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SOA-Based Platform Use in Development and Operation of Automation Solutions: Challenges, Opportunities, and Supporting Pillars towards Emerging Trends

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Abstract: The paper which is based on a literature review combined with a case study, spanning manufacturing and process industry contexts, set out to determine whether there is an emerging trend to use a service-oriented architecture (SOA)-based platform supporting microservices while developing and operating automation solutions while also considering effects and implications. The results point out that there is a significant potential, during the lifecycle, to save significant engineering time/effort during the development-related and operations phases while integrating systems and adding new types of sensors or other equipment. In addition, the results indicate that there are also business development advantages when promoting an SOA-based architecture supporting microservices towards monolith architectures and that a cybersecurity baseline can be included as part of the platform baseline. However, there is a threshold, before the benefits can be reaped, in terms of the need to build up a competency and skills set concerning the platform, SOA and microservices, as many providers of automation solutions are still doing the development in a traditional old monolithic style with hard-coded integrations between components and systems. Finally, we see an emerging trend to use a competent SOA-based platform in the development and operation of automation solutions.

Keywords: automation solutions; cost savings; integration; lifecycle; manufacturing industry; microservices; operations; process industry; SOA; software development

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1. Introduction

This paper addresses a literature review combined with a case study, comprising five cases, where service-oriented architecture (SOA)-based platforms supporting microservices, i.e., automation software platforms, are used to develop and operate automation solutions in value-chains pertaining to manufacturing and process industry contexts all over the European Union. The underlying reason to conduct the literature review combined with the case study is that today's problems related to development and operation of automation software, using traditional development and 1-to-1 integrations is not a viable option. The current set of problems can be summarized as follows: new functionality with a lot more data available is based on architectures which were not intended for this; high effort/cost is required; solutions are sensitive due to lack of error handling, logging and monitoring; it is hard to make integrations and changes; solutions are hard-coded instead of configurable; there are interoperability and protocol version issues, and it is hard to wrap security around solutions, as most do not have any inherent security level [1–8]. Thus, it seems more and more of a dead-end to pursue the path with traditional development of legacy automation solutions with 1-to-1 integrations [3,4,9,10]. In addition, the aforementioned often also causes hard vendor lock-ins for the whole lifecycle of an automation solution. Thus, what is needed is a way to get away from: hard-coding to configuration; having many potential services to dynamically select among instead of one static function; grow organically instead of having a "big bang"; prototype/test/learn and move quickly instead of long preparations, and only test where there are dependencies instead of testing it all. One potential way out of this, according to the literature review, is to investigate the use of SOA-based platforms supporting microservices for development and operation of automation solutions. Hence, the research question posed in the case study addresses how many improvements have been made using an SOA-based platform, compared to traditional development, and where in the lifecycle are the improvements embodied?

Another enabler and source of requirements for platform thinking is that IT environments at manufacturing and process industry companies and organizations are increasingly becoming connected with the OT (Operational Technology) environments where the production and distribution processes are operated using automation solutions. This IT/OT convergence, in the sense that the environments are connected and integrated with more IT-equipment also used in OT-environments, is led by the Industry 4.0 concept with system-of-systems interoperability and vertical and horizontal integrations in value-chains spurred by an increased wish to use data for decision-making and optimization of processes and businesses. Unfortunately, in the light of recent advanced cyberattacks, this poses higher requirements on cybersecurity for IT/OT-environments as well as the cybersecurity hygiene at the partners in the value-chains and providers of software, cloud services and remote or on-site services. A proficient level of cybersecurity is no longer something merely desirable, but a harsh requirement to stay in business (https://www.nytimes.com/2021/05/08/us/politics/cyberattack-colonial-pipeline.html accessed on 9 December 2021) (https://edition.cnn.com/2021/07/06/tech/kaseya-ransomware-what-we-know/index.html, accessed on 9 December 2021).

The problem addressed by the paper is that the traditional way of doing development and operation of professional automation solutions is not efficient and scalable, due to new requirements for: faster implementations, improved flexibility, improved cybersecurity, the need to use a lot more data and integrate to many surrounding systems. Therefore, we will also look for evidence or indications as to whether there is an emerging trend to use a competent SOA-based platform supporting microservices for development and operation of automation solutions.

2. Related Work—Software Platforms for Use during Development and Operation of Automation Solution and Their Related Cloud Services

Developers of automation solutions are faced with a number of challenges, such as: the need to increase the speed of development and addition of new functionality, the desire to use more data from automation solutions for decision-making, simulation/optimization, fleet management, remote management, etc. In order to facilitate this, Demirkan and Delen [11] introduce a conceptual architecture of service-oriented decision-support, comprising data warehouses, online analytical processing, operational systems and end-user components. The concept has since been used by many others. Concerning cloud services, there are three common cloud service offerings: Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS) and Infrastructure-as-a-Service (IaaS). Further, there are a number of specialized supporting cloud service offerings, such as Monitoring-as-a-Service (with manned security operations centers), Identity-as-a-Service or general Security-as-a-Service providing support to the three most common ones.

Paniagua and Delsing [12] conclude in a survey, where a number of industrial frameworks for IoT (Arrowhead Framework, AUTOSAR, BaSyx, FIWARE, IoTivity, LWM2M, OCF, AWS IoT, Azure IoT suite, Google cloud IoT, ThingWorx, Bosch IoT Suite, IBM Watson IoT, Cisco IoT cloud connect, Oracle IoT, Salesforce IoT, Kura from Eclipse and SmartThings from Samsung) are investigated, that the main reason for the increased interest in such frameworks is the pain during deployment of large-scale industrial applications. They further add that the selected framework should not only support the flexible nature of IoT systems, but also provide adequate functionality in terms of: realtime and runtime features, architectural approaches, hardware constraints, standardization, industrial support, entry barriers, interoperability, and security. Thus, there are a number of platforms to use for software development related to cloud services and IT-systems, but fewer targeting OT-environments and automation solution development. Here, we also exclude platforms mainly used for data collection and analysis, which are also used more and more in OT-environments for data analytics and optimization purposes. Derhamy et al. [13] divide a number of cloud service platforms for IoT/automation into categories: global cloud, peer-to-peer and local cloud. Concerning global cloud platforms, available as part of Amazon's AWS, Microsoft's Azure (IoT HUB), Google's Cloud Platform and IBM's Bluemix and Watson. These are very usable for an automation solution's cloud portal part residing on the Internet but less usable in an OT-environment setting. The cloud portal part can provide data analysis, simulations and optimization of the function of an automation solution as well as predictive/conditional maintenance needs. Regarding peer-to-peer, Derhamy et al. [13] bring up platforms and frameworks from, for instance: IPSO, Thread, ThingSquare, IzoT, SEP 2.0, AllJoyn and IoTivity. All these consider IoT application development from a device level and support a high level of peer-to-peer operation, which is suitable for home automation and device management. The local cloud is now manifested mainly by the Arrowhead Framework [14] targeting challenges related to IoT-based automation in a local cloud context. Currently, the Arrowhead Framework is unique with its concept and tools for integration of applications between secure localized clouds. The Arrowhead Framework abstracts IoT devices as services in order to enable interoperability between a lot of IoT devices and applications. Further, the Arrowhead Framework provides an improved local cloud compared to global clouds, since it "glues" together IoT equipment, realtime data, baseline for data and service security, flexibility to change, and scalability [14]. Using a local cloud, it is easy to decide whether to keep the data originating from the automation solution within the local cloud on the inside of the organization or company or to securely transfer and keep it in another local cloud or global cloud solution. Thus, to sum up the cloud platforms, there are an increasing number of multi-usable cloud service platforms. However, most of these do not have an efficient way, in terms of effort and costs, to integrate and subsequently operate a large number of IoT-devices from various manufacturers for many years.

As service-oriented business processes start to appear, Dyche [15] posits that, for architecture and infrastructure where standardized processes for accessing data are included, the platform on which the data are stored is unimportant. The key is to apply a standard set of transformations to the various sources of data and thereafter facilitate solutions to access the data via open standards service requests, and thus access data regardless of the solution manufacturer. A problem concerning data sources is that many IoT devices, for instance, do not comply with standards and therefore require a means to be securely and efficiently integrated.

Usually, the most significant benefits from using the SOA concept are the reuse of technology and agility to change [16]. Here, the reuse of business processes is more significant than the reuse of technology, as SOA determines the same business activities and puts them in a group as a service. Hence, SOA will decrease the application duplication by reducing process replication. In addition, the use of microservices enables, by using small independent inter-connected services instead of complex monoliths, a number of sustainable benefits which have been found in general IT and cloud contexts: increased reuse of code, lowered complexity; considerably faster agile development and testing cycles due to less dependencies code-wise; continuous automatized and integrated development, testing, deployment, operations and maintenance (i.e., DevOps or DevSecOps), and less support required as a consequence of fewer bugs [17,18].

The use of platforms and cloud computing renders many interesting technological and economic advantages. However, some end users, such as manufacturing and process industries, hesitate to move their IT/OT infrastructures partly or completely to the cloud. Birk and Waegner [19] posit that one of the large concerns is cloud security and the threat of non-transparence and cyberattacks. The non-transparence often originates from the fact that many of the large cloud service providers do not allow their customers to inspect what is in the data centers. Jensen et al. [20] add that it is still not obvious how the technical security issues and the trust issues can be resolved. These issues must be figured out, together with, for instance, the legal requirements imposed by the EU (General Data Protection Regulation, GDPR, and Schrems II), the USA and all countries with non-homogeneous data laws, and by any organization or company that wishes to use cloud services where sensitive information is stored, processed or communicated in between countries.

Pertaining to improvements from using IoT or cloud service platforms, related to automation solution development and operation, Fylaktopoulos et al. [21] present results which indicate that even inexperienced developers are able to craft solutions in the cloud in a significantly shorter time. Further, Delsing et al. [22] indicate time savings of about 70–80% when using the Arrowhead Framework compared to legacy technology-based implementations. In addition, Lindström et al. [23] outline effort reductions from using a multi-usable cloud platform while developing and operating an Industrial IoT solution with 50–75% improvements compared to traditional development. According to MacLennan and Van Belle [24], neither academia nor industry have published much work on estimating efforts/costs for SOA-based software development and also, there is no common method for such estimations. Further, they deem that the top challenge was to establish baseline metrics for successful SOA implementations. The top perceived benefit, however, is an increased composability, which is hard to achieve if using a traditional and monolithic data infrastructure.

3. Research Approach

The research approach was based on a literature review combined with a case study. The findings of both the related work review and the literature review were used to provide guidance in the case study planning.

The literature review, see Section 4, had the aim to reveal: challenges, opportunities, supporting pillars, and emerging trends within development of automation systems based on SOA or not. The review had its focus on recent literature, from 2017 to 2021, but also a limited number of older literature of interest were reviewed. The search of the review had a general start and was then narrowed down to key contributions for professional automation systems. The sequences of key words used in the searches were:

- Automation system development, 3,230,000 hits, 30 reviewed (a lot concerned home automation and not professional automation systems);
- soa automation system development, 52,100 hits, 30 reviewed;
- soa “automation system” development, 2940 hits, 40 reviewed;
- soa “automation solution” development, 262 hits, 40 reviewed.

The aim of the case study was to continue with the findings and look deeper into why organizations and companies consider it is a good idea to develop automation systems using an SOA-based platform. The case-study methodology used was as proposed by Yin [25] with “a linear but iterative process” (p. 1) comprising: planning, design, preparation, data collection, data analysis, and sharing of results. The case study was conducted between 2017–2021 and comprised five cases which are further outlined below. The research question is “How many improvements have been made using an SOA-based platform, compared to traditional development, and where in the lifecycle are the improvements embodied?”. The “how” in the research question indicates that a case-study methodology is appropriate to use. In addition, a case-study methodology was suitable, as the researchers did not directly participate in the work spanning multiple contexts and development cases.

The case-study cases involved both companies and a major EU-funded research project, Arrowhead Tools, as outlined below:

- Arrowhead Tools is a large-scale EU RDI project mainly funded by ECSEL with a total budget of M Euro 91 (Available online: https://arrowhead.eu/arrowheadtools/news/europe-s-largest-project-for-digitization-of-industry/ accessed on 9 December 2021). Arrowhead Tools aims to create engineering tools for the next generation of solutions

in digitalization and automation for the European industry. The data collected targets more than 30 use cases conducted, as part of the project work, in various manufacturing and process industry contexts. Data were collected as part of the project work during 2020–2021. The predecessor projects to Arrowhead Tools, e.g., Arrowhead and Productive 4.0, have resulted in an SOA-based automation platform named Arrowhead Framework [19] and the Arrowhead Tools project adds usable tools to increase the usability of the Arrowhead Framework in industrial settings. Since 2006, a string of RDI projects preceded these 3 projects, where initial concepts and ideas were crafted.
- LKAB is a mining company located in Sweden and is very active in development of the future smart, digitalized, and sustainable mining at great depths. Further, LKAB is very active in developing production processes for fossil-free steel production based on hydrogen and electricity. Data were collected during 2021. LKAB develops its own automation/middleware platform, named LOMI (LKAB Open Mine Integrator).
- Sinetiq AB is a recent spin-off from BnearIT AB and is a high-tech SME located in Sweden and active in the Swedish market. Sinetiq AB provides integrations and advice based on SOA within both IT- and OT-environments. Data were collected during 2021. Sinetiq AB's knowledge-base and ideas are based on their own experience as well as experience from employees' participation in the string of Arrowhead Framework-related RDI projects since 2012.
- Smart Recycling AB is a spin-off from BnearIT AB and Electrotech AB, and is a high-tech SME located in Sweden and very active on the northern European market. Smart Recycling AB provides cloud services and products related to circular economy and participates in small and large research and development projects. Data were collected between 2018–2021. Smart Recycling AB's own SOA-based cloud platform is based on their own experience as well as experience from participation in the string of Arrowhead Framework-related RDI projects since 2013.
- ThingWave AB is a high-tech SME located in Sweden and is active within EU, North and South America as well as Australia. ThingWave AB provides customized development and a number of monitoring cloud solutions for various OT environments (both production and distribution) above and below ground. Data were collected during 2017–2021. ThingWave AB's own SOA-based IoT platform is based on their own experience as well as experience from participation in the string of Arrowhead Framework-related RDI projects since 2006.

The planning of the case study was made to initially cover 3 cases but was expanded to cover 5 cases, whereof one with more than 30 use cases. The intent was to follow the contexts and study if there were any significant improvements/efficiency gains, and where in the lifecycles these occurred. The design of the case study included: formulating the study question, stating study propositions: (1) what do the case companies need to change, as well at their value-chain, in terms of, e.g., interoperability, technology, development processes/practices, competencies/skills, and infrastructure, in order to improve various parts of the lifecycle? Further, the unit of analysis was the organizational level of the 4 companies. In addition, explanation building will be used to link the data to the propositions. Here, the Arrowhead Project is not included, due to its limited duration and that it will not by itself use the automation platform. It was decided that the criteria for interpreting the case study's findings would be established via rival explanations based on Patton's [26] approach, balanced defensively and offensively. The researchers wish to investigate whether using an SOA-based platform supporting microservices is an emerging trend or should be a trend.

In order to prepare for the case study, a number of presentations, architectural/technical specifications, technical plans, and business and marketing documents were analyzed. The data collection was done through semi-structured interviews [27,28] combined with workshops [29] at Smart Recycling AB and ThingWave AB. Semi-structured interviews were used, with open-ended questions [27], allowing the respondents to give detailed answers and the possibility to add extra information where deemed necessary [28]. The duration of the interviews was between one and two hours and the duration of the workshops was approximately two hours. In order to strengthen the validity of the case study, the collected data were displayed using a projector during the interviews and workshops, allowing the respondents/participants to immediately read and accept the collected data. Subsequently, the collected data were displayed and analyzed using matrices and pattern matching (cf. [30]). The analyzed data were finally summarized into a matrix, and the findings categorized according to the areas of concern, i.e., improvements/efficiency gains and where this occurs in the lifecycle. Finally, the results were shared with the case companies and the Arrowhead Tools project (as well as with a broader audience through this paper).

4. Literature Review—Challenges, Opportunities, and Supporting Pillars towards Emerging Trends

A literature review has been conducted and combined with the related work to provide input for the following case study. The literature review's results are summarized in Table 1 and the results are sorted in three categories: challenges, opportunities, and supporting pillars concerning development of professional automation systems. The focus has been on recent literature and most of the selected literature are published during 2019–2021, but also older literature found addressing development of professional automation systems were reviewed in order to capture the most recent progress. Below Table 1, there is an analysis of emerging trends found in the literature reviewed. The emerging trends are then looked further into by the following case studies.

Table 1. Summary of results from the literature review.

Author	Challenge	Opportunity	Supporting Pillars	Comments
Mendes et al., 2009 [1]	Complexity and heterogenous industrial automation systems requires significant development and maintenance efforts	Use of service-oriented software agents in production systems for collaborative industrial automation	Use of multi-agent systems (components/microservices) with SOA	Achieving flexibility and interoperability through moving to an SOA-based design and use of multi-agents. This is intended to decrease the development and maintenance efforts as well
Vyatkin et al., 2009 [9]	Pick-and-place design, simulation, formal verification, and deployment of automation systems	Validation of the design for industrial automation systems	Use of systematic application of formal methods based on intelligent (replaceable) mechatronic components	Closed-loop modeling, holistic design and validation of automated manufacturing systems. The "embedded grand challenge" is not yet solved
Do Orio et al., 2014 [31]	Self-learning production systems	Evolvable production systems with context-awareness and data-mining capabilities	Use of artificial intelligence (AI) and SOA	Enabling production systems to change their behavior according to context in order to become agile
Sanjeewa, 2019 [32]	Self-healing of distributed systems	Use of cloud computing and automated strategies to heal distributed systems (VM cluster)	Use of containers, SOA, and an automation platform	Solution with auto-scaling and healing agent for recovery and self-healing, based on WSO2 cluster, of distributed systems

Table 1. *Cont.*

Author	Challenge	Opportunity	Supporting Pillars	Comments
Marcu et al., 2020 [2]	High initial investment to become smart	IoT/SoS architecture for smart cities and agriculture	Use of SOA	Architecture based on Arrowhead Framework. Improved interoperability (IoT, systems, SoS) and scalability enables smart cities and agriculture with realtime or close to realtime features
Lehtola, 2020 [3]	Migration of automation systems to a microservice architecture	Decrease complexity by decomposition of applications into small independent services and move away from monoliths	Use of microservices and SOA	As the migration process involves a multitude of stakeholders and actors, these do not necessarily have the same interests and viewpoints on critical matters, although the long-term benefits may be very interesting. The key is to get all working in the same direction
Liang et al., 2020 [33]	Which are the key technologies to research and develop for use in development of smart equipment?	Smart substation automation systems for electric grids with plug-in functionality, flexible service description, and remote monitor-ing/management	Separation of system application service platform and SOA-based basic functionality service platform. In addition, agent technologies and visual editing and configuration were used	By using new technologies in substations, combined with improved operations and maintenance, they become more safe, efficient, and the service level is improved, too
Venanzi et al., 2020 [34]	Massive adoption of IoT nodes in supply chains	Improved integrability and interoperability in supply chains saving engineering work (i.e., less time and efforts)	IoT-based automation and integration (by abstracting IoT objects to services). The SOA-based platform enables: IoT interoperability, realtime data handling, cybersecurity baseline, and scalability.	Architecture based on Arrowhead Framework. Improved integrability, interoperability (IoT, systems, SoS) enables smart supply chains
Bian and Liu, 2020 [35]	Smart and integrated substation automation systems for smart grids	Improved independence of devices and entities due to integrability and interoperability	Use of SOA and standardized protocols for information exchange during design, configuration, operation and maintenance enables "smart" substations	Unified SOA-based platform establishes unified standards and protocols etc. for integration and interoperability between different layers of systems

Table 1. *Cont.*

Author	Challenge	Opportunity	Supporting Pillars	Comments
Yi et al., 2020 [36]	Autonomous operation of power distribution automation systems, which use processing intensive protocols	Improve power distribution operations and the necessary information exchange with upheld consistency and improved interoperability Get plug-and-play for devices	Use of cloud-edge-device architecture and move from SOA monolith to SOA with microservices	Managing performance and scalability problems by using a device-edge-cloud architecture based on SOA with microservices and renewing the information model
Haghgoo et al., 2020 [4]	Poor performance and scalability in management and automation systems in power grid	Get on-demand scalability and autonomy using cloud computing and smart automation systems	Use of SOA-based middleware/cloud platform for service restoration	Restoration of unreliable, poor performing, and non-scalable automation systems using the FIWARE framework
Coito et al., 2020 [37]	Realtime data acquisition and management within industrial automation systems, interoperability of data, and complex data transformation steps involving high-volume and high-frequency data in industrial processes	Get intelligent automation combining automation with analytics and decision-making by artificial intelligence in order to achieve smart manufacturing and mass customization while improving resource efficiency	Use of cloud services and data warehousing combined with standardized communications standard	Demonstrating intelligent automation within the pharmaceutical industry using the OPC-UA communications standard and time-sensitive networks where interoperability and near realtime features are necessary
Roldán-Gómez et al., 2021 [5]	Cybersecurity issues in IoT-devices and systems	Use of intelligent IoT architectures in smart industries and cites	Use of complex event processing, machine learning (ML), and SOA	Comparison of Mule and WSO2 IoT architectures to detect cybersecurity attacks (realtime) in cyber-physical systems
Traboulsia and Knautha, 2021 [10]	Inadequate control of thermal heating and cooling in commercial buildings	Improved analysis and management of heating and cooling	Addition and use of sensors and IoT tool, using a number of protocols and APIs to collect the data, based on an open-source IoT platform	Comparison of 9 IoT platforms, and out of these, ThingsBoard was selected for the use case and it was shown that workforce productivity can be affected by an improved in-door climate, in particular during the cold seasons
Dorofeev et al., 2021 [6]	Software complexity in control systems. Need to keep the complexity at an acceptable level	Save engineering time for further development and maintenance by using "skill interfaces" modeled and derived from interface descriptions and production plans	Use of SOA and orchestration module to automate generation of models	Generating fault-tolerant orchestrators embodying complex logic, by automating the "skill" composition, improves flexibility of automation systems and efficiency of the engineering work

Table 1. *Cont.*

Author	Challenge	Opportunity	Supporting Pillars	Comments
Keung et al., 2021 [7]	Improve operational efficiency in automation systems and the related business processes	Improved operational efficiency in business processes through robotic process automation	Use of robotic process automation, classification algorithms, and AI in cloud-based cyber-physical systems within a robotic mobile fulfillment system	Data-driven order correlation and storage allocation assignment problems are solved by improved classification algorithms used for intelligent automation

From Table 1, it is possible to distinguish emerging trends such as the need to implement intelligent automation systems, become further efficient in terms of development/operation/maintenance of automation systems, and enhance the automation of routine engineering tasks. Vyatkin et al. [9] (p. 27) refer to parts of this large challenge as the "embedded grand challenge". One way to do this is to move away from the traditional monolith automation systems and invest in SOA and microservices to transition to a better situation. The use of a competent SOA-based platform and microservices for development of professional automation systems will be further investigated in the five case studies in Section 5.

5. An SOA-Based Platform Example and Case Study Results

This section comprises, firstly, to provide a better understanding, an overview of an example architecture regarding an SOA-based platform supporting microservices and its main components, and the relation in between those. Secondly, the collected data from the five cases have been analyzed and the results are visualized to provide an overview followed by additional in-depth details for each of the five cases.

5.1. A High-Level Architecture Overview of an Example SOA-Based Platform

Below, there is an example of how an SOA-based platform, also based on microservices, can be embodied in terms of overall architecture and its main components, and relations in between these. Figure 1 outlines the overall architecture of the Arrowhead Framework [8]. The overall architecture encompasses a small number of necessary core systems and services, including an authorization system (for users and services), a service registry (where services can be registered and looked up), and an orchestration system (in order to maintain system connections). Further, there is an application systems and services part, which comprises the actual business logic and provisioning, which differ for each context. In addition, the SOA principle is based on the foundation of the three Ls: Lookup (discover/set presence), Loosely coupled (autonomies and distributed components), and Late binding (dynamic system of system compositions) supported by strictly defined service contracts and architectural methods.

A service can be a provider, consumer or both a provider and consumer. The service registry enables selection of the desired service from a range of many similar services. However, firstly, the orchestrator manages the system connection and ensures that there is an authorization to use the service wanted. If wanted, a minimum cybersecurity requirement baseline, such as authentication level and encryption algorithm with key length, can be part of the authorization scheme or else disqualify the service request connection.

5.2. Results from the Five Cases—Visualization with Summary of Improvements

The results from the case study and its five cases, plus a summary of the improvements perceived, are visualized in Table 2 in order to provide a comprehensive overview. Additional details on the results are available in the following subsections. Within Table 2, an "x" means the case finds significant improvements during that phase of the lifecycle. Further, an "o" is the same as an "x" but multiple use cases can be part of this entry.

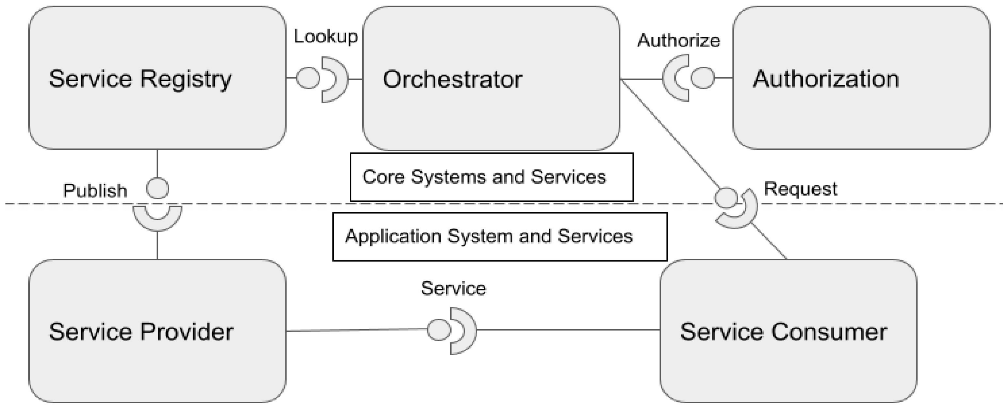

Figure 1. Outline of general architecture—Arrowhead Framework.

Thus, the use of the SOA-based platforms varies somewhat among the cases, depending on the focus and targeted problems. However, using pattern matching [30], it is clear that the companies who develop solutions/products, etc., find that there is a clear and significant benefit during the following phases: business development, design/development/piloting/test, installation/commissioning, and operations. LKAB, a mining company, sees the main benefits at the start and end of the lifecycle, where LKAB also gets the most value due to the fact that the length of the operations phase is commonly the longest phase of the lifecycle. Arrowhead Tools, which is a different being compared to the other case organizations, places more focus on the engineering phases of the lifecycle, as well as on the following operations phase. All cases except LKAB, which has yet not measured any hard data concerning improvements, indicates that there is an overall minimum improvement of approximately 50% and, on the upper side, a change in magnitude. In addition, although without any hard data to support the views, LKAB states that "we do not want to go back again to 1-to-1 integrations!" which supports the contention that there is a clear benefit/improvement from using an SOA-based platform supporting microservices.

5.3. Additional Details on the Results from the Arrowhead Tools Case (Comprising More Than 30 Use Cases)

The Arrowhead Tools project continues to add necessary tools to the Arrowhead Framework to enable more companies and organizations to use the Arrowhead Framework (platform) while building and operating automation solutions of various kinds where security, integrations, and interoperability between systems-of-systems are key for success. During the project, comprising more than 30 relevant use cases, the focus has been to use the Arrowhead Framework to build various tools to increase the usability and enable more organizations and companies to use the platform. The areas of interest have been mainly the 4 development-related phases (i.e., "engineering work") and the operations phase later on. The measurements and estimated improvements have been recorded in two project deliverables and show, overall, very promising results. However, to be able to achieve the results, there is an investment required in skills and competencies to be able to understand the concept, how to further develop it, and how to best use it during the whole lifecycle. Nevertheless, if the investment is made, it seems like the ones who have started do not want to go back to the old traditional way of development of automation solutions or to integrate various types of systems. As the use cases have spanned a number of manufacturing and process industries, e.g., manufacturing and production of vehicles, bearings, semiconductors, and consumer products, the generalizability level of the Arrowhead Framework (platform) with the new tools is deemed as high.

Table 2. Visualization of results and summary of improvements.

Phase of Lifecycle/Case	Arrowhead Tools (Multiple Use Cases)	LKAB	Sinetiq AB	Smart Recycling AB	ThingWave AB
Business development		x	x	x	x
Requirement engineering		x			
Design	o		x	x	x
Development	o		x	x	x
Piloting/early test at customers	o		x	x	x
Test/QA	o		x	x	x
Procurement (with customization)		x			
Installation/ Commissioning	o	x		x	x
Operations (with maintenance and upgrades)		x	x	x	x
De-commissioning, repurposing, down-cycling or re-cycling etc.					
Improvement	The results are from an RDI project, and the minimum requirement was a time improvement of 20–50% concerning the specific part/phase—which was surpassed by most of the use cases. The exceptional use cases had improvements of 83% and 96% for their limited part of the lifecycle. Thus, in general, there were time improvements of at least 50%	Do not have any hard numbers yet, but will get more agile, add more value to processes faster and "we do not want to go back again to 1-to-1 integrations!"	The development time decreases with a magnitude (e.g., what took hours takes minutes, what took weeks takes days, and what took years takes months)	Based on 6 larger development projects—50–75% improvement in effort from using the SOA-based platform approach with changed development processes/practices	General improvement from business development to end of test/QA is 1:4, i.e., about 75% time/effort improvement. Concerning the operations with maintenance and upgrades, the more extensive installation it is, the more improvement there will be. Thus, the time/effort improvement numbers scale beneficially with the number of sensors and actuators, etc.

5.4. Additional Details on the Results from the LKAB Case

LKAB develops its own SOA-based platform, LOMI, with functionalities such as: message bus, container environment, and integration services (with low code integration), more with the intent to get real-time access to (streaming) data from the mining processes for exchange with other processes and for management decision-support purposes. The intent is to follow the main industrial standards and thus increase interoperability to connected mining equipment and software solutions from third parties. The SOA-based LOMI and standards provide loose binding, such as work-order systems that can be independent of the maintenance system used and to ensure that there is the flexibility of having systems on premise, in the cloud or in hybrids of these. One of the main benefits of LOMI is that LKAB can be more agile and can make changes and add additional requirements/functionality "as the show goes on", and add more value to the processes faster. Cloud technology, model-based development, design-by-contract, and increased use of modeling/simulations are supporting improvements from LOMI as well. LKAB considers that the quality of data will be of paramount importance, as more and more is based on data at the same time as software increasingly takes over functionality from hardware. In the future, LKAB wants all hardware and software added to the work processes to be "Internet or IoT-ready" in terms of plug-and-play, security, safety, secure updates of software, self-configuration, fleet management, etc. As LKAB procures a lot of software and hardware, LKAB has started to require, instead of monoliths, that the architecture is future-proofed by using SOA principles and microservices in order to avoid costly and time-consuming changes and integrations. To facilitate all this, LKAB will transform the IT/OT-infrastructure for preparing additions of the Internet/IoT-ready hardware and software to come. LKAB anticipates that most benefits/improvements will be realized in the operations phase where maintenance and upgrades are made continuously, and where improved availability and less testing are efficiency boosters for the mining processes. Here, it is also necessary to keep the hardware/software/service providers data apart and also secure LKAB's own data. All the above, together with an increasing use of digital twins enabled, will make it easier to change and make additions to the mining processes.

5.5. Additional Details on the Results from the Sinteq AB Case

Sinetiq AB has made its own cloud service/IoT platform, based on ideas and concepts from the Arrowhead Framework, but is not limited to using only this. The main problems addressed in customer cases are to help customers to get more SOA-ified, gain control of the present and future needs, and eventually, to meet the future with more flexibility and agility. Examples of applications and integrations built on the platform include: vehicle part manufacturing process, sensor information systems, sensor intelligence systems, integration of monolith systems with other systems, verification, and compliance tool for integrations and products. The main benefits can be seen in the ability to make advanced prototypes for customer integration problems really quickly (i.e., a magnitude faster than with traditional 1-to-1 integrations), and then to smoothly replace the prototypes with the real integrations with desired level of quality. The use of microservices enables de-coupling and thus, faster development and later changes as well as an efficient modeling for calculating the allocation of processing power to meet customer requirements concerning speed and availability. In addition, the increased flexibility enables the mixing of own components/services with off-the-shelf or customized ones from third parties. The possibility for rapid prototyping and agility in development are important factors in early business development, as a few examples can be realized, and then the customers learn the difference compared to the use of monoliths and the problems related to such. Sinetiq AB sees the initial documentation of interfaces and service definitions as the foundation for the subsequent efficient development-related phases, where development and tests get streamlined and only need to focus on what has been changed and the dependencies thereof. This also makes it very efficient to integrate to one or many systems at the same time. Sinetiq AB plans to augment the platform with components to monitor flow through services/nodes to measure if sufficient or when quality is too low, and also develop test tools with digital twins and simulation possibilities for services. Sinetiq AB considers that a system will never get finalized, and trying to make it all perfect from the start is not feasible and thus, it is better to build it piece by piece and continuously improve these pieces.

5.6. Additional Details on the Results from the Smart Recycling AB Case

Smart Recycling AB has made its own cloud service/IoT platform, based on ideas and concepts from the Arrowhead Framework, and uses it, for instance, to build the service of measuring and trending the filling level of recycling containers for glass, metals, plastics, and paper, spanning from the sensors deployed, communications, security, data collection and analysis, and visualization of data and results. The visualization provides decision-making support to operators responsible for emptying the recycling containers before they become overfilled or to not empty them until properly filled up. Data mining employed enables operators to further understand the filling variations/patterns during a year when there is a frequent need or less frequent need to empty the containers. Some lessons learned from the development are that the strict rule to define service contracts/definitions combined with faster development has made the company competitive. In addition, the fleet management functionality, the capacity to manage mass-deployed sensors over vast geographical areas, continuous improvements to remove complexity and build in everything necessary into the sensor package, have streamlined it all further. Some of the issues overcome were related to: efficient infrastructure, getting the mobile communications to work on a long-term basis (low battery consumption at end points), to find new skilled employees, and to develop existing employees to acquire the required skills and competencies. Additional tough challenges to overcome were to redefine the work processes (from traditional development and business development to agile) and to set up service/support for national/international coverage along with finding a sustainable business model.

5.7. Additional Details on the Results from the Thingwave AB Case

ThingWave AB has made its own IoT platform, based on ideas and concepts from the Arrowhead Framework, and uses it to build a number of customer offerings regarding remote monitoring and management of industrial processes and critical infrastructures. Examples of offerings are ground support monitoring (IoT enabled rock bolts and seismic sensing for underground cavities), digital twins, smart ventilation, and condition monitoring for industrial machinery. The investment made in the development of the IoT platform has been significant for an SME, but now it pays off in terms of business development wins where prototypes and integrations between systems can be shown to work with about 25% of the effort expected by customers. The development phases are also considerably faster by using strict service descriptions, microservices, and new own developed communications protocols for fast and efficient sensor communication in order to reduce power consumption and improve data rate. This also enables connection of machines and equipment not yet connected (having communications interfaces) to remote monitoring and management. ThingWave AB uses more and more IT-equipment in OT-environments (production and distribution), which is a benefit due to lower prices, and these are faster/easier to replace than vendor-specific OT-equipment. Thus, ThingWave AB is not interested in going back to traditional hard-coded development and integrations with hard dependencies to vendor-specific OT-equipment or systems. The agile process and microservices are a great benefit, as customers can, after a prototype is working, quickly replace it with a newly tested and verified microservice, which is put into production, due to the isolation and limited dependencies to others. Thus, the test and verification effort (i.e., quality assurance) has also been speeded up, and fewer bugs slip through and are faster to rectify if needed. Regarding the installation/commissioning and operations phases, it is within these areas that ThingWave AB sees the greatest potential to streamline the efforts required in terms of hands-on activities, and to operate and maintain an automation solution and its integrations. Remote monitoring and fleet management functionality, such as: plug-and-play, self-configuration, group configurations, secure upgrading of software, etc., all reduce the need to walk around a mine, mill or factory in order to ensure that all software and configurations are up-to-date and working.

6. Analysis

The summary of the results below Table 2 indicates that, for where data is available on improvements, improvements in time/effort during the phases or parts of the lifecycle where an SOA-based platform supporting microservices has successfully been used, exceed 50%. Further, the literature review, see Table 1, also indicates the same type of improvements and reasons for improvement. If the SOA-based platform is used really well, the upper side results indicate very considerable improvements. Thus, the results give a strong indication that this should be of interest for organizations and companies involved in development of automation solutions, or procure and operate such in their own manufacturing/production or distribution processes. In particular, companies developing more than one professional automation solution or having integrations of many systems to manage should be interested. To actually not investigate the potential and use would be daring, as it will eventually lead to lower competitiveness and profitability for both the provider of the automation solutions as well as the end users. Further, it may also make it hard to recruit younger personnel, with needed skills and competencies, if considered to be an incumbent with old low technology.

Regarding time and effort improvements, in smaller companies, they are often the same, whereas in larger companies or organizations, they may not be, due to the fact that the processes are more complex and involve a lot of other people whose time may not be cut, as the effort or time spent is cut by others. For larger organizations, improved overall cost and total development project time may be better outcomes to measure and use concerning improvements. However, decreasing the time and efforts needed is, in general, a very good thing to achieve and it enables freed-up engineers and experts to do other tasks, to create and craft additional improvements. Thus, this can create a beneficial spiral of improvements and higher overall efficiency, which will likely be appreciated by customers and value-chain partners.

Concerning the generalizability of the case studies' results, these are deemed to be highly generalizable due to the nature of the cases and their contexts spanning manufacturing and process industries. However, as mentioned in the Results section, there is a threshold and investment required before the benefits/improvements can be reaped, in acquisition of needed skills and competencies, and either finding or developing an own SOA-based platform to use.

The research question posed in the paper has been answered (see Table 1), as has been demonstrated by the findings from case studies, supported by the literature review, involving both providers and an end user of automation solutions. To sum up the analysis, the results point to potential benefits/improvements of using an SOA-based platform, supporting microservices that are too significant for all organizations and companies involved in the development or operations of automation solutions, to neglect investigation of such a platform. Which SOA-based platform to use depends on the needs and where in the lifecycle the most benefits/improvements are perceived or expected.

7. Discussion and Conclusions

The paper contributes to literature with a literature review combined with a case study, comprising five cases spanning various manufacturing and process industry contexts as well as a large-scale RDI project's use cases, the results of which point to the fact that there is a potential for improvements exceeding 50% regarding time/efforts during parts of a lifecycle concerning development and operation of automation solutions by using an SOA-based platform supporting microservices. However, there are prerequisites in terms of changes required in work processes and acquisition of competencies and skills to fill before these benefits can be achieved. Further, the paper makes an addition to practice by indicating which needs to change in terms of thinking and architecture that can be used in business development and prototype situations in order to quickly move from idea to test, and then speedily and seamlessly to a real implementation. In addition, the managerial contribution of the paper is an indication that there is a need to change how to work in order to be able to use the potential power of an SOA-based platform, the need to meet a number of pre-conditions, such as skills and competencies required, and get over the threshold to be able to use an SOA-based platform. The threshold applies not only to the own organization or company, but to the value-chain(s) participated in and how interoperable these are. Thus, to be able to reap significant benefits and leverage on the improvements, well-considered managerial work and efforts are required in order to succeed.

The results presented in Table 2 are aligned with the quantified results of previous studies [22,23]. Further, the literature review also provides a strong indication that a lot can be improved in terms of less engineering effort, time and costs for development, operation and maintenance (i.e., the whole lifecycle) of professional automation systems, if moving away from the old way and architectures used when developing such (cf. [1–4,9,34–36]). However, these indications are not quantified. This reinforces the motive for investigating the use of an SOA-based platform supporting microservices (if not already doing so) during development and operation of automation solutions. To provide better transparency on the measurements of improvements regarding effort/time/cost achieved, it would be beneficial to have a common and accepted method allowing cross-comparisons of outcomes (cf., [24]). Thus, it is possible to question the details of the results in this study, but the overall indication clearly points in a positive direction. Further, the results of this study are important, as there are a great many developers and operators of automation solutions, such as software developers, industrial integrators, manufacturing, and process industries along with critical infrastructures. All these actors are together very important for business- and society-related value-chains, and they need to stay competitive and profitable to endure tough times and continue to develop.

The case study's proposition also brings up the need to investigate for change at the case companies and within their value-chains; here, the critical part is to decide to start using an SOA-based platform supporting microservices, change the work processes to agile, define a new architecture based on microservices and SOA principles, and acquire necessary skills and competencies. This also requires partners, providers, and third parties to also future-proof their solutions in order to enable interoperability, security, easy integrations, and efficient operations with high availability.

Concerning the rival explanations, in terms of whether using an SOA-based platform supporting microservices is an emerging trend or should be one, the results indicate that it is indeed an emerging trend, and it is necessary for developers and operators (i.e., end users) of automation solutions to jump onboard or slowly become non-competitive, non-profitable, and unattractive as employers for skilled and competent workers and engineers. The results point to potential benefits/improvements, which can be achieved as preconditions are met, and that are too compelling for all organizations and companies involved in development or operations of automation solutions to ignore investigation of the use of an SOA-based platform supporting microservices.

To conclude, the results point to the fact that use of SOA-based platforms supporting microservices is an emerging trend among organizations and companies involved in development and operation of automation solutions. To continue with traditional development and operation of monolithic legacy automation solutions will eventually become too costly, and will require too much time/effort to be competitive and profitable compared to the surrounding competitors, as well as in light of society's demands for continuous improvements.

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