the roles or by logic assumptions. From that point, the information flows can be designed. That means, information sources, database-systems, processing-systems and the exchange ways and rates need to be identified and put into order.

As a result of this step, two different information flow maps are created. One that represent the actual state of information flows and the other one shows the desired information flows.

3.2.2 Step 2: Identifying Solutions

After identifying the actual and the desired state, a matching of both states needs to be conducted. By comparing the existing information needs and demands to the desired ones, gaps of the information transmission can be identified. For example, a worker may not get the right parameters to set up a machine correctly. In addition, it is possible to determine missing data storage and processing systems. Missing processing systems could lead, for instance, to single, unconnected pieces of information from various sources that are far less valuable for the recipient than suitably merged information could be. Moreover, the current and the needed frequency of provided data updates can be determined by comparing the two states. This allows to derive the requirements for parts of the information system. Overall, the second step should result in an overview of identified gaps and suggested solutions.

3.2.3 Step 3: Evaluation and Decision

Following the identification of the gap between actual and target state, the proposed solutions need to be evaluated to identify the best match. To do so, the conceived solutions need to be transferred in an actual specification list that can e.g. be used to approach service providers. Subsequently, the evaluation of the provided solutions and the service providers can be done. This evaluation is based on individual parameters for each companies and does not represent the main focus of the presented work.

4 USING THE ILN TO MODEL FUTURE GRID INFORMATION LOGISTICS

In order to demonstrate its purpose, the ILN will be used to model the information logistics of the energy grid operators. This will be done twice, once for the current situation and once for the future grid. The examples will each focus on the task of network monitoring and the procurement of the necessary data, because maintaining network stability is most crucial and has to be done continuously with the latest data available. The diagrams have been created based on the German grid. However, they can easily be adapted to other developed electricity grids for example in Europe or the USA.

4.1 Current Situation

Nowadays, network monitoring is a task to be executed by the respective transmission network operator. Even though decentralized energy production is rising, the distribution grids are still working unidirectional, conducting energy top-down to customers. This kind of use makes them easy to maintain (see chapter 2.3.1). Thus, the transmission grids that conduct energy bi-directionally have to be the focus of careful operation and maintenance today.

Apart from reacting to unforeseeable events like disruptions, management of grid stability is based on the amount of power that is to be delivered from the various power plants' grid connection points to the distribution grid connection points. For this, the transmission grid operator needs to save all standing data of energy generation facilities from energy suppliers in a database and receive updated information in case of change. The database also contains all historical data that links weather and other factors to consumption and grid load and automatically fetches live data from the grid. The deliverable amount of energy is negotiated at energy markets.

There are different markets where energy is traded, usually a futures and options market where future energy generation capacities are traded and a spot market to balance supply and demand for the 24 hours to come. Because the current examination focusses on grid stability management rather than grid development, only the spot market is of interest. Apart from the energy suppliers, the spot market also communicates with companies buying energy (see Figure 7) and other market actors that are not part of the visualization. Every quarter of an hour, the spot market informs energy suppliers and transmission grid operator about the energy delivery schedule.

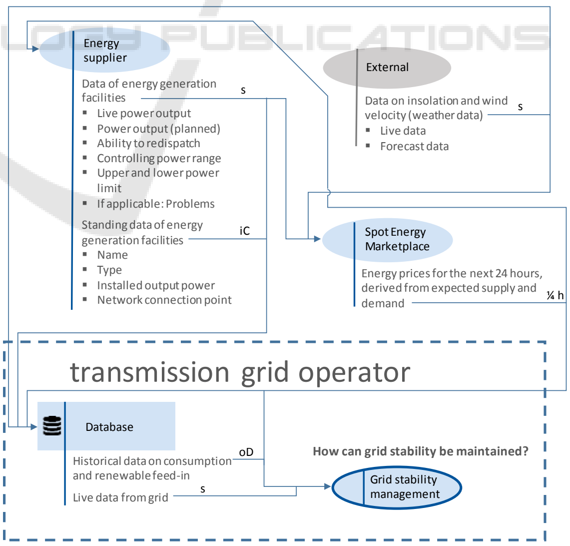

Figure 7: Todays logistics of information for grid stability management.

4.2 Future Situation

As stated before (see chapter 2.3.2), the development of the energy distribution system is directed towards a smart grid. The future grid chosen to be examined in this paper is set after significant changes with regard to renewable energy generation have taken, though some time before total automation takes over by means of smart grid.

It has to be mentioned that the design of the future situation modelled here is hypothetical. It is guesswork in what sequence and manner the various smart grid traits will be implemented, but current developments like the EU's smart meter rollout lead to some educated guesses for an intermediate level between now and the fully developed smart grid:

The spot market will still have the same function (compare chapter 4.1), but will handle a lot more traffic, as consumers and prosumers will become stakeholders on the market by means of smart meters (see Figure 8). While consumers can offer DSM-potential, prosumers also provide energy (e.g. in groups as virtual power plant).

The operation of transmission and distribution grids will still be separated. Distribution grid operators will use local weather forecast data and the data made available by smart meters to forecast internal bottlenecks as well as power surplus and deficit that will reach the transmission grid over the course of the next day. To compute the anticipated course of the day, measuring point operators collect all necessary data from grid, energy suppliers, external sources and smart meters of consumers and prosumers. Measuring point operators can be contractors or departments of the distribution grid operator. There is no equivalent role in transmission

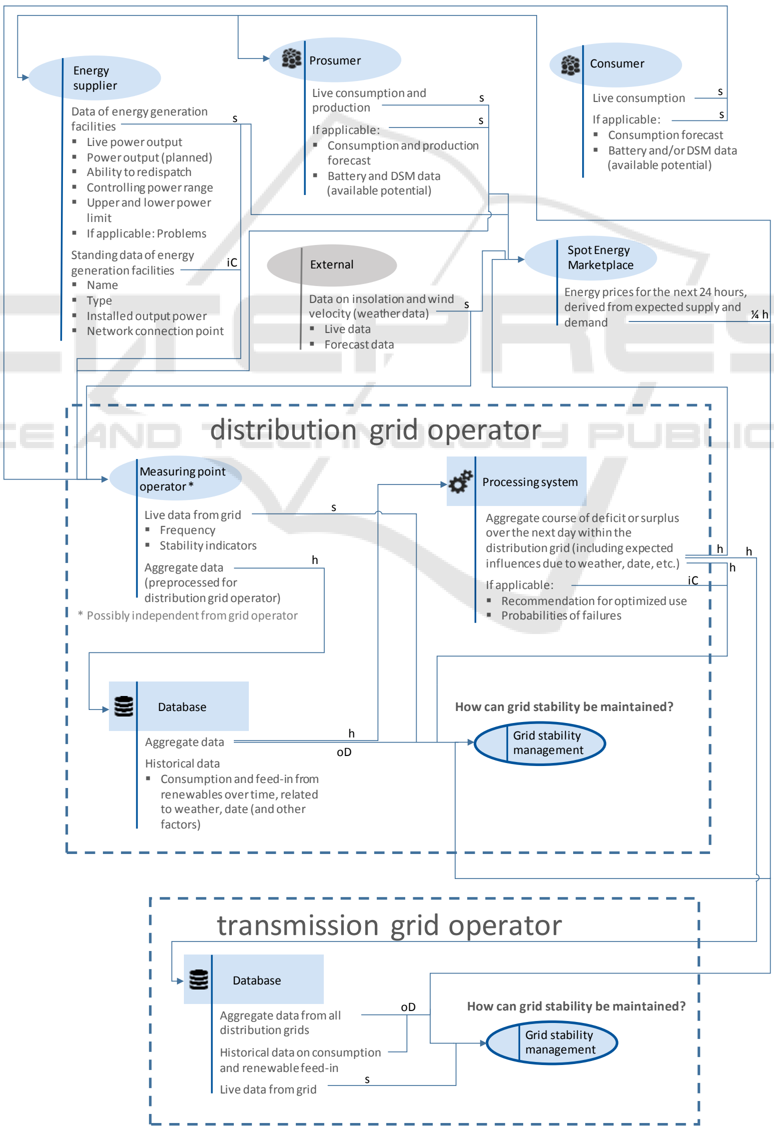

Figure 8: Future logistics of information for grid stability management.

grid operation because the main task of retrieving smart meter data does not apply there. The database automatically collects live data from the grid.

After pre-processing, the data is passed on to the distribution grid operator’s database, which is the basis for the processing system. The database archives all received data, so that the processing system can also rely on historical data when computing the surplus and deficit forecast. The spot market, the distribution grid stability management and the transmission grid operator receive the progression of necessary supply or generated surplus from the processing system. The transmission grid operator’s database saves the accumulated data and passes them on to the associated grid stability management, while the spot market uses the data to set the energy prices accordingly.

5 CONCLUSIONS

The proposed ILN approach helps to structure overwhelming amounts of information, as the given examples show. By means of visualizing the flows of information, one can determine the – for a certain task – actually required information and involved stakeholders. By that, the presented notation supports the implementation of IT systems and therefore reduces the costs of digitalization and automation. This becomes more relevant as future IT systems, like the smart grid, will be significantly more complex and flexible. Especially for the design of independent subsystems like nodes in a smart grid, the ILN can help to predefine open systems interconnections.

The ILN has been developed within the research project eSafeNet. In the context of this project the Notation has been successfully applied to the information logistics of involved project partners. The ILN can generally be applied to enhance complex information logistics, for example internal information exchange in industrial companies. Thus, the next step should be to create a software tool to simplify the application of the ILN in further use cases.

ACKNOWLEDGEMENTS

This article arose during the work of the authors, within the context of the research project eSafeNet (project number: 03ET7549A) funded by the Federal Ministry for Economic Affairs and Energy in Germany.

REFERENCES

Celli, G., Pilo, F. and Pisano, G. (2004), *Meshed vs. Radial MV Distribution Network in Presence of Large Amount of DG: 10 - 13 Oct. 2004, [New York, NY]*, IEEE Operations Center, Piscataway, NJ.

Divan, D. and Kandula, P. (2016), “Distributed Power Electronics. An Enabler for the Future Grid”, *CPSS Transactions on Power Electronics and Applications*, Vol. 1 No. 1, pp. 57–65.

Durugbo, C., Tiwari, A. and Alcock, J.R. (2013), “Modelling information flow for organisations. A review of approaches and future challenges”, *International Journal of Information Management*, Vol. 33 No. 3, pp. 597–610.

Farhangi, H. (2010), “The Path of the Smart Grid”, *IEEE power & energy magazine*, No. january/february 2010, pp. 18–28.

Gungor, V.C., Sahin, D. and Kocak, T. (2013), “A Survey on Smart Grid Potential Applications and Communication Requirements”, *IEEE Transactions on Industrial Informatics*, No. Vo. 9, NO. 1, February 2013, pp. 28–40.

Hirth, L. (2013), “The market value of variable renewables”, *Energy Economics*, Vol. 38, pp. 218–236.

Immoor, K.H. (1998), “Informationslogistik ais Dienstleistung fur vernetzte Unternehmen”, *Logistik im Unternehmen*, Vol. 12 No. 3, pp. 48–50.

Koch, U. (1996), *Bewertung und Wirtschaftlichkeitsermittlung logistischer Systeme: Zur Bedeutung von Informationen in der Logistik, Gabler Edition Wissenschaft*, Dt. Univ.-Verl; Gabler Verlag, Wiesbaden, Wiesbaden.

Krämer, K. (2002), *Automatisierung in Materialfluss und Logistik: Ebenen, Informationslogistik, Identifikationssysteme, intelligente Geräte, Informatik*, 1. Aufl, Dt. Univ.-Verl., Wiesbaden.

Krcmar, H. (2015), *Informationsmanagement*, 6., überarb. Aufl., Springer, Berlin, Heidelberg.

Pachauri, R.K. and Mayer, L. (Eds.) (2015), *Climate change 2014: Synthesis report*, Intergovernmental Panel on Climate Change, Geneva, Switzerland.

pwc (2016), “PwC's Global Data and Analytics Survey 2016. Big Decisions” (accessed 13 October 2017).

Saaty, T.L. (2008), “Decision making with the analytic hierarchy process”, *International journal of services sciences*, Vol. 1 No. 1, pp. 83–98.

Schneiders, C. (2014), *Visualisierung des Systemzustandes und Situationserfassung in großräumigen elektrischen Übertragungsnetzen*, 1. Aufl., Mainz, G, Aachen.

Su, W., Wang, J. and Roh, J. (2014), “Stochastic Energy Scheduling in Microgrids With Intermittent Renewable Energy Resources”, *IEEE Transactions on Smart Grid*, Vol. 5 No. 4, pp. 1876–1883.

Voß, S. and Gutenschwager, K. (2001), *Informationsmanagement: Mit 25 Tabellen*, Springer, Berlin [u.a.].