A Field Study: The Perception of Edge Computing for Production Industry

Volkan Gezer[1], Jakob Zietsch[2], Nils Weinert[2], and Martin Ruskowski[1]

[1]Innovative Factory Systems (IFS), German Research Center for Artificial Intelligence (DFKI), Kaiserslautern, Germany
Email: {volkan.gezer, martin.ruskowski}@dfki.de

[2]Siemens AG, Corporate Technology, Munich, Germany
Email: {jakob.zietsch, nils.weinert}@siemens.com

***Abstract*—The progressing digitalization of factories coincides with a growing amount of raw data being available in order to create valuable, data driven application. The Edge Computing paradigm is one of the key enablers to realize beneficial solutions, since it helps overcome obstacles such as capacity and latency restrictions or data privacy and protection requirements. However, realized industrial applications of Edge Computing Applications are rather limited as of today. Therefore, as part of the Factory Automation Edge Computing Operating System Reference Implementation (FAR-EDGE) project, a series of expert interviews covering viewpoints from both industry and academia was conducted in order to gain deeper insight on limiting factors and development challenges and expectations. The results are presented in this paper forming a brief snapshot of the current perception of Edge Computing contributing to the creation of an overall understanding of the needs of the manufacturing industry.**

***Keywords*–Edge Computing; Fog Computing; Survey.**

I. INTRODUCTION

With the increase of raw data streams within factories, the need arises to provide processing capabilities to transform them into valuable information and act on that information in a timely matter [1]. The rising Edge Computing (EC) paradigm fulfills this need by providing both hardware and software capabilities [2]. There are currently three major reference architectures with unique features in development that focus on the challenges arising from Industry 4.0 [3]. One of them is the FAR-EDGE reference architecture, currently applied in 13 active use cases, each focusing on one or more topics in the field of automation, analytics, and simulation [4]. Common goals within the use cases are a reduction of latency, an increase of data security and privacy protection, increasing processing performance while maintaining a high level of autonomy. An ideal solution would meet or even exceed these goals while providing all services required by any production environment. The development of such an all-in-one solution, if even possible, requires a significant amount of resources and development time. For most industrial use cases, this might be an overkill contradicting with the desire of industry to solve their current challenges as soon as possible and start migrating towards architectures supporting their continues growth [5]. Therefore, focusing on fulfilling the requirements of industry stakeholders is crucial for an efficient adoption and integration of the EC paradigm. While ”the research on the emerging domain is still in its infancy” [6], and only a few solutions being already deployed in industry, the question which factors are most relevant and should be prioritized in the development of reference architectures and software solutions is left unanswered. The increasing amount of surveys on EC, as well as similar paradigms [6]–[8], explicitly and implicitly cover are a large variety of essential factors and benefits for edge. However, in most cases it is neglected to present the current perception regarding the level of relevance and focus within industry and academia. In this paper, the results of a series of expert interviews conducted with both representatives of industry and academia are presented. The aim is to determine how EC is currently perceived within both domains. First, ten relevant factors for EC are rated according to their importance. Second, the necessary development distribution over the software development process is estimated. Last, the cost distribution throughout the life cycle is analyzed.

II. METHODOLOGY

This section will explain the interview questions in detail, and define how these questions contribute to the survey.

A. Overview

As described in Section I, the project builds and realizes its reference architecture in use cases defined by two industrial partners and a research partner within the consortium of the FAR-EDGE project. The project consortium also consists of several technology providers who provide software for the use cases. To interpret how these use cases and the solutions provided by technology providers match, nine expert interviews were conducted covering all aspects differentiating Edge Computing from Cloud Computing. The interviews are organized for each partner individually. The interview questions were provided beforehand. However, none of the answers of other partners were shared with anyone, whether they are involved in the particular use case or not. The interviews were recorded and the results transcribed accordingly accordingly summarizing. The following sections explain the methodology and specifically the interview questions in detail.

B. Definitions

This section will explain the questions that were asked to both kinds of partners. The interview questions are separated into five distinct sections. Although the questions were slightly different for technology providers and the use case owners, they targeted the same aspect from a different perspective. The use case owners are namely Volvo Trucks Company (VTC), Whirlpool (WHR), and SmartFactoryKL (SFK). Technology provider names are obscured for reasons of confidentiality. It is important to note that the prepared factors fostering Edge Computing applications and additional benefits aim for

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completeness. Even with a thorough investigation such a target is challenging to achieve. Therefore, the interviewees were encouraged to extend the list at any given moment if they see the need for it.

1) Evaluation of Relevant Factors for Edge Computing: The first part of the interview was on the evaluation of relevant factors for Edge Computing, that are preselected based on prior experience, as well as literature [2], [9], [10], to measure the use case requirements against the five imperatives of Edge Computing, namely: latency, data ownership, autonomy, quantity, and connectivity.

One of the key advantages of Edge Computing is to overcome latency constraints which are one of the reasons to prefer edge solutions over for a Cloud solution [11]. For the use case owners, the question was the measurement of the importance of the latency, whereas, for the technology providers, it was whether the solution satisfies the latency requirements of the use cases and if it helps improve the latency.

Similar to latency, data ownership, or privacy and security reasons are another cause for choosing an edge solution. Use case owners were whether they have a security issue at the moment and if the use case contains sensitive data. For the technology providers, the question was whether the data they work with is confidential, and if it leaves on-premise servers, which may cause an security issue.

Autonomy is the degree of being autonomous. In this question, it was targeted to learn if the system can govern itself without an operator, in case of a failure, etc. The use case owners were asked how autonomous they desire the solution to be. The technology providers had to answer this question by evaluating whether their solution is autonomous or not, and up to which degree.

Another benefit of Edge Computing is being able to pre-process the data at the field tier, helping reduce the network traffic and reducing the raw data that is transmitted to the Cloud. The use case owners had to answer how much data is being generated at the field tier, and whether this is a limit to increase the Quality of Service (QoS). For the technology providers, they were asked if the data being used needs to leave the Edge for decisions, and the size of the data.

The last question in relevant factors was on interactivity and connectivity. The use case owners were asked whether the actual setup needs multiple machinery to be communicated with each other for a successful production. The technology providers needed to answer if their solution always relies on the connection outside Edge, and if the solution allows even sub-components of the machinery interact with each other.

2) Importance of Additional Edge Computing Benefits: The second part of the interview was to decide on the importance of requirements of Edge Computing. These requirements were reliability, scalability, extensibility, abstraction, and interoperability, and partly taken from literature [10], [12].

An edge solution is intended to keep servicing without an internet connection. Use case owners were asked how important it is that the system works reliably, meaning how the production would be affected if a failure occurs. For the Individual Software Vendors (ISVs), it was asked whether their software can recover itself in case of a failure, and how the software affects the production in case if stops responding.

Scalability describes the capacity of the solution to adapt to its increasing users and products, whereas extensibility is more focused on the functionality. In scalability context, for the use case owners, it is asked whether they foresee an increase in the product and user base count. In the same context, the ISVs answered whether their solution supports a big number of users and products. Similarly, for extensibility, use case partners were asked whether they plan to deploy new services, devices, or functionality to their production plants. For the technology providers, we asked whether their software is extensible with minimum (re-)configuration if such deployments were made.

Modifications in the production systems may require low-level tweaks or configurations. These changes may break existing solutions. Application Programming Interfaces (APIs) introduced by abstraction can enable more straightforward configuration and better backward compatibility. Use case owners were asked if the plant structure is likely to change. Furthermore, the intention was to learn if they develop internal software which interacts with the edge solution. The technology partners answered whether their software could be used in legacy machines and if their solution introduces APIs to abstract the complexity.

Interoperability is an essential factor for complex systems since relying on a single proprietary solution may cause vendor lock-in problems in case the solution is no more updated or non-available. Working with too many solutions can also cause compatibility problems, which may require additional adapters and wrappers. The use case partners answered the degree of interaction between existing components from different providers.

3) Development Time Distribution for an Application: This part of the interview targeted the estimated time distribution (in percentage) of development for an application. Similar to Section II-B1 and Section II-B2, the definition of an application for both type of partners differ. For the use case partners, this section focused on the AS-IS and TO-BE values during the planning phase of the use case and the implementation of the solution without an edge solution. For the ISVs, this section took values for the designed or implemented TO-BE Edge application.

Time distribution values were collected in seven categories: (1) analysis, (2) design, (3) implementation and build (4) deployment, (5) testing, (6) revision, and (7) training. In the analysis, the use case partners report the time needed to analyze their non-edge solution and the current production line to create the ideas for their use cases. For the ISVs, this time includes the period for analyzing the use case to look for the solutions. Design for the use case partners includes the time to design the use case, including its requirements. For technology partners, the design time is the duration to plan the solution considering the requirements of the use cases. Training for use case owners represents the time required to train the workers or operators before introducing the edge solution. For the technology partners, it exemplifies the training time spent on instructing the edge solution.

4) Development Cost Distribution for an Application: Similar to Section II-B3, this part collected estimated cost distribution (in percentage) of development for an application. Costs are typically split among one-time costs (also called upfront costs) and recurring costs. If the solutions require no additional hardware apart from server hardware, usually, the distribution of the cost is expected to be similar to the time distribution. Upfront costs are analysis, design, implementation and build, deployment, testing, and training. Maintaining or revision costs are considered as recurring costs. As the Figure 2b shows, in this part, analysis and design costs are estimated higher than other costs.

Since determining the cost for the development the edge applications directly is challenging to upright impossible, the interview questions are designed so that the only the distribution of costs can be estimate based on the current progress of the development. At the end of the project, the estimated values will be compared with the actual numbers. If a technology provider is involved in more than one use case, the respective questions were repeated for each use case they are participating in. Additionally, contingency costs, which are unexpected costs, are going to be added after the project completion, if any exist.

5) Hardware and Software Distribution: The last part of the interview collected the distribution of the hardware and software for the TO-BE solution, to decide the tendency of the solution concerning hardware and software, in percentage. If a use case is only software-based, then the hardware questions such as reliability in Section II-B2, were unrelated.

The following section will summarize the results of the interviews explained in previous sections.

III. Results

Figure 1 summarizes the answers given to the first two parts of the interviews. The scenario column contains the use case owners, followed by the use case ID and the interviewee (actual names are obscured for reasons of confidentiality). The next two columns contain the evaluation results for the first and second part of the interview, respectively. The range from one to seven defines the importance of the attributes: one meaning not applicable, and seven being crucial. The presented attributes can be considered complete, as throughout all interviews no interview partner saw the need to adapt those in any way.

Third part of the interview is summarized in Figure 2a. The figure shows the development time distribution of six providers and three use case owners. Figure 2b depicts the development cost distribution of the edge solution. Similar to the development time distribution, the figure summarizes the answers of six technology providers and three use case owners.

IV. Discussion

Interview results showed that the technology providers and use case owners are well aligned concerning the chosen factors for Edge Computing and solutions covering additional edge criteria. The proposed list of relevant factors for Edge Computing did not have to be extended based on the interviews. Thus, the five chosen attributes - *Latency*, *Data Ownership*, *Autonomy*, *Data Quantity* and *Connectivity* - can be considered as sufficient when assessing Edge Computing implementations. As it may be noticed, one solution partner may rate the importance differently for different use cases. This is the case when the solution partner provided a different solution for that use case.

Focusing on Figure 1, the results can be interpreted in the following ways.

Unexpectedly, latency and data quantity factors were not critical due to reported low data transfer rates outside the factories. Only WHR use case requires that it has a very high importance, since the whole factory generates high traffic for actions to be taken.

For data ownership, the industrial use case owners see this criteria rather low, which might surprise at first - In the project, however, the agreement was made to not share any data meaning that even very low would already mean that their

Scenario	Use Case ID	Interviewee	Factors for EC: Latency	Data Ownership	Autonomy	Data Quantity	Connectivity	Additional benefits: Reliability	Scalability	Extensibility	Abstraction	Interoperability
VTC	1,2,3	Owner	4	3	7	2	6	6	7	7	6	6
		Provider #4	4	6	6	3	6	6	7	7	6	6
	4	Owner	2	3	3	2	2	6	5	5	4	6
		Provider #5	1	5	1	1	1	5	5	5	3	6
	5	Owner	3	3	7	2	6	4	6	5	6	1
		Provider #3	2	7	5	6	5	5	6	6	7	7
		Provider #2	4	7	6	7	6	5	7	7	6	7
WHR	1	Owner	6	1	7	1	5	7	1	1	5	5
		Provider #6	6	1	7	1	5	7	2	2	5	5
SFK	1	Owner	2	7	4	5	6	2	2	6	7	7
		Provider #3	2	7	5	6	5	5	6	6	7	7
	2,3,4	Owner	2	7	4	2	6	2	2	6	6	7
		Provider #6	2	7	4	2	6	2	2	6	6	7
	5	Owner	2	7	4	2	6	2	2	6	6	7
		Provider #6	6	1	7	1	5	7	1	1	5	5
		Provider #3	2	7	5	6	5	5	6	6	7	7
	6,7	Owner	2	7	4	2	6	2	2	3	6	7
		Provider #6	4	5	7	1	5	2	2	6	6	7

Legend	
1	Not applicable
2	Very Low
3	Low
4	Medium
5	High
6	Very high
7	Crucial

Figure 1. Results of the edge factors and the perceived importance of attributes

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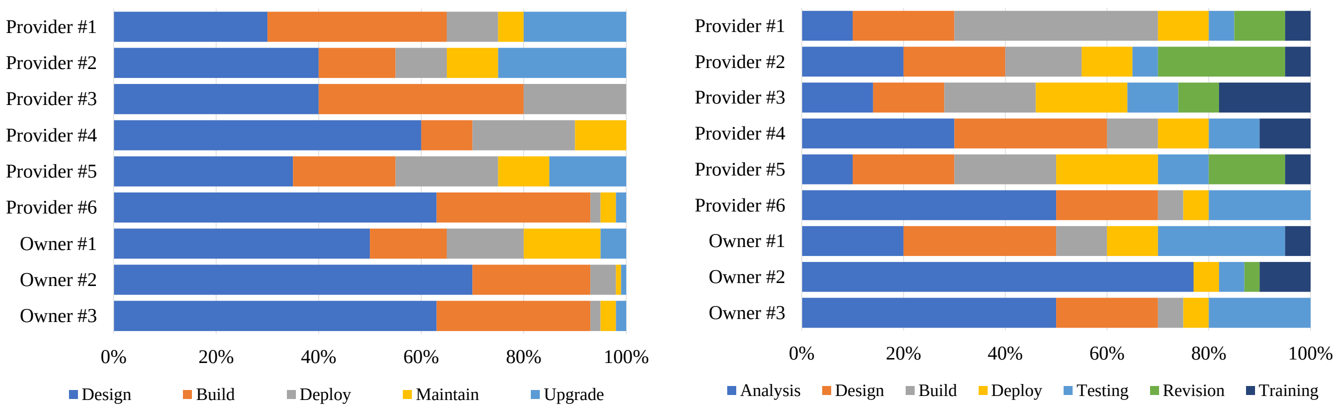

(a) Development time

(b) Development cost

Figure 2. Distribution of development time and cost distribution for Edge Computing implementation

data will not leave the boundaries of their factory. However, the test laboratory SFK contains hardware/software that is not yet robust and is prone to cyberattacks from within the network. This increases the necessity for each device/platform to contain the data accordingly.

In automation use cases (VTC #1-#3, WHR #1, SFK #2-#7), autonomy, and in analytics use cases, scalability and extensibility factors have higher importance than others. Edge solutions are given partial responsibility of the automation tasks. This leads to Autonomy being a crucial feature in the industrial use cases, except VTC use case #4. SFK is not affected from this criteria, as the factory has already been designed to work autonomously. Similarly, importance of reliability is very high in average, for the industrial partners and the solution providers. However, as SFK is a test laboratory, the solutions are developed to test the new technology inside, before applying them in the industrial world. Therefore, reliability is not vital for the prototypical applications. SFK as a test laboratory also requires very high extensibility, since one of its goals is to provide modular factory with minimal (re-)configuration. Provider #6 in fifth SFK use case seems to provide no extensibility for this use case, however, it can be discarded as the extensibility part of the use case is satisfied by the Provider #3 in the same use case.

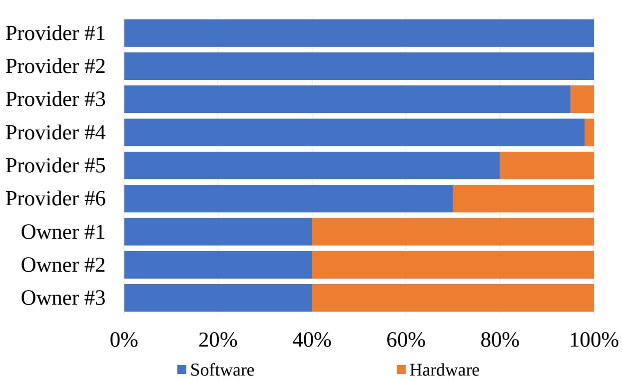

Figure 3. Hardware and Software distribution by all partners, w.r.t. their contributions to the project.

Abstraction importance is above high, as the solutions are asked to reduce the complexity of the existing systems. Vertically, except the fourth use case of VTC, which is a simulation, based on models, for all partners, it is important to increase backward compatibility for future technologies or allow legacy systems to continue functioning properly.

Interoperability is very important or even crucial for some partners. Except the fifth use case from VTC, which is an analytics use case consisting of only event identifiers, all use case owners and use case partners require and give above high attention to this factor. As the factories of the industrial partners are composed of components from different companies, interoperability will improve the efficiency once they scale, and prevent vendor lock-in problems. SFK also aims to continue the highly interoperable approach together with the solutions.

With respect to the development time distribution, the results seen in Figure 2a can be discussed as follows:

The high percentage of time spent on analysis is expected, as it means examination of the production plan for use case owners, and analysis of the given use case for the software providers. Similarly, design means sketching the use case for use case owners and designing the software for the given use case for software providers. The high training amount in analytics use cases are due to user interaction via the dashboard. However, the benefits of using analytics solutions reduce the time spent on evaluation of monitoring values, directly affecting maintenance time in the future, hence the costs. Less time requirement for deployment and testing can be explained as the deployment is mainly the software installation. Similarly, the project executes unit tests in component level during development, therefore, only final testing is conducted after deployment. Likewise, results collected for the development cost distribution shown in Figure 2b, can be interpreted as following:

The high cost requirement on design and build/implementation phase is directly related to the time values. Since most of the solutions are software-based, software development time is aligned with its costs. Use case owners and software providers agree that most resources are

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expected to be spent on designing and build/implementation steps. Furthermore, the costs are desired to be minimized for maintenance and upgrading after going for the edge solution.

Analytics technology provider foresees neither maintenance nor upgrade costs after deployment. This is because once the software is run, it can easily be scaled or extended to service the needs. Moreover, they do not expect to provide an upgrade to the final solution.

As mentioned in Section II-B5, the last part of the interview was to identify the percentage of hardware and software usage by the partners. As it can be seen from Figure 3, the results show that the use case partners, namely Whirlpool (WHR), Volvo Trucks Company (VTC), and SmartFactoryKL (SFKL), are the partners who contribute to the project with more hardware than software.

V. Conclusion and Future Work

Edge Computing is a recent paradigm, which moves computing power, applications and services from centralized units into the logical extremes or at the closest locations to the source and provides data processing power there. Factory Automation Edge Computing Operating System Reference Implementation (FAR-EDGE) is one of the ongoing actions on Edge Computing, which focuses on three functional domains: automation, simulation, and analytics. In this work, interviews were organized with all consortium members; firstly, to get feedback from the partners and to figure out, to which degree Edge Computing is a better alternative to the Cloud for specific use cases. Secondly, comparing the answers from use case owners and Individual Software Vendors (ISVs), to understand, how many of the important factors have been covered by the developed or in progress solutions. Thirdly, to identify the driving factors and benefits as perceived by both, solution providers and use case owners. Finally, to give a breakdown of the estimated development time and development costs to assess which step takes the most resource during development and the degree of decrease in the development time with the edge solution.

The findings in the survey are depicted in the figures in Section II-B3 and Section II-B4. Main findings from these figures can be derived as follows: (1) the industrial partners do not want to distribute their production related data, or they only plan to distribute non-identifying data, which increases the importance of data ownership, (2) except for simulation use cases or the simulation sections of the use cases, importance of abstraction is above very high, to support the legacy systems and to provide increased backward compatibility in the future, (3) automation use cases require that the autonomy is crucial for the factories due to production rates, and to reduce the amount of time for configurations or setup, (4) the solutions provided for the industrial partners need to be reliable as downtimes in factories reduce the efficiency and the productivity, however, for the test laboratory the prototypes can be deployed easier for further testing. Moreover, most of the development time and the costs are expected to be spent during the analysis and design time. Some of the use case owners target reducing the deployment time whereas some of the technology providers foresee that their solution will require neither maintenance nor upgrade.

As mentioned in Section I, this paper described the report of the initial evaluation results, which are going to be compared with the factual numbers after project is completed. This research included nine consortium members which is not yet ideal to get a clear picture. In the future, it is planned to increase the amount of participants to get a clearer view on the criteria.

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