A Process-Oriented Evaluation Framework for In-Memory Technology Applications

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***Abstract*—For several years, it has been predicted that In-memory based IT-systems will become a key technology in addressing the challenges of increasing data volumes and computational speed requirements. Nevertheless, many companies seem reluctant to switch to this technology. Missing application scenarios are often cited as the main cause of the slow spreading. To adress this research gap, this work will introduce a framework for the analysis and evaluation of potential applications of In-memory IT-Systems. The developed framework offers researchers as well as the corporate sector the opportunity to evaluate the suitability of such IT systems for existing as well as future use cases. The development process follows the approach of the design science research. In the first phase relevant influencing factors for the use of In-memory systems are identified conducting a literature review. In the second phase an expert survey is carried out for the evaluation and the identification of further influencing factors. The results show that an acceleration of IT processing does not generate substantial added value. In particular, business-related factors have been neglected in the past. Therefore, a structured analysis framework is introduced considering both, data and analysis factors as well as economical factors. In the last step the introduced framework is applied based on selected cross-industry uses cases to underline the evaluation capabilities.**

Keywords–In-Memory IT-Systems; Case Study; In-Memory Computing; In-Memory Database.

I. Introduction

In this work, we introduce a design science based system, able to identify and evaluate influential factors for potential application scenarios of In-memory IT-systems [1]. The aim of this approach is to examine existing as well as potential future scenarios. Based on an analysis framework, the requirements and their feasibility of use cases are examined. In order to identify possible influence factors of In-memory application scenarios, case studies and scientific literature are analyzed. Subsequently, the influence factors found are evaluated with the help of field experts who participated in an expert survey, also identifying yet unknown and additional factors.

In December 2014, Amazon introduced the ”Prime Now” service, which guarantees the delivery of several thousands of products within an hour [2]. In the field of high frequency trading, fractions of a second can determine profit or loss [3]. Sociologists have been talking about this subject as the ”age of acceleration” for quite some time [4]. Never before in history were decision makers forced to make entrepreneurial decisions under greater time pressure than today. Furthermore, increasingly huge and heterogeneous data sets are challenging companies. Due to the increasing computational demands, conventional IT solutions reach their performance limits more and more frequently. One of the most promising technologies for solving these challenges are In-memory-based IT systems (IMIS). Although the technology was subject to high expectations in the past, the predicted boom has not yet begun. In this context, many companies complain about the lack of useful and economical application scenarios [5][6]. In a study by the American SAP user group, this point is mentioned as one of the main causes for the delayed distribution [7]. The reasons for this is, among others, the previous focus on technical aspects [8]. A study by the market research company PAC [9], on the other hand, shows that the In-memory technology is of great interest to many companies and can play an important role in the future. 36% of the surveyed company representatives see this technology as an important building block in future IT landscapes. In this field of tension, it becomes clear that the In-memory technology has great potential that has not yet been exploited. Our contribution starts at this point. With the aid of our framework practitioners are able to assess the potential of IMIS.

The paper is organized as follows. Section II introduces the technical background and the related work in the field of IMIS. In Section III the research methodology is presented. Afterwards the results of the literature review and the expert survey are presented in Section III. Section IV comprises the conception and structuring of the framework. The application of the developed framework is shown based on selected use cases in Section V. The final section summarizes the contributions to practice and research.

II. Research Background

The idea of using main memory to store data is not new. These concepts were introduced in the 1980s and 1990s [10][11]. At that time, the main focus was a very fast response times which were realized by main memory databases. The speed advantage in comparison to conventional hard disk data access is illustrated in Table I. Due to high costs and low memory sizes, the interest regarding In-memory databases decreased and the technology almost fell into oblivion. With the introduction of the HANA platform [12], the IT-software provider SAP has once again placed the focus on IMIS.

TABLE I. Data Access Overview (cited from [13]).

Action	**Time**
Main memory access	100ns
Read 1MB sequentially from memory	250 000ns
Disk seek	5 000 000ns
Read 1MB sequentially from disk	30 000 000ns

A. Problem Context

The previous concerns about the durability of the stored data could be eliminated by the use of non-volatile RAM [14]. The concept of IMIS includes more than a pure data storage in the main memory. In contrast to conventional relational databases, the data is no longer stored row-based, but most often column-based [15]. The concept of a column-based data storage is illustrated in Figure 1. The advantage of a column-based storage is on the one side a better data compression and on the other side a better suitability for analytical tasks.

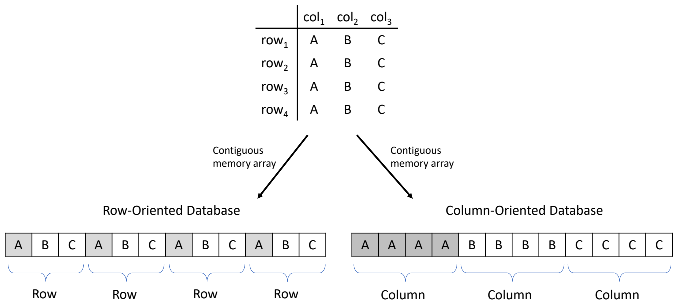

Figure 1. Row- and Column-oriented data layout (adapted according to [13])

Originally, the main application area of IMIS were fast and flexible analysis of large amounts of data in data warehouses. In the meantime, the application areas were extended to transaction systems. The goal here is to dissolve the historically grown separation between online analytical processing (OLAP) and online transaction processing (OLTP) systems [16][17][18]. These hybrid systems are referred to as Online Mixed Workload Processing (OLXP) [19] and Hybrid Transactional/Analytical Processing (HTAP) [20].

The advantage of a common data storage is the elimination of extract, transform, load (ETL) processes from the OLTP into the OLAP system. In addition, transactional data can be used for analytical and planning tasks. Furthermore, there is a potential for savings through the elimination of an additional system [13]. However, it is important to note that analysis and transaction systems have fundamentally different characteristics and requirements [21]. Analytical systems are generally used for the support of specialists and executives. Decisions at these company levels are, in most cases, characterized as strategically or tactically, that means for a longer period. The data access during the execution of analysis are almost exclusively read-only [21][22]. On the other hand, transaction systems are used to solve everyday business tasks of a company. In most cases, the time horizon only covers a relatively short period [23]. The typical transactional workload is also largely read access, but compared with analyzes, with a significantly higher proportion of write accesses [21]. The merging of OLAP and OLTP systems to an OLXP / HTAP system leads not only to the advantages mentioned, but also to problems and difficulties. From a technical point of view, hybrid workloads (line / column-based & read / write) must be simultaneously processed [24][25][26]. The merging to a common information system also leads to a stronger dependency on the respective system provider. In order to be able to exploit the entire benefit of an IMIS, a large number of applications and processes have to be adapted.

B. Related Work

IT providers, such as SAP have predominantly driven the hype surrounding the In-memory technology in the past years. The focus of recent developments was mostly technology-oriented. Similar tendencies can be found in early scientific contributions. Mainly technical features, such as the column-based storage of data [15], data compression [27] or the persistence of volatile storage media [28] were investigated. An alternative approach for the analysis of possible In-memory applications tries to assess the advantages and potentials on the basis of business requirements. In the first publications in this area [29][30][31] Piller and Hagedorn are investigating factors for evaluating In-memory applications. The authors examine the potential of IMIS in the retail sector. Despite the early stage of this technology at the time of the investigation, initial application patterns have already been identified. Similar results are also reported by Cundius et al. in their work [32][33]. They developed a model for evaluating real-time IT systems. The focus of this work was on the workflow-specific properties of real-time IT systems. In [34] the characteristics of In-memory systems were described. Based on the identified attributes application capabilities were derived. As mentioned in the previous section, the starting point of the IMIS developments is the acceleration of analytical applications. In the field of real-time analytics Nadj and Schieder [35] evolved a taxonomy for the characterization of real-time business intelligence.

The use of IMIS not only has an impact on data processing, but also on the downstream decision-making and implementation processes. Vom Brocke et al. examine the connection between the In-memory technology and the resulting business use in their contributions [36][37][38]. They conclude that a value-creation for companies is strongly related to the adaption of processes. Vom Brocke et al. as well as Bärenfänger et al. [39] conclude that the introduction of In-memory technology not only leads to a direct benefit, but to a large extent to downstream improvements in the process flow. Meier et al. further pursue the aim of an economic evaluation in [40]. They also divided the economic effects into direct and indirect attributable effects.

One of the most important innovations of IMIS is the combination of analysis and transaction systems. Winter et al. analyze the properties of IMIS in one of the first case studies [41]. In addition to the volume of data, the integration of the analysis and transaction system is identified as the most important indicator for the assessment of IMIS. This point is also highlighted in several other scientific papers in this field [19][29][30][42]. From a solely technical perspective, IMIS offers huge potential. However, the question arises which companies or application areas can exploit this potential in practice. For many companies predefined reports and evaluations on a daily basis will still be sufficient. For others, the use of real-time data can become a decisive competitive advantage.

Another circumstance that influences the valuation and therefore also the decision concerning the use of IMIS is the uncertainty about the possible performance benefits. Research in this area has shown that In-memory databases do not always perform better than traditional relational databases. A prerequisite for a real performance advantage, for example, is a certain amount of data volume and the number of users [43].

Previous application examples often refer to very specific or exotic tasks. A popular example of the application of IMIS is the analysis of sports data, e.g., in Formula 1 [44] or soccer [45]. Although these examples are quite illustrative, they are not suitable to provide insights into the solution of ”everyday” business problems. The lack of economic use cases is regarded as one of the main obstacles to the adoption of IMIS. This is mentioned in scientific literature [29][42][46] as well as from a company point of view [5][8].

III. Research Methodolgy

The goal of this research work is to examine and structure IMIS use cases with regard to their success factors. The methodology of Design Science Research [47] was used to develop the framework. The aim of this approach is to make comprehensible, scientifically sound and practice-relevant statements in the context of information systems. The design process is not static, it allows changes to be incorporated into the existing model. In the so-called design science research cycle, the results repeatedly iterate through the various stages of the model development [48]. The whole design science research cycle as adapted from [48] is shown in Figure 2. The approach comprised three pillars, evironment, design science research core and knowledge base. The environment pillar is where the object of interest and the application domain reside [47]. This includes organizations, people and technologies. The knowledge base is comprised by foundations and methodologies. Hevner et. al [47] state that this includes foundational theories, frameworks, instruments, constructs, models and methods. The approach further contains three cycles within and between the pillars to ensure that both the relevance and a rigor methodology are ensured during the design phase. The advantage is that the dynamic characteristics of business needs can be directly taken into account. The detailed elaboration of the three phases is described in the following section:

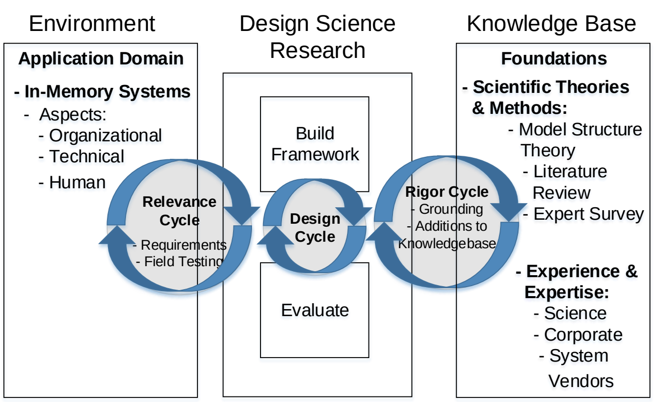

Figure 2. Design Science Research Cycle (adapted according to [48])

Relevance Cycle: The goal of each research is the development of an idea or model which is relevant for the application domain and improves its environment. To reach this goal we validated the relevance of our model multiple times. Starting point and motivation of this research project was the already mentioned demand from business as well as science. During the development the relevance was ensured by the inclusion of experts from science, companies and system providers.

Rigor Cycle: Performing scientific work requires the consideration of thoroughly and established methods with regard to the problem context. To address these requirements we have evaluated and selected appropriate methods for the construction of our framework. The methodology described by Klein and Scholl [49] was used to define the overall structure of the framework. The main advantage of the used methodology is the avoidance of structural defects during the modeling phase. Hereby, it was possible to develop a well-designed and feasible decision model. For this purpose, the scope of the model was first restricted in order to consider only the aspects, which are relevant for the problem solving. After the relevant influential factors were identified, they were subdivided through a structural analysis. As a result of this structuring process, an operationalizable target system for assessing and analyzing In-memory use cases has been created.

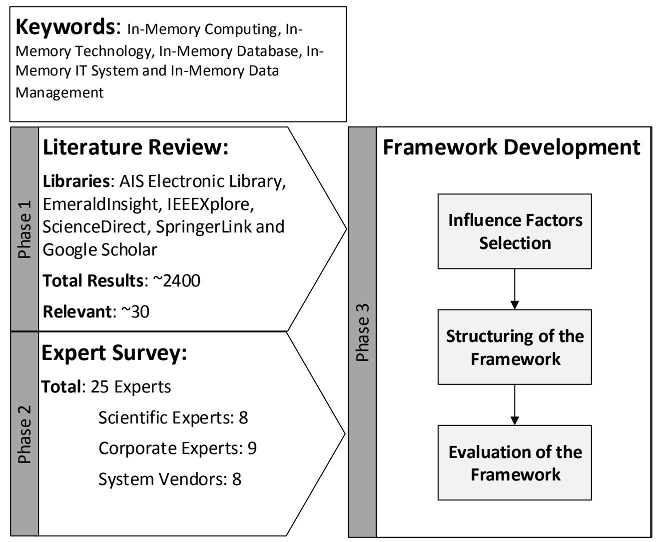

Figure 3. Illustration of the research methodology

Design Cycle: In order to gather the basic factors influencing the framework, scientific work and previous case studies in the field of IMIS were analyzed and evaluated during the first design phase. In terms of research method, this was accomplished according to Webster and Watson [51]. In the literature review, established literature databases (AIS Electronic Library, EmeraldInsight, IEEEXplore, ScienceDirect, SpringerLink and Google Scholar) were investigated. The search included the following key words: "In-Memory Computing", "In-Memory Technology", "In-Memory Database", "In-Memory IT System" and "In-Memory Data Management". Subsequently, a backward search was carried out. Therefore, only papers dealing with the application and the business perspective of IMIS were used. The study of the literature databases revealed that around 2400 scientific publications have so far dealt with IMIS. During the litertaure review phase we conducted a backward as well as a forward search as suggested by Webster and Watson [51]. In the backward search, the quoted sources of the keyword search were analyzed to determine the results of prior research. Based on these results we used Google Scholar to identify the citing articles. Due to the context of this paper only publications with an business perspective were considered. Hence, 30 relevant papers remained. The detailed results are explained in the next section. During the second design phase a qualitative expert survey [52] was carried out to evaluate the results and identify further factors. In particular, the expert survey was carried out to reveal further findings on challenges from an economic point of view. In order to cover a broad range of opinions and experiences, the experts were composed of representatives from different fields. In total 25 experts in the field of IMIS were interviewed. These included scientists, company representatives as well as representatives of leading

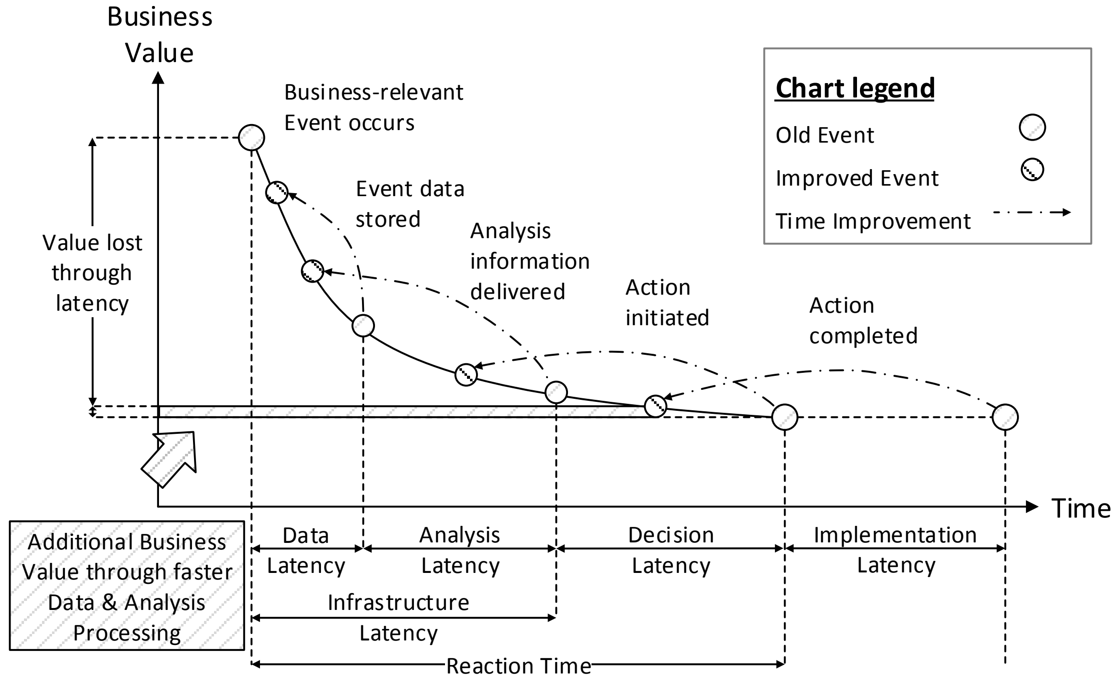

Figure 4. Correlation between time and business value (adapted according to [50])

IMIS providers. To ensure a comprehensive knowledge base we only included experts with a proven experience with In-memory systems. The scientific experts were selected based on publications in the area of IMIS as well as knowledge in the field of databases and information systems. The interviewed representatives of the system providers and the companies were also selected on the basis of their experience in this area. Because of the relative high aquistion costs of IMIS systems only corporate representatives from medium and large companies have been included. In semi-structured interviews the experts were asked about the potential and the obstacles of the In-memory technology. In addition, the experts were asked to evaluate possible application scenarios and their characteristics in detail. An overview of the research methodologies is shown in Figure 3.

IV. Results from the Literature Review and Expert Survey

This section outlines the steps of the design cycle process. The results of the literature review are presented in the first part. The findings from this part form the foundation of the created artifact. In the second part, the results of the expert survey are presented. In the context of the design science cycle, the expert survey is used to evaluate the previous results as well as to reveal new influence factors.

A. Results of the literature and case study review

The examined contributions used different approaches to deal with the analysis and assessment of the scenarios. The work [29] by Piller and Hagedorn has proven to be a suitable basis for the model presented in this work. Starting from the business process characteristics described in this study, further influencing factors were identified and classified.

Main memory-based databases are often mentioned to solve the challenges which are associated with so called Big Data applications. Due to the availability of larger main memory and advanced compression by the column orientation, IMIS is able to process large amounts of data [13][53]. Therefore, it is appropriate to include the data volume of a use case into the consideration. Apart from the data volume, a number of other factors play a decisive role. These include, for example, the urgency of the results [29][30][38][50] or the dynamics of the data [29][30][32]. Hence, high-performance systems have a strong positive effect if the data changes frequently. If the underlying data changes only rarely and to a small extent, the potential additional value of a real-time result is very limited. An example for this are purchase proposals in large online shops based on customer segmentation, which change in general only rarely or marginally. A further influencing parameter is the number and type of source systems [54][55]. In order to cover a broad range of information, it may be advantageous to integrate several different source systems. However, from a critical point of view, problems emerge. The transmission from external sources can lead to delays. A further and currently very often-discussed topic is the veracity of information [56].

As already mentioned in Section II, business processes must be adapted with regard to the newly gained flexibility and speed of data analysis in order to exploit the full potential [32][36][37]. The need for process adaptation has to be clarified on the base of the time business-value relationship concept from Hackathorn [50]. Figure 4 visualizes this concept and shows that the information-processing latency caused by IMIS can be reduced, but the additional business profit is relatively low. In order to generate a higher added value, it is also necessary to modify and accelerate the downstream decision-making and implementation processes.

B. Results of the expert survey

In order to evaluate the results and identify further influential factors, a semistructured expert study was conducted. One of the most frequent points mentioned in the interviews was the high uncertainty regarding the economic benefit. Despite the decline in hardware costs, the purchase of a main memory-based information system is associated with both high investment costs and a significant total cost of ownership [40]. As with any other investment decision, sufficient value must be generated to cover the cost of acquisition. A large proportion of the interviewed company representatives have criticized the poor cost-benefit ratio concerning IMIS and mentioned several causes. In most business applications, mainly "conventional" analysis and evaluations are carried out in the information system. These are already defined in advance or can be well predicted and scheduled. Due to the tactical or strategic character of the decisions, there is no exceptional urgency to obtain the results in most cases.

Out of traditional OLAP tasks, the In-memory technology is perceived more positively. This includes, for example, the areas of predictive maintenance or the integration and analysis of social media. To implement a predictive maintenance, a large number of sensors must be integrated into the analytical system. The continuous measurement results in a high volume of data. Ideally, these data should be analysed as quickly as possible. Another example is the processing of social media, where large quantities of unstructured texts have to be processed. These two examples already confirm a significant proportion of the influencing factors from the first design phase. Another important criterion frequently mentioned were implementation conditions. According to the experts, not only the speed of decision-making is a relevant factor, but also the technical effort and legal obstacles that have to be considered. These factors were not taken into account in the previous literature. Efforts for the indoor localization or digital price tags were cited as examples for technical obstacles. An example for legal obstacles are the data privacy laws regarding the analysis of personal data, especially in european countries like Germany, Spain or the Netherlands.

V. Concept and Structure of the Evaluation Framework

The literature review as well as the results from the expert study make clear that a variety of factors influence the assessment of IMIS scenarios. To support the IMIS decision process it is necessary to structure the influence factors. According to Klein and Scholl [49] the decision factors were divided into a goal hierarchy. This enables a better unterstanding and usability of the model. Based on the results of the literature review, the factors can be clustered into two main categories: data and analysis factors. In the category analysis factors, a large part of the investigations dealt with questions of urgency, complexity or flexibility of analysis. Another segment of research focuses on data-driven factors. These include, among other issues, the volume, the topicality and the dynamics of data. As the hesitant spread of IMIS shows, the technical advantages alone are not enough to generate a substantial benefit. In the past research of IMIS, this fact was rarely taken into account. To consider aspects which are related to, e.g., real-time decisions and to take the results of the expert study into account, the framework was extended by the category of economic factors. This category contains factors with regard to internal as well as external implementation conditions, which are particularly important in the corporate context. This part of the goal hierarchy comprises, e.g., the legal framework or the target group acceptance. The resulting decision model is summarized in Figure 5.

Another issue to be considered is the distinct impact of the influence factors. The different characteristics of the factors show that some have a positive effect on the use of IMIS, while others have a negative impact. To take this into account, we have extended the IMIS evaluation framework by an additional influence indicator. The positive influences are quite obvious on the basis of the technical characteristics. In case of, e.g., a high urgency or a strong data dynamic, the In-memory technology can point out its advantages. An example for factors which are limitating the benefit of IMIS is the amount and kind of source systems. The integration of numerous external source systems can lead to latencies regarding the data provision. Another example are limitations caused by legal regulations. In several countries privacy policies prohibit the analysis of personal data. For a better understanding the decision criterias of our framework are explained in the following part:

A. Analysis factors

Urgency: How fast are the results of the evaluations needed? These factor focuses on the required response time for results of the IT-system, for instance, if deadlines have to be met or subsequent process depend on the results of upstream processes along a critical path. Another example are ad hoc reports requested by high management level [29][30][36][53].

Complexity of the evaluations: How complex is the calculation of the results? The complexity of the calculation depends on the algorithms used and the underlying data [19][29][30].

Flexibility of analysis: Is it more common for new analysis to be performed spontaneously? So far, reports have often been pre-aggregated. The creation of spontaneous evaluations may take a significant amount of time [19][29][41][66].

Degree of detail of the evaluations: In previous information systems, the analyzed data is mostly pre-aggregated. With the help of modern IT systems, evaluations of every level of detail can be implemented [29][46][55].

Integration of Analysis and Transaction System - hybrid workload: This involves the processing of hybrid workloads, here both transactional and analytical data are used for the tasks to be accomplished. These hybrid systems are called OLXP or HTAP. The advantage of shared data management is the elimination of extraction, transformation and loading (ETL) processes from the OLTP system to the OLAP system. In addition, real-time data can be used for analyzes, evaluations or planning [19][29][30][41][42].

Number and type of data sources: From how many sources and from which types the data is obtained. Internal sources are easier to implement and faster to retrieve in most

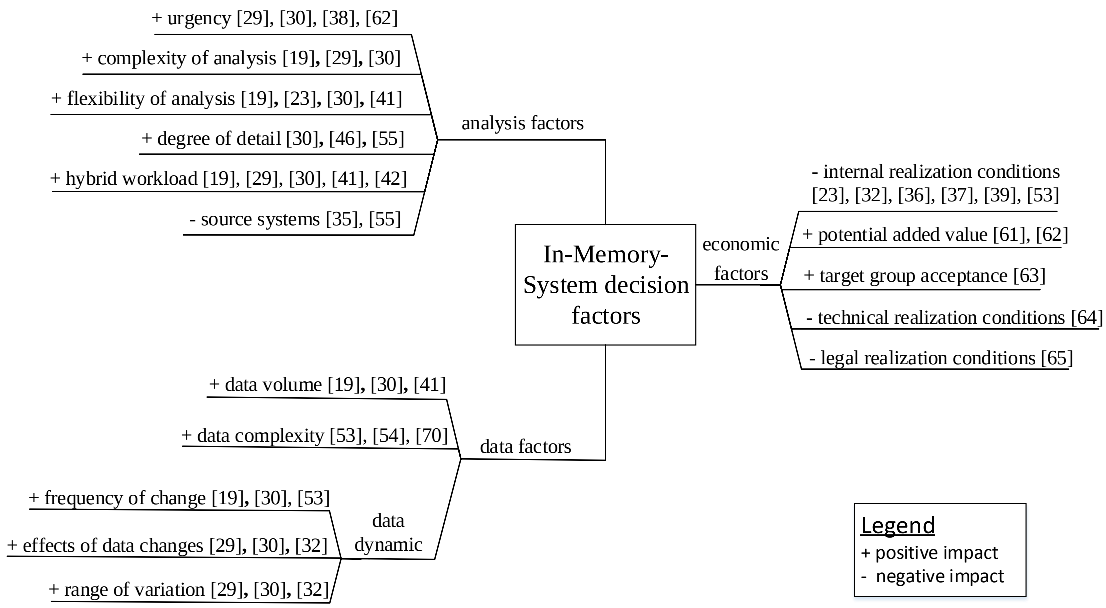

Figure 5. Overview of the analysis and evaluation framework

cases. They further offer a higher predictability for changes in the interface, e.g., changes in the API. For external sources, such as social media or cloud services, however, delays may occur and interfaces have to be updated on a regular basis [55][54].

B. *Characteristics of the underlying data - data factors*

Data volume: How big is the underlying dataset. In general the use of In-memory systems is economically more reasonable with large data volumes. Smaller amounts of data can be usually processed by conventional means [19][29][41].

Data Complexity: In addition to volume and the rate of change, the complexity of data plays a crucial role in big data. The complexity depends on the one hand on the format and on the other hand on the data structure. Data can be categorised as structured in a table like manner, semi-structured like XML, JSON, text files or unstructered data, such as images and video. Especially the processing of unstructered data usually requires additional methods, such as text-mining and filtering and enhancing images in order to perform image recognition techniques [57][58][60].

Characteristics of the underlying data - data dynamics

Frequency of change - topicality of the data: Which requirements are made in terms of timeliness? Decisive here is how much added value can be generated by the second-precise data in comparison to data that is updated in a minutely, hourly or daily manner. If the requirements on the topicality of the data s lower, techniques such as caching and temporal data storage may be used [19][29][53][67].

Effects of the data changes: The influcence factor focus on the implications of data variations regarding the business success [29][30][32]. This factor can be interpreted as the sensitivity of economical effects if data changes. For instance, even small irregularities during the paint work in the automobile assembly lead to elaborate amendments in the subsequent production process.

Range of variation: To what extend does the performance measures change and what is the potential impact of data variations on the business [29][30][32]?

C. *Characteristics of industry - economic factors*

Internal realization conditions and implementation period: How quickly can the results and decisions from the IT system be implemented. The use of real-time data has no added value if, despite a rapid calculation, several days are required for the implementation of the results. The availability of real-time information makes it necessary to react quickly to changes. For the use of the entire potential, it is often necessary to comprehensively adapt the affected business processes in a company [23][32][36][38][39][63][53].

Potential (economic) added value: The acquisition of a new IT system entails high investment costs. This raises the question of whether the target market has enough potential to generate the necessary added value [61][62].

Target group acceptance: Are customers ready and willing to deliver all necessary data (e.g., GPS data)? On the other hand, it is also important to know if a customer is constantly accepting fluctuating prices in the supermarket [63].

Technical realization conditions: Is it actually possible to collect and transfer the desired data in due time under difficult conditions? For example, the transmission of sensor data from a Brazilian silvermine (or other remote locations) to the company's IT system [64].

Legal realization conditions: To what extent may data be evaluated at all or is the system applicable worldwide. In Germany, for example, there are very strict requirements regarding the data privacy and the processing of personal data. Legal issues in terms of data privacy may occur across borders or make once legal practices illegal in terms of the General Data Protection Regulation (GDPR) [68]. Another example is the decision against the permission of so called geoblocking and discrimination of EU online shop users [69].

VI. Application example of the framework

In this section the functionality of the framework will be shown based on selected application examples from different sectors. The examples were discussed during the expert interviews and in initial case studies. Based on the selected use cases, the advantages of our IMIS evaluation framework are clarified.

1) Case study "Analysis of Sales and Inventory Data": The analysis of sales and inventory data is one of the core tasks in the retail sector. One goal is the reduction of storage and delivery costs. At the same time out-of-stock situations should be avoided. Thereby, it is necessary to take current sales figures, fluctuations due to promotions as well as external influences into account. The main characteristics of this business process are described below:

Data characteristics: Due to the large number of sales transactions the underlying data volume is quite high. Sales documents in the retail sector are well-structured and can therefore be easily processed. A complex transformation is not necessary. The sales figures are subject to extensive and quite frequent variations. In practice, fluctuations can occur up to 500% [70]. This can lead to out-of-stock situations within a very short time. This in turn leads to a decreasing customer satisfaction and the loss of potential sales [71].

Analysis characteristics: Caused by the already mentioned variations of the sales figures it is necessary to recognize anomalies as fast as possible. Therefore, high requirements regarding the urgency of the analysis are formulated in this case. The analysis of the information is mostly based on recurring standard reports. The complexity of the evaluation as well as the complexity of the underlying data in this case study is typically low. To detect the anomalies it is sufficient to evaluate the current inventory information which is typically stored in transactional systems.

Economic characteristics: Due to the high range of fluctuations in sales figures, the fast detection of corresponding anomalies and the avoidance of out-of-stock situations leads to a better customer satisfaction and a economic benefit. At this point, the question arises which measures can be taken to minimize the fluctuations. In the work of Piller and Hagedorn [29], only non-price measures are proposed to reduce sales fluctuation. In this case, there are no legal or technical obstacles to the realization of the measures. As shown in Figure 4, not only the improved data availability and faster data processing play a role to generate business value, but also the downstream decision and implementation processes. In the example, "Analysis of Sales and Inventory Data," this issue represents the main weakness. Even with multiple daily supplies, deliveries may take several hours. This long implementation latency diminishes the advantages of an accelerated data and analysis processing.

Evaluation of the case study: Evaluating the presented characteristics, it becomes clear that in overall the data requirements are on a high level. This is caused in particular by the high data volume and high frequency of data changes. The analyses requirements can be summarized as low up to medium. Although the results need to be quickly processed they include only transactional tasks, the analysis are predictable and not particularly complex. From a technical perspective the use of an IMIS System is not essential. In combination with the economic limitations, traditional enterprise resource planing system are still able to monitor and control of stock levels.

2) Case study "Spatial Analytics in Soccer": As already mentioned in Section II-B the analysis of soccer was one of the first IMIS application scenarios and one of the most popular showcases. In this case, video and sensor data from soccer matches are evaluated and recommendations are given to the coaches. With the help of the evaluation model presented in this work, the potential for the use of spatial analysis in soccer should be assessed.

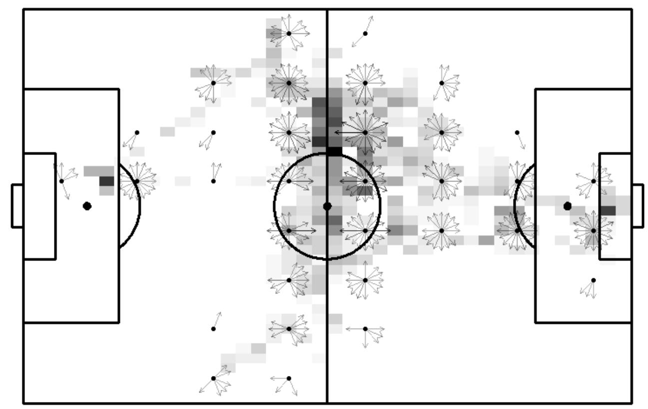

Figure 6. Example of a spatial analysis in soccer

Data characteristics: The processing of spatial data places very high demands on IT systems. In the case of spatial analysis in soccer this involves very large amounts of data with a complex structure [72]. The constant movement of the players on the field leads to a high frequency of data changes. A sample spatial analysis in soccer is visualized in a movement heatmap diagram in Figure 6. This example illustrates well the high demands on the data processing.

Analysis characteristics: The fixed time horizon of a soccer game demands, that the results of the analysis have to be provided within at least 90 minutes. Furthermore, the continuous changes in a game lead to a very fast decrease of the competitive advantage of the information. Most added value is therefore achieved by the provisioning in real-time. Another challenge is the processing of video recordings in conjunction with pattern recognition. This requires the use of advanced algorithms. The demanded degree of detail varies between individual and team analysis. All these points highlight the high requirements regarding the analysis capabilities.

Economic characteristics: From an economic point of view, competitive advantages through better and faster information promise a tremendous added value. The implementation of this case has shown that the required technical capabilities are available. It can be assumed that the players are able to realize the suggestions from the IT system. So far there are no limitations which interfere the use of spatial analysis in soccer. The limiting factors in this scenario are the legal reglementations. An extraction from the FIFA Statutes shows that such aids are not allowed during a soccer match: "information and data transmitted from the devices/systems is not permitted to be received or used in the technical area during the match" cited from [73]. The technical area depicts a designated space on the soccer field restricted to the technical staff, coaches and substitute players. This restriction severely limits the potential added value. As a result, the analysis can only be used for the post-processing and the preparation of games.

Evaluation of the case study: The evaluation of the attributes from a technical point of view implies the suitability of an IMIS. The data as well as the analysis characteristics require a sophisticated IT system. Due to the permanent recording of the spatial information, very large amounts of data accumulate. Conventional information systems can not complete these tasks in sufficient time. The benefit of the presented framework becomes especially clear when the economic factors are considered. Basically, a faster and more flexible processing would lead to a high economic benefit. The major benefit in this use case is limited through legal reglementations. These reglementations result in an forced implementation latency of several hours. Within this time horizon also conventional IT systems are able to perform the calculations. An IMIS system is therefore not mandatory.

3) Case study "Management of Renewable Energy": The energy revolution and the closely related use of renewable energy resources is one of the greatest challenges facing states, companies and individuals today. The scenario to be analyzed comprise a holistic "energy cycle" - from the generation to the transmission up to the consumer. The concept of a connected intelligent energy network is often called 'smart grid'. The efficient execution of this holistic energy process requires the consideration of numerous factors such as the weather, the energy grid utilization or the current consumption. The process characteristics are described below analogously to the previous examples:

Data characteristics: In the energy sector very large amounts of data accrue every day. These data is generated e.g., by smart meter devices, weather stations or the continous application of sensors. This variety of data sources leads to an increasing of the data complexity. The data processing increasingly requires the consideration of complex data structures [74]. Another challenging characteristic is the high data dynamic. The amount of the produced energy, the energy demand, etc. are frequently changing. In addition to the high frequency of changes the impact of data changes is substantial. All in all the demands placed on data processing can be assessed as high in the examined criteria.

Analysis characteristics: The efficient control of measures requires, that the analysis results have to be available in real-time. In this use case, current data from a variety of source systems must be taken into account. Analogous to the previous case this results in an interaction of transactional and analytical tasks. An important part of the management of renewable energy is the prediction of the produced energy. Thereby complex procedures are used, considering for example weather conditions [75]. Similar to the data requirements there are high analysis requirements.

Economic characteristics: As already described in the introduction of this use case, this scenario offers comprehensive possibilities for improvements. The potential added value comprises beside monetary savings also positive ecological aspects. Through the use of smart meter devices, controllable energy networks and improved weather forecasts the technical requirements for smart grids are already in place. The only weak point in the economic evaluation of this scenario is the inconsistent user acceptance. Studies in this field have revealed a differing acceptance to adopt to this technology [76].

Evaluation of the case study: The technical requirements in this case are very high in all areas. The large data volume, the data volatility, recently changing data, the need for quick responses and the combination of analytical and transactional tasks are strong indicators for the suitability of an IMIS. The economic analysis of this example also shows a high added value through faster data processing. Furthermore, the realization conditions indicates no basic obstacles. The model therefore indicates the suitability of the In-memory technology in all examined categories.

VII. CONCLUSION

The aim of this work was to create a framework for analyzing and evaluating application scenarios in the context of IMIS. As current research as well as statements from industry experts show, such a framework was missing. To cover all relevant factors for the application of an IMIS, not only theoretical work was included in this work. Through the inclusion of corporate experts, also practical aspects have been considered. Based on the first case studies in this area and scientific work, a large part of the influencing factors could be identified. Results show that the influence factors found through literature review and expert study could be divided into three main categories: analysis factors, data-driven factors and economic factors. Based on the expert survey, it was also possible to confirm the factors from the literature and to uncover other previously unconsidered factors. In order to take account of all aspects relevant to the companies, the model was expanded by features with regard to the profitability and the feasibility of possible fields of application. These include, for instance, the implementation conditions, legal obstacles or the acceptance of target groups. The capabilities of the framework were emphasized through the presented cross-industry use cases. It became clear that the evaluation of possible IMIS application scenarios requires a holistic view of all aspects. The presented model can be used as an additional assessment instrument for corporate decision makers.

In a next step, it will be necessary to evaluate the suitability of the framework based on quantitative investigations in different industry sectors. The use cases presented in this work indicate a relevance variation in terms of the assessment of the influence factors. It is supposed that the relevance of the influcence factors varies between branches and companies. Another question not considered in this work is the implicit and explicit nature of the influence factors in terms of value creation. Some factors like urgency have a very direct explicit impact on the value creation whereas other factors such as data complexity or data volume have a more indirect and implicit impact. Consequently, this fact should be taken into account in future work.

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