Design Science Report

Course „IT Management berufsintegrierend M.Sc.“

Module „IT Management & Research“

Summer Term 2019

WIRTSCHAFT
HOCHSCHULE MAINZ
UNIVERSITY OF
APPLIED SCIENCES

Analysis of a design science project based on the guidelines by Hevner et al.

Specifying autonomy in the Internet of Things: the autonomy model and notation

Writer

Pierre Bachor | Matriculation number 911816

David Eller | Matriculation number 911979

Adviser

Prof. Dr. Gunther Piller

Table of Contents

List of Figures

1 Summary of given task

The university of applied science „Hochschule Mainz“ offers a master degree course called „IT Management“. This course includes the module „IT Management & Research“, led by Prof. Dr. Gunther Piller. In Summer Term 2019 the IT Management students get a complex task within this module: Analyse a design science project based on the guidelines by Hevner et al. (Hevner, Salvatore, Park, & Ram, 2004)

First, the students have to read the article „Design Science in Information System research by Hevner et al.“ to build knowledge of principles of design science research in information management and IT. The article describes various procedures for identifying, analyzing, and solving a problem, based on a framework and seven guidelines. The core aspect to reach this goal is the development of an artifact. The theoretical knowledge gained by reading the article will then be applied on the basis of a practical use case. Tasked with analyzing an appropriate case study, the students searched online on various platforms. The specified requirements of the research: Finding a paper with a Ranking of A-D, according to sources listed by „Verband der Hochschullehrer für Betriebswirtschaft“ (Website: https://vhbonline.org/vhb4you/jourqual/vhb-jourqual-3/teilrating-wi/). After finding a suitable source, the students searched for a paper that meets the requirements to begin their analysis. The aim of this task is to get a better understanding of the use and value of design science research methods for current corporate questions and projects in IT management.

The following analysis refers to a paper titled „**Specifying autonomy in the Internet of Things: the autonomy model and notation”** (Janiesch, Fischer, Winkelmann, & Nentwich, 2019)**.** The next chapter describes the content of their paper and gives a short summary of the research project.

2 Summary of the research project

The Internet of Things (IoT) offers new possibilities due to the networking of different components. Automating behavior and autonomous machines are key factors in industrial value chains in smart services. With the possibility of interconnected sensor and actuators, enterprises can improve the performance and quality of their operations, using cyber-physical systems (CPS). Currently, not any machine needs full autonomy when networking with other machines or people. But it is necessary to specify rules for machine behavior and equip the machines with a reasonable amount of autonomy to benefit from the potentials of IoT. How to develop and implement such machines in an adequate way?

To answer this question, the authors performed a comprehensive literature review to extract 12 requirements for the design of autonomous agents in IoT. Further, they introduce a set of characteristics for agents and a classification framework for interactions in multi-agent systems. The paper also describes the development of a conceptual modeling language consisting of a meta model and a notation to define the specification and design of autonomous agents used within IoT and CPS. This “autonomy model and notation”, as mentioned in the title, is the basis for a concept for the future development of autonomous machines. The author's findings additionally have been applied to a smart factory scenario to illustrate the suitability of the meta model and prove the ability to support the construction of information models of autonomous agents. According to this practical use case, the authors explain and discuss their findings, the future benefits, and opportunities for further development but also limitations in current scenarios.

In the research project described, did the authors adhere to the seven guidelines of Hevner et al.? This question will be answered in the following chapter after a short explanation of the framework and the guidelines mentioned before.

3 Guidelines of Hevner et al.

Hevner et al. have a great influence on future research methodology with their results at that time. They developed a framework and seven guidelines.

The framework is based on three sections: The section “**Environment**” represents the problem to be solved, from the point of view of the researcher. The "**Knowledge Base**" is a pool of resources that the researcher can use to accomplish his task. Previous methods and foundations designed in research are available too. The last section is called “**IS Research**”: It represents the actual development of an artifact. This artifact is formed from a cycle of development and evaluation. The researcher uses the existing "knowledge base" and expands it by creating a new artifact, thus expanding the existing knowledge.

Furthermore, Hevner et al. describe seven guidelines to perform adequate design research. The guidelines are shown in Figure 1, followed by the analysis of the paper in relation to each of these guidelines in the upcoming subchapters.

Table 1. Design-Science Research Guidelines

Guideline	Description
Guideline 1: Design as an Artifact	Design-science research must produce a viable artifact in the form of a construct, a model, a method, or an instantiation.
Guideline 2: Problem Relevance	The objective of design-science research is to develop technology-based solutions to important and relevant business problems.
Guideline 3: Design Evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research Rigor	Design-science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact requires utilizing available means to reach desired ends while satisfying laws in the problem environment.
Guideline 7: Communication of Research	Design-science research must be presented effectively both to technology-oriented as well as management-oriented audiences.

Figure 1 – Design-Science Research Guidelines by Hevner et al.

3.1 Design as an Artifact

The result of their research is a new artifact: **the autonomy model and notation**. It consists of a general data model and a specific graphical notation. The intention is to provide a master blueprint to model autonomy and specify autonomy for smart objects in IoT or CPS in general. The meta model incorporates three categories:

- **Interfaces**: Comprises an agent´s sensors and actuators, which provide the technical foundation for event object recognition
- **Nature**: The social and ethical self-concept describes the agents conduct within a group and give an indication of how conflicts will be resolved within a network
- **Behavior**: Specification of agents goals, utility functions, rules, and states. Their interplay describes the autonomous behavior of an agent.

This metamodel has been transformed into a graphical notation that is capable of capturing actions and behaviors of autonomous agents.

3.2 Problem Relevance

Industry 4.0 transforms processes that replace established organization principles and leads to new usecases, made possible by networking between interconnected machines and people. Industrial value chains substantially change with the usage of smart services. Artifical intelligence and big data analytics, two technologys in the context of Industry 4.0, also have greatly improved the usage of collected data. The analysis of this data helps to extract meaningful information. At the current state, humans are greatly involved in this process. The ability for problem solving is limited by human boundaries, they cannot make all necessary decisions in time to use the maximum potential. Machines can help to exceed these boundaries and optimize processes if they are equipped with autonoumous behaviour.

It is not feasible to equip any machine with full autonomy while networking with other machines or people. But rules for machine behavior with an adequate degree of autonomy is needed to realize the benefits of IoT. Machines have to act as autonomous agents in an industrial value chain and become self-determined and self-contained to situationally control their actions by thereselves. Currently, there is a lack of methodologies and guidelines to support the design and implementation of these machines. Research and practice have not yet defined a generally accepted methodology to address this problem. Previous guides only consider the autonomy of smart objects in IoT implicitly and do not address the practical and explicit design of autonomous agents. The authors try to fill that gap with their developed artifcact: the autonomy model and notation.

3.3 Design Evaluation

The utility, quality, and efficacy of the developed design artifact must be demonstrated via a well-executed evaluation method. In this paper, a **Scenario-based illustration** has been used to offer an overview of the possibilities of the artifact. The situation is an excerpt from a scenario for CPS in smart factories provided by the German National Academy of Science and Engineering. In the scenario, a customer has ordered furniture from producer A for his new kitchen. The smart factory from producer A can use multiple raw materials to produce the desired furniture for the customer. Certain raw materials become unavailable and the smart factory must use alternative materials. There are only two options to deal with that issue during this scenario:

1. As the result is equal in quality, the artificial production agent decides autonomously that a different material can be selected and gives the go ahead.
2. The artificial production agent does not have full autonomy and has to give the customer a two-week window in which they can veto his decision to select a new material.

The autonomous artificial agent is a composition of a raw data analyzer agent, which is capable of determining raw material alternatives, and a decision maker agent, which has plan-discretion competence to issue a new work order. Based on the autonomy level (different interaction levels between human and artificial agents -> level 1 is fully machine autonomy, level 20 is full human autonomy) scenario 1 has reached level 1, and scenario 2 has reached level 6. For verification of the results, all other levels of autonomy are modeled exemplarily. No case was found which was not supported via the artifact. The authors evaluate the resulting models comply with the guidelines of modeling if the notation supports the developer during the design of good conceptual models. Therefore, they use common principles for verification. It is possible to transform all constructs from the meta model (based on the scenario) into notational elements. These notation elements can be used to specify their real-world relationships and do not violate the guidelines of modeling. It is also possible to integrate the notation with other notations to model the autonomy of business processes in BPMN or components in a UML diagram. During the transformation from the meta model to the notation it was checked whether there were no constructs that are not relevant or eliminable without a considerable loss of meaning. In order to ensure that, they continuously attempted to substitute or eliminate constructs during the modeling process in order to measure the importance and explanatory power of each notational element. No constructs that were substituted of eliminated could be identified.

3.4 Research Contribution

The developed artifact will help to close the gap of the conceptual design of agents, which should act autonomously, due to a lack of support in different design languages (like for e.g.: UML or BPMN). The authors described in detail the result of their literature review and the current challenge for the IoT and CPS developers. The transformation from the 12 design requirements to a meta model and into the graphical notation is described in detail and transparent.

3.5 Research Rigor

IoT generates large amounts of data today. All these data have to be analyzed and aggregated to meaningful decision-relevant information. Decisions need to be taken, approved or executed by humans. The limitation of the cognitive capabilities of the decision-makers to solve problems is one significant challenge today. It is impossible to address all the necessary decisions in a timely manner. One option to address that challenge is the increase of the autonomy of machines by equipping them with the capabilities for independent decision making. But there is no generally accepted methodology for the design and implementation of artificial agents in IoT. After a systematic literature review, 12 design requirements (DR) for explicit specifications of autonomous agents in the IoT and CPS were defined. This DR are the basis for developing a meta model. The development of the graphical notation that is augmented with syntactical and semantical guidelines is the next step. Both form the artifact. During the entire development, the focus was on generic design requirements independent of specific use cases. Therefore, the definition of the 12 DR are generalized and thus also the meta model and the graphical notation, because they based on the design requirements.

3.6 Design as a Search Process

This design guideline is not covered within the article. Therefore, it cannot be evaluated.

3.7 Communication of Research

The targets audience of this paper are the developers of machines in an IoT environment, which may benefit from the results of the study. The result can be used for further research and development in this sector. The authors even nominate possible future potentials like a graphical modeling tool or the extension of the model and notation to aspects of privacy, safety, and trustworthiness. Management-oriented communication is not part of this paper.

4 Overall evaluation of the research approach

Finally, were the seven guidelines by Hevner et al. used by the authors to incorporate them into research? In general, they managed to conduct their research in compliance with these guidelines. They described their developed artifact in detail, gave a description of their addressed problem and how they plan to solve it. The aim of the authors has been defined clearly at the beginning. The used methods have been declared and they described step-by-step the development of the autonomy model and notation and the way they tested it in practical usecases, including the documentation of the test results.

In chapter 3.6 and 3.7, the guidelines were neglected and not separately taken into account. They lacked at the description of the search process and also did not define explicitly, who could use the benefits of their developed autonomy model and notation in business. Management issues were not highlighted in the paper, they clearly focussed on technical aspects. The authors also gave no explanation, why they didn´t address these mentioned subjects either.

Even if there is room for improvement, the authors understood and used the guidelines of Hevner et al. in order to optimize their paper appropriately.

References

Hevner, A. R., Salvatore, M. T., Park, J., & Ram, S. (2004, March). Design Science in Information Systems Research. *MIS Quarterly*. Retrieved 07 10, 2019

Janiesch, C., Fischer, M., Winkelmann, A., & Nentwich, V. (2019). Specifying autonomy in the Internet of Things: the autonomy model and notation. (S. B. Heidelberg, Ed.) *Information Systems and e-Business Management* (Volume 17), 159-194. doi:https://doi.org/10.1007/s10257-018-0379-x