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Limits or Integration? – Manufacturing Execution Systems and Operational Business Intelligence

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ABSTRACT

Manufacturing Execution Systems (MES) and Operational Business Intelligence (OpBI) analyze and control operational activities in different organizational application fields. This raises the question how far these concepts are interrelated in context of company-wide process coordination and analysis. The goal of this paper is the evaluation and conceptual classification of MES and OpBI to base subsequent research actions. A literature review is conducted to recognize if a relationship of the concepts is taken into account in academics and to look for research gaps. Therefore, a representative number of articles have been extracted from selected scientific databases. The review results in four publications illuminating only single correlation aspects. This leads to the conclusion that further research in context of MES and OpBI is needed.

Keywords

Manufacturing Execution System, Operational Business Intelligence, Literature Review, Process analysis.

INTRODUCTION

The design of business processes is a determining competitive factor. Increased informal networks not only influence the processes within an organization, but changes also relationships to customers and suppliers. Therefore, companies have to keep their business processes flexible, which requires a consistently optimization. The range of conformable concepts allowing efficient support is large and manifold. But recently, Manufacturing Execution Systems (MES) and Operational Business Intelligence (OpBI) came into the discussion since they are a promising support of process flexibility. However, such aforementioned concepts come from different perspective – the engineering and the decision support point of view. This raises the discussion whether the concepts are equal or have at least such similarities so that a combined approach seems to be more promising. Therefore, the paper's goal is to analyze the concepts of MES and OpBI to show overlapping or differences as basis for a conjoint process oriented and flexible decision support oriented infrastructure.

Decision making in real-time has provoked business-oriented concepts like Operational Business Intelligence (OpBI) (Felden et al., 2010). OpBI is an integrative approach for information delivery using traditional BI-techniques like e.g. Data Warehousing or Online Analytical Processing (OLAP) to organize and improve business processes (Cunningham, 2005; Eckerson, 2007; Marjanovic, 2007). Popular application fields are sales and marketing (Eckerson, 2007). An engineering driven concept is used for IT-support of control and analysis activities especially in production environments. Manufacturing Execution Systems (MES) coordinate operational activities across the whole production lifecycle to enhance the performance and quality of plants or processes based on generated information for real-time decisions (MESA, 1997a). Both, OpBI and MES are integrative approaches to facilitate operational control and analysis of processes in real-time, but they are used in different organizational fields. The investigation of reasons for boundary of the concepts on domain-specific conditions gives implications how far company-wide process control is supportable by OpBI and MES. Therefore, the paper contributes a state-of-the-art giving a literature based classification of OpBI and MES, which is important in academic research to avoid duplication and to consider relevant findings.

Section 2 sheds light on reasons for the domain-specific application of MES and OpBI. Hence, academic literature is analyzed regarding to the interrelation of the concepts. While MES is defined by several associations as MESA or ISA (MESA, 1997a; ISA, 2000), the perception of OpBI is fuzzy due to related terms like e.g. Real-time BI or Active Data Warehousing (Eckerson, 2007). Therefore, the literature review is not fixed on OpBI. General BI-related terms are also considered to ensure profundity. The underlying method to build this state-of-the-art is explained in Section 3 and the results of its application are presented in Section 4. Finally, the paper is summarized to give conclusions and further research perspectives.

STATUS QUO OF OPERATIONAL BUSINESS INTELLIGENCE AND MANUFACTURING EXECUTION SYSTEMS

The scope of OpBI and MES is the analysis of processes to recognize weak points, malfunctions or business interruptions. Organizations are able to improve their management of business processes continuously and to generate interdisciplinary process information. The section shows the extension of traditional BI to OpBI and explains thereafter the concept of MES. Finally, the analysis of the concepts results in a classification within the organizational structure of an enterprise.

Traditional BI-systems are focusing on management decisions (Sahai and Ranjan, 2008). The support reaches from operational planning level up to top management nowadays. It is a bottom-up approach in the organization. Relevant data are collected from the external sources or from internal operational systems (Gangadharan and Swamy, 2004). From these sources, the data are extracted, loaded and transformed (ETL-process) into the data warehouse (Berson et al., 2002). This is a persistent database decoupled from operational systems to support reporting and analysis activities within the whole organization (Kimball and Ross, 2002). The systematically gathered data are used so that the management is able to make suitable decisions. Techniques like online analytical processing (OLAP) or data mining characterize the analysis of the data (Gluchowski et al., 2008; Han and Kamber, 2001). The following table comprises the functions of BI:

Function	Description
Business relevant information	BI concentrates on business-relevant information. This is a balancing act, because it is complex to find a compromise between incomplete information and unnecessary memory usage.
Data collection	Operational data are collected from external and internal sources. This leads to the task of connecting the data sources with a centralized data store. Access rights and security aspects are to be considered.
Data preparation	Data preparation generates usable information from raw data. To accomplish this, the data has to be interrelated, expertise has to be implemented and mathematical procedures have to be applied.
Decision support	BI is designed to improve decision fundamentals by providing adequate information. It is important to focus on information certainly influencing the decision, to avoid unnecessary expenses.
Information representation	Information is to be presented, so that users are able to manage their organizational tasks. Therefore it is essential to understand the user's business model for offering adequate information.

Table 1. Functions of BI (Schrödl, 2006)

Corporate Performance Management (CPM) enhances the concept of BI considering the organization as closed-loop system, where strategic, tactical, and operational management is interrelated (Golfarelli et al., 2004; Melchert et al., 2004). This implicates the trend to Real-time Analytics next to Business Process Automation and Process Performance Management (Melchert et al., 2004). In context of real-time the spread between the occurrence of an event and the execution of the subsequent decision is important. The so called action time involves three kinds of delay: data latency, analysis latency, and decision latency (Hackathorn, 2004). Latency and real-time characterizes OpBI (White, 2006). This development of BI has the same functions as traditional systems, but the focus is on analysis and control of business processes (Cunningham, 2005). Data consolidation can be realized by the Operational Data Store (ODS) (White, 2006). The ODS has to manage the trade-off between performance and flexibility by an integration of operational applications with a data warehouse (Inmon, 2005). The knowledge of operational process execution is linked to the management supporting BI-system. In result, OpBI is advantageous in process analysis in real-time by dint of mature techniques of traditional BI-systems and integration of operational key figures in tactical or strategic decision making for instance in context of process design (Felden et al., 2010). Examples of application are analysis of customer behavior to avoid migration or fraud detection. This suggests the business context of OpBI. While sale, finance, marketing, or service is mainly supported, the concept is moderately driven within the field of manufacturing (Eckerson, 2007). A related term to OpBI and ODS is Operational Data Warehousing (ODW) intending to enhance data models and interfaces of prevalent data warehouse architectures to facilitate interoperability to operational systems (Russom, 2010). The application fields are similar to them of OpBI. ODW is often used in financial application or Customer Relationship Management (CRM) and seldom applied in field of manufacturing (Russom, 2010).

A common approach to support the decision making on the shop-floor is the MES (Younus et al., 2010), which is placed between the layer of Enterprise Resource Planning (ERP) and the layer of process, controls and automation (ISA, 2000). It realizes vertical integration by enabling of task-oriented compaction, communication and access of data (Kletti, 2007). Between the layers, a bi-directional data stream is preceded. The ERP-system responsible for order and resource planning communicates desired quantities to the MES, which has to execute target-performance comparison permanently and reports the results back to ERP. The target-performance comparison is to be done over the full production cycle using real-time data (MESA, 1997a). So, operational performance is enhanced by reporting crucial information regarding to the production process. The MES-architecture consists of application layer, functional layer, and data interface layer (Fei, 2010). The data interface layer enables the access of MES-database on machines and plants to gather relevant data. The application layer presents the information generated out of a MES-database on several clients. Users are able to send requests and to get desired results. Therefore, MES functions have to be implemented considering that manufacturing environments are manifold depending on the complexity of the product and the underlying production process. To meet the different production conditions, MES are covering eleven functions (MESA, 1997b):

Function	**Description**
Data collection	All relevant data regarding to materials, operators, machines and processes of the company are gathered and organized in real-time. The data are used to figure out possible improvements.
Dispatching production units	Production units are managed with work orders and instructions assigned to dedicated parts of the shop-floor. To react on occurrences of the ongoing production adjustments have to be taken.
Document control	All relevant information regarding to products, processes and design have to be accessible to the employees. Also certification statements regarding work and other conditions are gathered.
Labor management	Labor management ensures that every shift is properly recorded and organized. This is done under the consideration of employees' qualifications, the structure of the work and the current business needs.
Maintenance management	Machines, plants and other operational assets have to be kept in the state of functionality. Failures and malfunctions must be repaired by documenting of problems and corrective actions.
Performance analysis	Performance analysis compares the achieved efficiency of the production environment with desired quantities of the business or ERP level. Process and quality parameter information is provided.
Process management	The monitoring of process activities provides information to operators about the production activities. The goal is to optimize the planning and provide a real time control over the actual production.
Product tracking and genealogy	A full product history for progressing of production units is to be created for single units, lots or batches. Process transparency over the whole product lifecycle can be achieved.
Quality management	Products and processes of manufacturing value creation are analyzed to avoid non-conformities. Abnormalities are identified and corrected. Information of laboratory studies is also incorporated.
Resource allocation	The state of production relevant resources is managed and monitored in real-time. Also detailed history information of the resources is provided in order to realize that the plant is properly equipped.
Scheduling	The planning of operational sequences in production proceeds under consideration of available resources and capacities. Overlapping operations are managed to minimize the setup time.

Table 2. Functions of MES according to MESA

MES and OpBI have comparable functions regarding to data management and analysis, while MES have a broader range of tasks. Figure 1 summarizes the present analysis in context of the organizational structure of an enterprise:

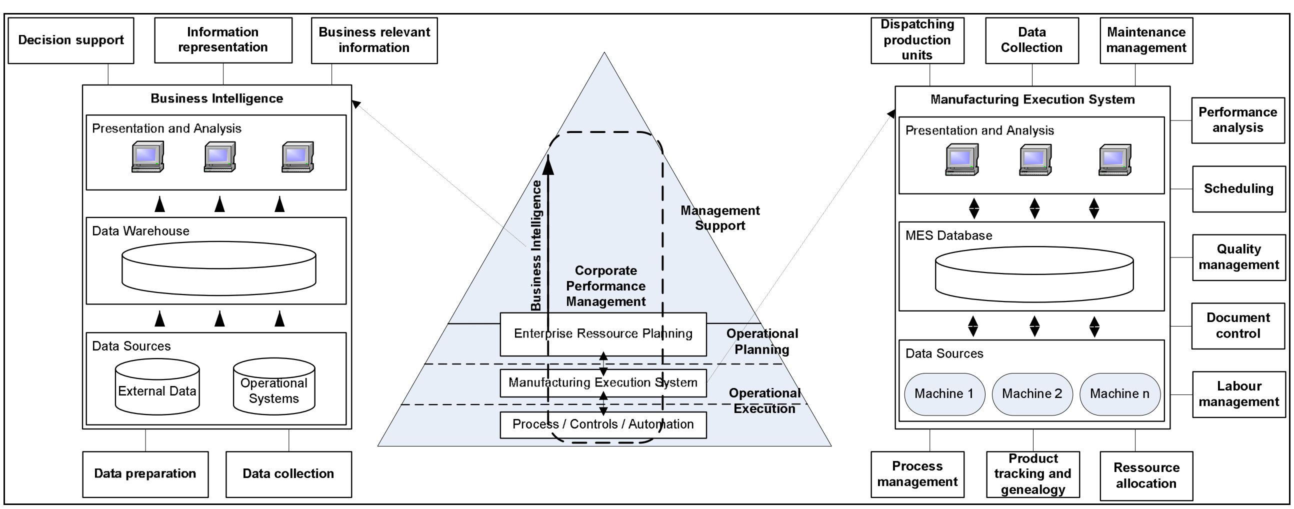

Figure 1. Classification of MES and BI within the organization

The functions of BI/OpBI and MES consider an integrated provision of data as well as purposive reporting and analysis. While a traditional BI-system delivers decision relevant information on management support level, the MES has a comparable intention in operational execution. If the MES gets more complex by including a high number of operational processes, the similarity to OpBI will grow. This is associated with a performance lost and limitation of decision-making in real-time, because an increasing complexity requires a higher degree on interfaces (Saenz de Ugarte et al., 2009). Furthermore, the limited analysis capabilities of the MES (Alpar and Louis, 2007) question the benefits of such a strategy. OpBI also forces the decision-making in real-time, has comprehensive analysis capabilities and facilitates company-wide process control. But as already mentioned in this section the concept is seldom applied in manufacturing. A possible reason is that the MES covers more functions than operational BI, because it is especially designed for production environments (Meyer et al., 2009). Hence, OpBI cannot compensate a MES and vice versa. From this it follows that the concepts are insulated applications, if they are not integrated.

The classification of the concepts shows, that there is a need for combined consideration. Thereby, the integration of OpBI and MES notably supports business processes management in the whole organization, because the implementation of performance indicators is enriched with information from process analysis. This leads to improvements of the business processes itself and allows an interdisciplinary synchronization. In addition to the benefits for process oriented decision support in organizations new market potential for IT vendors of BI and MES solutions is generated. Research is needed to base the achievement of these benefits on comprehensive investigations. Therefore, information is necessary how far the topic has been discussed in academics to date. The next section presents a literature research to give an overview about published works in these fields.

METHOD OF LITERATURE REVIEW

The literature review intents to describe, summarize, evaluate or integrate the findings of previous research based on primary investigations and can follow a process consisting of five phases (Fettke, 2006):

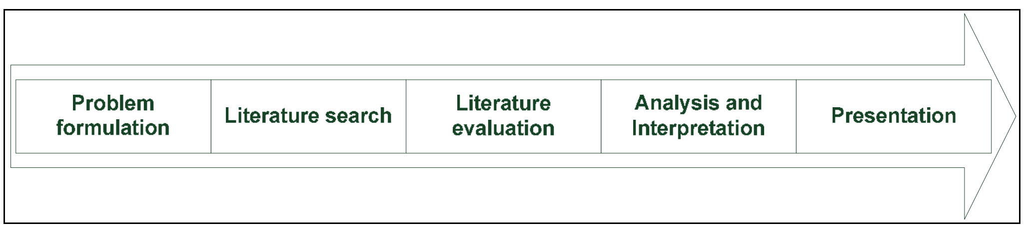

Figure 2. Phase-oriented process to realize a literature review

During the problem formulation, the question that has to be answered by the review gets formulated, delimited and further specified. The next phase of literature search makes suitable contributions to the given problem available. A pool of literature sources is defined, where the contributions are extracted. The third phase evaluates the located literature to examine the identified literature concerning its relevancy. Subsequently, the literature has to be processed and proper systemized. Analysis and interpretation of the literature take place thereafter. Within this phase, the findings of the literature evaluation will be explored and rated. This has to be done against the formulated problem. Finally, the research results have to be presented.

RESULTS

There are significant results from the various phases of the review process. Since the problem is explained in the introduction and refined in Section 2, the subsequent description focuses on a presentation of search, evaluation as well as analysis and interpretation of literature considering integration aspects of MES and BI.

Literature search

The scientific databases of Business Source Complete (BSC), IEEE Xplore, AIS electronic Library (AISeL), ACM Digital Library, Emerald and Science Direct (SD) are the basis of the literature search, because the they cover a wide range on scientific publications. To ensure comparability, there are some restrictions:

- Terms are entered full and in quotation marks.
- The appearance of the terms is limited to abstract, title or keywords of the article.
- The date of publication is not later than December 31, 2010.

Initially, the search is split in two categories: MES and BI-related terms. The first category includes only the term *Manufacturing Execution System* to distinguish it from previous concepts as e.g. *Computer Integrated Manufacturing (CIM)* or adjacent areas as *Manufacturing Resource Planning (MRP)*. This procedure ensures that the extracted contributions consider MES according to the definition in section two. To get representative number of articles for the BI-related category the following terms have been chosen: *Business Intelligence (BI)*, *Data Warehouse (DW)*, *Online Analytical Processing (OLAP)*, *Operational Business Intelligence (OpBI)*, *Operational Data Store (ODS)* and *Operational Data Warehouse (ODW)*. The search leads to a total number of articles as depicted on the following chart:

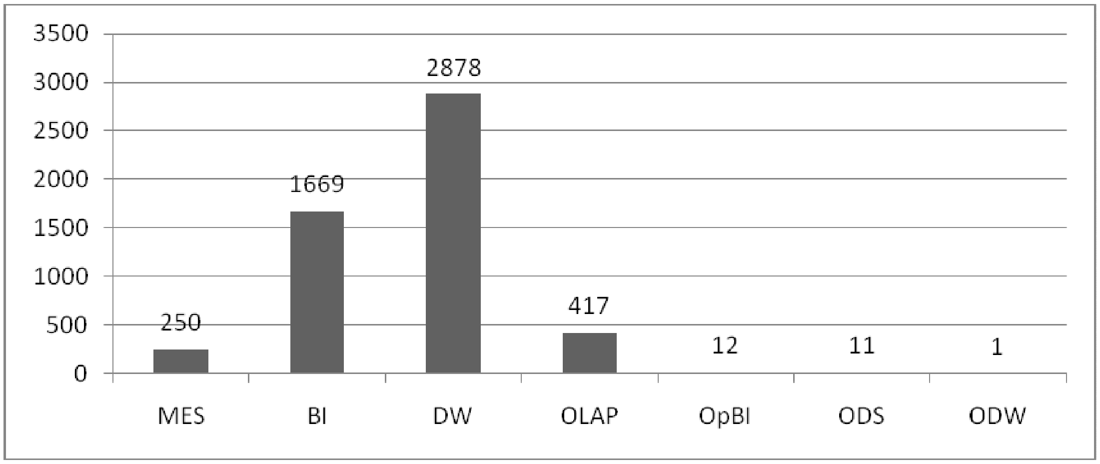

Figure 3. Total Number of Articles in all Databases

250 articles are dealing with MES. Substantial results are also reached for *BI, DW* and *OLAP*. Based on this intermediate result of literature search, the BI-related terms are combined with *MES*, while at least one has to be included in abstract, title or keyword of the particular article. The final result represents the following table, which includes duplicates. The highest compliance could be found upon the combination of the search items *MES* and *DW*. The search result reflects almost no relation in context of research activities regarding MES and OpBI. Since it is questionable whether intensification of searching changes this fact significantly, the review process continues by analyzing all of the extracted articles.

Database / Search Term	BSC	IEEE	AISeL	ACM	Emerald	SD	Total
MES + BI	0	0	4	0	0	1	**5**
MES + DW	0	3	4	0	0	0	**7**
MES + OLAP	0	2	2	0	0	0	**4**
MES + OpBI	0	0	1	0	0	0	**1**
MES + ODS	0	0	1	0	0	0	**1**
MES + ODW	0	0	0	0	0	0	**0**

Table 3. Evaluation of MES publications for their relevance in context of BI

Literature evaluation

The literature evaluation eliminates duplicates within the search results. After the elimination, seven articles remained. These were exactly the articles that could be found when searching MES in combination with DW. The following table shows the remaining articles and describes their key aspects. The remaining articles are examined whether the core of their attention is the integration of BI and MES after elimination of duplicates. This examination reveals that the articles Nr. 1, Nr. 5 and Nr. 7 are not longer relevant.

Nr.	Author, Year: Title	Key Aspects
1	Cheng and Lin, 2004: A Holonic Information Exchange System for e-Manufacturing	A proposal for information exchange between operational systems with different formats is presented. The role of so called holons (association of software agent and physical device) is investigated regarding to MES, ERP and Data Warehouse to facilitate the information exchange.
2	Chen and Wu, 2005: Data Warehouse Design for Manufacturing Execution Systems	A multi-dimensional data model and snowflake schema for a MES-related data warehouse is developed. Based on this OLAP-cubes are used to analyze production indices.
3	Chen et al., 2006: Design and Implementation of an Intelligent Manufacturing Execution System for Semiconductor Manufacturing Industry	The article discusses integration of MES, data warehouse, OLAP and data mining to build up an intelligent MES.
4	Koch et al., 2010: Manufacturing Execution Systems and Business Intelligence for Production Environments	The focus is on investigation of the relationship between ODS and MES. Based on qualitative and quantitative exploration an integration framework is derived.
5	Hollstein and Lasi , 2010: A Changeability Approach for Process Management and Decision Support on the Shop Floor	A concept for operational management to organize the production process according to restrictions of original equipment manufacturers is presented.
6	Louis and Olbrich, 2010: Architecture for analyzing manufacturing execution data - using Business Intelligence logic	Architecture to integrate MES data into the BI-Tool of an ERP system is described. The investigation is based on a case study, where a prototype is modelled for extraction of MES data in real-time.
7	Olbrich, 2010: Warehousing and Analyzing Streaming Data Quality Information	Problems of data quality influencing the decision support in case of distributed applications are investigated.

Table 4. Remaining articles after elimination of duplicates

Analysis and interpretation

The amount of published research in field of MES has been increased over the last period of 18 years (see Figure 4). Referring to BI the huge amount of scientific publications is emphasized, too (e.g. Jourdan et al., 2008).

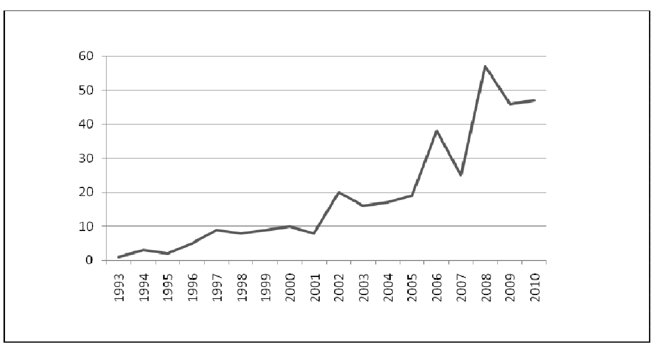

Figure 4. Publications in field of MES

Four of the evaluated articles address integration aspects of MES and BI. The term Business Intelligence is used in two publications (Nr. 4 and Nr. 6 of table 4). Koch et al. (2010) explore how the concepts of BI and MES are integrated in a practical context. Therefore, they present two case studies, where the connection of MES, ERP and BI is investigated in automotive and chemical industries. In addition, a survey is conducted to identify the benefits of MES for organizational-wide reporting with BI. An integration framework is derived based on the case study and the survey results, where the ODS is the interface between operational systems and the BI-solution. This framework considers a lot of operational systems, which ensures organizational-wide integration. Certain information regarding to technical implementation are missing. Louis and Olbrich (2010) focus on architecture requirements to separate the MES analysis function form operational execution level. Therefore, they carry out a case study to implement a prototype, where the shop floor data are integrated into the ERP-related BI-system. For implementation technical configuration aspects for data extraction is given. Unfortunately, the prototype requires the availability of a BI-supported ERP-System. Other operational systems are not explicated. Worthy of criticism is also the decoupling of the analysis function from MES, because this limits the versatility of the concept and the standardization efforts.

The other two contributions consider data warehousing and OLAP (Nr. 2 and Nr. 3 of table 4). This is consistent to the narrow understanding of BI, because these are central components for integrated management and preparation of data. Chen and Wu (2005) propose a multidimensional database for MES. They define categories for further queries and design snowflake schemas for these categories. An implementation environment is proposed and query pages are presented for the so called *MES-Data Warehouse*. Chen et al. (2006) aim to design, implement and operate an intelligent MES. This includes frameworks and procedures to integrate MES, data warehouse, decision-making analysis and data mining. Both contributions (Nr. 2 and Nr. 3 of table 4) neglect the organizational-wide context, because they do not consider other operational systems for e.g. ERP, supply chain or customer relations. The focus is on multidimensional analysis of MES data, which supports decision making on shop floor level, but not for the whole organization. Nevertheless, these findings show that there is a basis for an integration of BI and MES.

For statistical analysis, the four contributions, the content has just lit, are referred to the total number of articles for the single search terms of *MES, BI*, *DW* and *OLAP*. Due to the insufficient number of matches for *OpBI*, *ODS* and *ODW,* these terms are not considered. Table 5 demonstrates the state of investigation regarding the single and the whole research area. The percentage of articles considering MES and BI-related terms is marginal.

Single term	Total number of articles	Percentage of articles considering MES and BI-related terms
Manufacturing Execution System	250	1,60
Data Warehouse	2878	0,14
Business Intelligence	1669	0,24
Online Analytical Processing	417	0,96
Total	**5214**	
	mean	**0,31**
	std. dev.	**0,71**

Table 5. Statistical analysis

CONCLUSION

MES and OpBI are not equal. They deliver information regarding the process analysis in different application fields. The integration of MES and OpBI to realize a process oriented decision support in real-time is hardly investigated. The literature review covering a representative but not all-embracing pool of publications has made four articles available. The contributions consider multi-dimensional analysis of shop-floor data and the role of MES for company-wide decision making. These are single aspects of integration, while the benefits of interrelation between OpBI and MES are only strived in one publication. This fact can be caused by the different roots of the concepts. OpBI is economic-driven. The MES comes from an engineering perspective and the awareness level only recently increases in business. This explains the different application fields of the concepts. In academics, OpBI seem to be a novel topic, because of the manageable amount of matches in literature review. A reason is that the term is non-exhaustive defined, which is confirmed through availability of related terms e.g. Real-time BI or Active Data Warehousing.

The marginal state of research requires further investigation to provide new insights regarding to the analysis and control of business processes. The integration of OpBI and MES enables an enhanced process management, where processes are comprehensively coordinated and optimized. So, organizations are able to react fast and flexible on business occurrences increasing their competitiveness.

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