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A Systematic Literature Review: Key Performance Indicators on Feeding-as-a-Service

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Abstract. In the evolving landscape of modern manufacturing, a novel concept known as Feeding-as-a-Service (FaaS) is emerging, part of the larger Automation-as-a-Service (AaaS) framework. FaaS aims to optimize feeding systems in cloud manufacturing environments to meet the demands of mass customization and allow for quick responses to production changes. Therefore, it fits into the Manufacturing-as-a-Service (MaaS) system as well. As the manufacturing industry undergoes significant transformations through automation and service-oriented models, understanding how FaaS fits into the other frameworks is essential.

This study presents a systematic literature review with two primary objectives: first, to contextualize FaaS within AaaS and MaaS, highlighting similarities, differences, and distinctive characteristics; second, to identify and clarify the essential Key Performance Indicators (KPIs) crucial for its strategic implementation.

KPIs are pivotal metrics guiding organizations toward manufacturing excellence. In this context, common KPIs focus on efficiency and quality, such as resource utilization, and error rates. Other KPIs are also crucial, such as the ones related to cost reduction and customer satisfaction. For FaaS, the most relevant include also data security, data management, and network speed.

This research provides a valuable KPI framework for FaaS developers, aiding in strategic decision-making and deployment in industrial settings. It also contributes to a broader understanding of KPIs in manufacturing, which benefits both researchers and industrial practitioners.

The results of the review, though, fail to address other crucial indicators for 'as-a-Service' business, such as Churn Rate and Total Contract Value. Future research will address these limitations through methods ranging from questionnaires to practitioner interviews, with the aim of gathering the knowledge needed for real-world implementations.

Keywords. Key performance indicators, feeding-as-a-service, automation-as-a-service, manufacturing-as-a-service, cloud manufacturing

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1. Introduction

The traditional mass production models have given way to the concept of mass customization, where a swift response to dynamic market demands is crucial [1]. This shift has outlined the challenge of production bottlenecks, which occur mostly at production switches, required for high variety. This hinders just-in-time deliveries, critical for meeting customer expectations [2]. For SMEs, bottlenecks are primarily associated with the setup of machines and robots required at every production change, due in part to the low degree of automation and low number of collaborative robots employed [1,3,4].

To respond to the challenges, a novel concept called Feeding-as-a-Service (FaaS) has been proposed [5]. FaaS is a module-based application that aims at maximum flexibility, and reduction of down times, and represents a novel example of the broader concept of Automation-as-a-Service (AaaS) for the optimization of feeding systems in cloud manufacturing environments. AaaS propositions within Industry 4.0 typically provide cloud-based software solutions and robotic systems that can be integrated into a company's existing software and processes [6]. FaaS proposes a similar idea for factories operating under mass customization demands, where the ability to seamlessly switch from one product to another makes a difference in meeting just-in-time delivery requirements.

FaaS also falls under the Manufacturing-as-a-Service (MaaS) paradigm [7], which aims to make manufacturing capacities available as a service, allowing for more flexible production. It has evolved to include cloud computing and smart manufacturing, enabling companies to bring their product designs to life quickly, by giving access to production capabilities, through online platforms [8]. Companies can upload their product designs and the MaaS provider produces the physical items as per the requirements [9].

AaaS and MaaS concepts play a key role for the business model where sales converge with ad-hoc service delivery. Their development changed how to conduct business operations and how to design manufacturing processes [10]. FaaS stands in between, addressing one of the critical challenges: efficient feeding and handling of materials and components. It focuses on optimizing feeding systems to enhance the production process, automating the loading and unloading of machinery setups. It also has deep roots within the cloud and IoT realms, offering data-driven, cloud-based services [5]. To visualize FaaS in relation to the mentioned paradigms and their features, Figure 1 shows its sweet-spot in the context of application spectrum, service interpretation, and specific focus.

FaaS is a newly proposed solution that addresses a specific aspect of manufacturing, namely feeding systems, but does not yet have an industrial implementation. To take the first steps toward a real-world application, it is pivotal to formulate a list of Key Performance Indicators (KPIs) that align with the system's objectives and desired behaviors. This step is essential because organizations often face challenges in selecting appropriate performance measures. Common misinterpretations include a lack of clarity regarding the behaviors they want to encourage, a tendency to focus on outputs rather than outcomes, and a failure to consider the long-term impact of the chosen measures [11].

FaaS is inherently connected to other concepts addressing mass customization and servitization, sharing goals such as enhancing efficiency through reconfiguration and rapid production. As FaaS evolves, understanding relevant KPIs is crucial. This paper proposes a systematic literature review of related as-a-Service implementations to extract critical KPIs, answering the research questions and deriving a list applicable to FaaS.

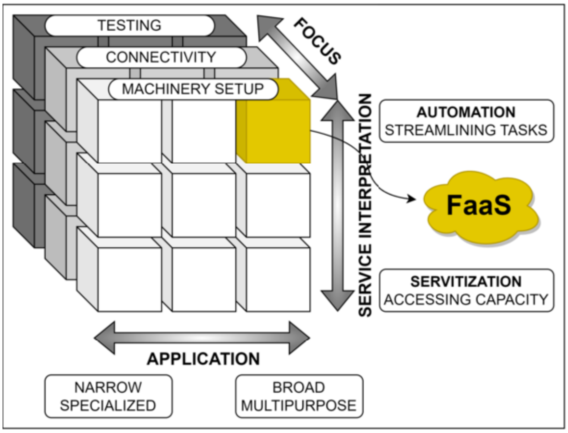

Figure 1. FaaS sweet-spot in relation to the features of the as-a-Service paradigms

This research assists researchers to expand the field, formulate case studies, and aids practitioners to find effective performance indicators for their applications. In light of the presented objectives, this paper aims to answer the following research questions.

1. What are the common KPIs for AaaS and MaaS, and how do they reflect efficiency, quality, responsiveness, and customer satisfaction?
2. How does a FaaS implementation fit into the framework of AaaS and MaaS?
3. What are the essential KPIs that underpin the strategic implementation of FaaS?

2. Background

The modern manufacturing industry is defined by a transformation placing more relevance on automation and service-oriented models. Understanding the relationships of FaaS with the established AaaS, and MaaS concepts is crucial for industrial progress.

AaaS has a broader perspective: it focuses on providing businesses with automation solutions and tools that span a wide spectrum. It is a digital-centric concept that requires the deployment of cloud-based software or robotic systems to automate processes. AaaS aims to streamline digital and administrative tasks, such as data entry, customer service, and supply chain management, ultimately seeking to boost efficiency, reduce reliance on human labor, and enhance overall productivity [1]. One current example is the Robotics and Automation as a Service (RAaaS) framework, whose main goal is to aid the development of complex software, their installation and maintenance, and ease the distribution and sharing of data from machines [12]. Another paper presents Test Automation-as-a-Service (TAaaS) as a cloud-based, automated testing platform for life cycle evaluations, that delivers an easy-to-use web application skipping many steps such as purchasing tools, setting up the environment and dealing with code and software jargon [13].

MaaS focuses on offering physical manufacturing capabilities to businesses, reducing the need to invest in, own, or operate proprietary manufacturing facilities. MaaS providers grant companies access to a variety of production resources, including 3D printers, CNC machines, or injection molding [8]. The primary goal is to help the development of rapid prototyping, and scaling of physical products for SMEs [7]. This has been proposed for additive manufacturing operations, where, in addition to outsourcing knowledge and manufacturing capacity, the need to purchase expensive powdered materials is removed. Given the critical importance of controlling parameters for both material and the manufacturing process, significant cost savings are realized [14,15]. Regardless of the needed technology, a common approach is to deploy a shared digital platform that supports the exploitation of companies' manufacturing potential. This supports enterprises with limited or no manufacturing availability [16], and both parties can also benefit from the collection and sharing of data and information to support online services [17].

Equipment as a Service (EaaS) stands as a notable example of usage-based business model innovation (BMI) within the field of manufacturing. Here, technology and digitalization play a significant role in driving the evolution of business models [18]. The transformation involves established firms, as well as emerging ones, shifting away from product-centric models towards a focus on usage-based business models [19]. The difference with leasing lies in the cost structure. Leasing assumes a fixed cost whatever the equipment usage, whereas EaaS only charges the actual equipment usage [20].

One paper presents Industrial Robots as a Service (IRaaS), which focuses on servitization of software via cloud computing and hardware, to help SMEs overcome large initial investments, uncertainties about return on investment and lack of expertise that stops them from employing robots to a larger extent [21]. The iRaaS idea is composed of four main elements: Flexibility (Plug and Produce, mobility), Usability (Easy Programming, Intuitive Interaction), Safety (Standards, Strategies), and Business Models (Time-based, Usage-based), some of the concepts that also helped in establishing the FaaS idea [5].

FaaS integrates with 'as-a-Service' offerings in smart manufacturing, as it streamlines the handling of materials and components, adding to the digital automation of AaaS. Additionally, it becomes an essential enabler of MaaS, as efficient feeding is critical for smooth production processes. Nevertheless, the financial advantages of servitization may not always be as clear as anticipated, a phenomenon often referred to as the 'service paradox' [22]. This highlights the necessity of providing a better clarification of such models and how they are assessed, using KPIs. The struggle for companies is the creation of proactive measures and selecting the right set of KPIs for long-term analysis [11].

It is necessary to extract a list of KPIs, which are quantifiable measures that evaluate the performance of processes or systems [23]. In manufacturing firms, they are a common language to bridge the gap between strategic planning and operational execution. They play a crucial role in extracting data-driven insights, in facilitating communication between management and the operational side of the firm, in ensuring transparency of results, and in holding everyone in a company accountable for their performance. In the context of modern manufacturing, KPIs provide the necessary benchmark to measure the success of a project [11]. By measuring progress and reasoning over KPIs meaning, it is possible to drive improvements and enhance the quality and timeliness of deliveries [24].

Not all measures are KPIs. There are four types of performance measures, divided in two groups: Result Indicators and Performance Indicators, the former indication of a combined effort to obtain results, the latter focusing on the end result of each part of the system to align it to the overall objective. Each group has Key and Standard indicators, including Key Result Indicators summarizing performance and the well known KPIs. They represent system performance in critical success factors and are essential to have impact on the system's capabilities [11]. When transitioning to 'as-a-Service' business models, selecting the right KPIs becomes essential, as they provide insights into the health and performance of the new scenario. Correctly established KPIs also present other benefits such as the creation of a continuous improvement environment [23].

There are two ways to formulate new KPIs: the direct approach dictates that the objective can be directly associated with a measurable entity, such as the number of finished products (measured directly off the production line). The indirect method requires calculations before meaningful information can be expressed, as for the cycle time (the difference between the start and end times in the production process) [11]. Within the ISO standard that frames the creation of indicators, specific eligibility criteria for the success of manufacturing operations are explicitly outlined. The standard also provides necessary information regarding content and context, essentially identifying quantifiable elements and the list of conditions that must be met. Depending on the intended purpose, KPIs can be categorized into different groups, including cost, time, quality, maintenance, production, and others [23]. The second part of the same ISO standard includes several elements used for describing and formulating KPIs, as well as the formal structure they should adhere to [25]. This standard is extensively utilized in this paper for the characterization, description, formulation, and to establish the structure of the relevant extracted KPIs, which will serve as the basis for future FaaS implementations.

3. Method

A systematic literature review is employed to achieve the papers' objective. It is a way of collecting and evaluating the available literature and studies relevant to a specific topic, or research question [26]. FaaS is a novel proposal, and available literature lacks comprehensive insights into the specific KPIs associated with it. By conducting an SLR, we survey existing literature on related as-a-Service implementations, providing a structured approach to identifying, evaluating, and synthesizing relevant KPIs. The SLR is chosen also for its inherent ability to facilitate comparisons. Through this methodology, we aim to discover connections in the KPIs employed in various as-a-Service models, including AaaS, and MaaS. Such comparison allows the analysis and provides valuable insights for practitioners and researchers. Lastly, the systematic analysis ensures that our investigation is comprehensive and not limited to a specific subset of literature.

The review is developed in three steps: (i) Planning; (ii) Execution; and (iii) Analysis [27]. In the first step, the systematic review protocol is developed, i.e., a document that specifies the research questions, the methodologies used to collect the literature, the information needed from the papers, and a fixed structure for the selection, extraction, and analysis of data. It also states the inclusion and qualifying criteria used during the execution phase, when the studies are collected and selected. The last step consists of the extraction and synthesis of the knowledge and information obtained from the literature.

This systematic literature review includes the studies related to KPIs development and definition within the framework of MaaS, AaaS, and cloud manufacturing environments. The aim of the review is to outline the groundwork and form a base of reference for focusing future research and experimentation with FaaS ideas. Therefore, two main goals define the research focus of the review protocol: (i) identify the KPIs formulated in previous research instances of AaaS, MaaS, and cloud manufacturing implementation; (ii) identify the information related to those KPIs, e.g., name, unit of measurement, de-

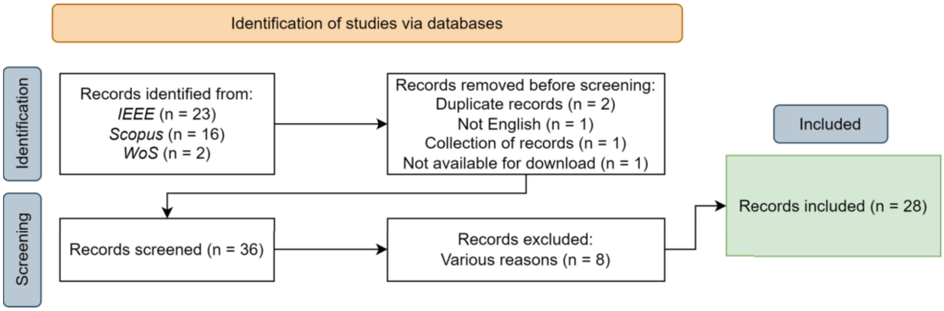

Figure 2. Process of identification of the literature

scription. From the resulting database, researchers can classify them, then identify the most suitable to be utilized in a following FaaS implementation.

The string to query electronic databases includes the union of the acronyms (as well as the full phrases) MaaS, AaaS, EaaS (Equipment-as-a-Service), RaaS (Robots-as-a-Service) with cloud manufacturing, searched for in Abstract, Keywords, and Title; this is searched in intersection with the term Key Performance Indicators and its acronym, in all metadata. The databases used for the search are the relevant ones available to KTH employees, namely *IEEE digital library*, *Scopus*, and *Web of Science (WoS)*. In order to conduct the selection of the relevant papers, fulfilling this inclusion criteria is required:

1. proposition or direct application of as-a-service manufacturing implementation;
2. focus on performance metrics, such as efficiency, quality, and productivity.

To be considered for the final selection, the paper must be written in English and the manuscript must be available for download. The selection of only the most relevant databases as sources ensures that the extracted KPIs are widely used and recognized.

Following the selection process, 41 papers are identified. After applying the criteria, a total of 36 manuscripts are kept for analysis. One entry is removed from the search results because it is a full Procedia book, a collection of several papers. The final database includes studies from *IEEE* and *Scopus*, as the search conducted in *WoS* results in duplicate papers. During the screening stage, eight manuscripts are marked as false positives, leading to their exclusion from the final included record list (see also Figure 2).

The final set of papers defines the material needed for the Analysis step, which enables the extraction and recording of data on relevant KPIs in a digital database, in strict accordance with the protocol. A list of KPIs is collected for each paper: if the paper explicitly states one, this is added directly to the collection; in cases where they are not, we closely examine the paper for any requirements, or measurements that imply the use of important metrics or indicators. These are analyzed and reasoned as potential KPIs, taking into consideration the context and objectives of the study. As a result, the extracted indicators often are repeated entries, common to more than one article.

Consequently, a synthesis process merges repeated or similar entries into the same KPI, and a separate column is added to the database to count the number of times each of them is found in the initial database. The synthesized information is then categorized based on the 'purpose', as stated in [25]. However, these categories are from the year 2014, and may not precisely reflect the findings from the collected studies. Therefore, where possible, we incorporate the extracted results into the categories specified in the standard. When not possible, we create new relevant categories and place the indicators there. Additional information about direct and indirect measures, the type of KPI and the purpose is also recorded in the database. Separately, each indicator is fully described in accordance with the ISO 22400-1 "Structure of KPI description", but an expansion of this structure is required to fill the needs of the new as-a-Service offerings. Therefore, a new standard framework, which represents an initial, tentative approach for describing such KPIs is built to accommodate for additional key information, and is shown in Section 4.

4. Results

The database with the twenty-eight included articles spans from 2012 to 2023, the year when this review is written, showing an increased interest on as-a-Service implementations in manufacturing, during the last decade. A total of 138 relevant KPIs are identified and recorded in the database, including repeated and similar ones. After the synthesis process, 34 main indicators remains, the most mentioned ones being: (i) *Data Security* (14 times); (ii) *Cost Reduction* (13 times); (iii) *Resource Utilization* (10 times). Indicators can be categorized based on a number of information that must be taken into account when using a pertinent measure (or a set of measures) for a particular purpose. With the aim of helping companies in the selection of indicators to monitor the performance of possible future FaaS implementation, the relevant indicators are classified according on the basis of seven main categories.

1. **Efficiency**: focuses on optimizing resource utilization, and estimating the efficiency of the service.
2. **Cost**: aims for cost reduction, management, and calculation of related expenses.
3. **Quality**: concerns the assessment of the manufacturing service quality.
4. **User Satisfaction**: measures the satisfaction levels of users of the service.
5. **Manufacturing Process**: establish scalability, sustainability, and other process-related aspects (sustainability is included since is otherwise self-standing).
6. **Provider**: pertains to the level of readiness and capability in providing the manufacturing services.
7. **Data**: emphasizes data security, and data management.

Some of the extracted indicators are formulated directly, others are indirect measures, as indicated in Figure 3. The majority is included in the categories **Efficiency**, and **Process**, with indicators such as *Resource Utilization* [16], *Responsiveness* [28], and *Scalability* [13]. However, the most mentioned ones are *Data Security* [17], in the category of **Data**, and *Cost Reduction*[29], in the category of **Cost**, underlining the highly relevant concerns about data exchange in this kind of cloud-based services, and the importance of monitoring and reducing cost to a minimum, to always optimize revenues.

The collected KPIs are described following the idea and structure proposed by the ISO standard [25]. An example can be seen with the description of *Resource Utilization*. From the proposed standard, to accommodate for the additional needs of as-a-Service manufacturing, we propose a new, expanded standard framework, which is shown in Table 1. The *Content* rows are mostly self-explanatory, though 'Scope' refers to the identification of the aspect of the "as-a-Service" model for which the KPI is relevant (can be service offering, customer segment, or subscription type). As per the *Context* part: 'Tim-

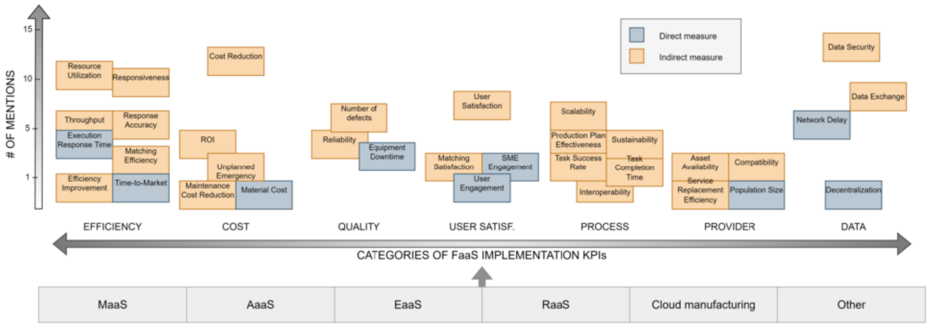

Figure 3. Categorization of common KPIs

ing' can be real-time (with every data acquisition timestamp), on demand (with a specific request), or periodically (with a time interval); it is often though a real-time monitoring to check the service performance constantly. We add a row 'Service model', to describe the type of "as-a-Service" to which the KPI is generally applicable (usually it is more than one). One row 'Category' to include the specified role that the KPI has, for example **Efficiency**. And one row 'Usage' out of the standard Notes, because it is important to display the specific information to clarify the applicability of the KPI. 'Audience' refers to the group mostly using the indicator, either operators, supervisors, or management; 'Production methodology' tells if the KPI is generally applicable for discrete, batch, or continuous production. The Effect model diagram is a standard representation of the KPI dependencies, but is not reported in this paper as it is not relevant.

5. Discussion

As shown in Section 4, more categories are needed than those presented in the ISO Standard 22400:2014. This necessity comes from the novel nature of servitization business proposals, whereas the standard was originally structured around the concept of MOM (Manufacturing Operations Management) and operational performance improvement, to increase the value creation processes of an enterprise. Nevertheless, this paper represents an initial effort to gather insights from the literature and categorize the main and crucial KPIs that underline the development of 'as-a-Service' models. The main goal is to assist researchers and practitioners to explore and create real-world applications. However, a more comprehensive analysis, spanning from additional literature to industrial expertise, is expected to reveal an even higher number of indicators, particularly those of critical importance in these settings, as we will discuss later in this Section.

The current results are a first iteration of a framework for classifying KPIs to give directions for future additions and developments. Moreover, the results address the primary objective of collecting and proposing indicators for use in future FaaS industrial installments, for both case-studies and real production scenarios. The database published online includes the common values underlining the proposals of 'as-a-Service' business models, reflecting the strive to improve efficiency, quality, user satisfaction, reduce cost, and more. The newly proposed feeding model can refer to the collection of KPIs in the database to formulate the crucial and necessary measures for industrial implementation.

Table 1. Example KPI (*Resource Utilization*), with an explanation of the included information. Takes from standard ISO22400-2:2014 [25], to create new framework of reference for 'aaS' offerings

KPI	*Resource Utilization*	
Content:		
Name	Resource Utilization	Name of the KPI
ID	KPIXXX	A user-defined unique identification of the KPI in the user environment.
Description	Efficient resource utilization	A brief description of the KPI.
Scope	*Service, customer	*Identification of the element or aspect of the "as-a-Service" model that the KPI is relevant for (service offering, customer segment, or subscription type).
Formula	$\frac{\textit{Machines in use}}{\textit{Available machines}}$	The mathematical formula used to calculate the KPI.
Unit of measure	%	The basic unit or dimension in which the KPI is expressed.
Range	0 % to 100 %	The logical limits of the KPI.
Trend	Higher-is-better	The direction in which higher values indicate better performance.
Context:		
Timing	Real-time	The timing at which the KPI is calculated (*often in real-time to monitor service performance constantly).
*Service model	FaaS	Type of "as-a-Service" model to which the KPI is generally applicable (MaaS, AaaS, other).
Category	Efficiency	The category of purpose to which the KPI belongs.
Audience	Supervisors, Management	The user groups that typically use this KPI.
Production methodology	Discrete, Batch, Continuous	The type of production methods to which the KPI is applicable.
Effect model diagram	Note: not reported in this paper	The effect model diagram is a graphical representation of the dependencies of the KPI elements.
*Usage	Identify bottlenecks, schedule maintenance, optimize allocation	Specific information that clarifies the interpretation or application of the KPI.
Notes	—	Can contain additional information related to the KPI.

*modified from the standard

Such propositions are mostly focused on resource utilization percentages, system responsiveness, cost reduction, return of investments, user feedback and production scalability. Another concern is the security and availability of data, making a quick, reliable, and secure network infrastructure of paramount importance for practical application.

So, for FaaS, the most pertinent indicators extend beyond conventional manufacturing metrics. While it is still true that reducing costs and optimizing revenues is the paramount objective of the industry, many aspects are ever more relevant in the servitization world, especially when looking at the increasing relevance that IoT is gaining. In this sense, the essential KPIs that are at the basis of the creation of a machine tending tool offered as a service are those pertaining to data management: in particular, *Data Security* [17] in the exchange of information and the speed of the network to send data are crucial. *Responsiveness* [28] of the system and *User Satisfaction* [30] also play a key role in the evaluation of the success of a business.

However, while the review of related literature collected extensive relevant studies, certain critical KPIs have not been explicitly mentioned and do not emerge from the analysis. One notable omission is the Overall Equipment Effectiveness (OEE), one of the most used KPI in manufacturing contexts. OEE measures the efficiency of equipment and is crucial to assess and improve production performance. Its omission may be due to a lack of focus on a specific manufacturing equipment, once again highlighting the need for future practical evolution in the field. It should be noted, though, that some of the collected entries in the database category **Efficiency**, such as *Resource Utilization* and *Responsiveness*, together might contribute to give an overall estimation of OEE.

A surprising outcome is that through a focused literature review that aimed specifically at searching indicators for services, some of the most relevant KPIs are missing: among these, we name *Churn Rate* and *Customer Churn Rate*, which are usually crucial measures for as-a-Service businesses. Churn Rate can signal customer dissatisfaction or external factors leading to discontinuation, and Customer Churn Rate provides insights into contractual customer losses. It might be worth to perform additional research to check if part of the literature is mistakenly excluded by the queries; however, the most likely useful continuation would be to perform a full survey of relevant (AaaS, MaaS, EaaS, and so on) industrial deployer, submitting questionnaires and performing interviews to experts in the field, to see if these very relevant KPIs emerge from the industrial world rather than from the academic literature. Other relevant KPIs that might emerge from such an exploration are, for example, Total Contract Value (TCV) and Annual Recurring Revenue (ARR), metrics for long-term financial planning and revenue trends.

Furthermore, the lack of emphasis on energy consumption and limited discussion of sustainability in the reviewed literature are noteworthy. Given their increasing importance and focus on environmental responsibility, there is a significant lack of understanding of the contribution to broader sustainability goals.

6. Conclusion and future works

This research involves mapping the state of the art and systematizing 138 key performance indicators, summarized into a collection of 34 main indicators relevant for Feeding-as-a-Service applications. The primary objective is to help the search, selection, customization, and development of new indicators according to a company's specific needs. The findings presented in this paper are part of a broader research project that previously developed the foundational concepts of FaaS: to allow the idea to evolve, additional research, namely case studies or action research, should be conducted. These strategies require the deployment of a FaaS system and collecting data through measurements, therefore a structured approach and predefined indicators become essential for this goal. Therefore, this paper presents the list of KPIs and their categorization, freely available for study and adoption in future implementations. This review is intended to help the advancement of the field with the final goal of a successful industry application. It also manages to propose a new standard framework for the description of such KPIs, which includes additional information that are very relevant in this field, when the business model "as-a-Service" is employed.

Limitations of this research include that the database entries are directly extracted from the literature, and they may not be immediately applicable to other situations, in turn requiring careful and time-consuming interpretation. Each paper contributes with their specific KPIs from various perspectives, and employing different measurement methods, therefore increasing possible bias in the merging and grouping phases. We tried to limit such bias as much as possible by having a thorough discussion between the authors and including other members of the research groups when cases of particular difficulties arose. Future developments would benefit from a more comprehensive examination of the similarities and differences between these indicators and an exploration of their interrelationships. It would also be a good addition to clarify the most commonly used variables and units of measurement for calculation, which could lead to the expansion of the database to one that simplifies calculations for companies. Lastly, it would be beneficial to perform additional exploratory research to comprehensively gather information and knowledge about KPIs from industrial practitioners, through questionnaires and interviews submitted to the experts in the field.

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