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ABSTRACT

In the domain of production, Manufacturing Execution Systems (MES) are becoming increasingly popular. State of the art MES not only bring interfaces to a large variety of shop floor systems, they also come with functionality for data integration, data analysis, and dashboard generation – features commonly associated with Business Intelligence (BI) systems. At the same time, Data Warehouse (DHW) based BI infrastructures are increasingly extended to the support of operational managerial levels (Operational BI). This contribution sheds light on whether or not BI systems and MES are at odds and in how far they are complementary. To achieve this, two subsequent studies have been conducted: a case study based exploration and a quantitative online survey. The study results motivate an integration framework for MES and BI systems.

Keywords

Operational Business Intelligence, Manufacturing Execution Systems, IT in production, decision support.

INTRODUCTION AND MOTIVATION

This contribution addresses a possible application of Business Intelligence solutions in the realm of manufacturing. The term *Business Intelligence* (BI) denotes integrated approaches to management support and is usually associated with *Data Warehouse Systems* (DWHs) that provide an integrated, subject-oriented and non-volatile repository for diverse analysis and reporting applications (e.g. for OLAP analysis, data mining, balanced scorecards etc.) (Moss and Atre 2005; Negash 2004; Baars and Kemper 2008).

BI infrastructures are increasingly extended towards the support of operational decisions. In the respective *Operational BI* scenarios, the DWH-based systems are used for data integration, data storage, data aggregation and report generation (Eckerson 2007; Marjanovic 2007). One possible application area for Operational BI is manufacturing and first examples for applying Operational BI systems in manufacturing environments can indeed be found.

However, it needs to be acknowledged that manufacturing is by no means new territory for IT support: There already is a variety of systems in use in this domain (Wigand, Mertens, Bodendorf, König, Picot and Schumann 2003). Not surprisingly so, giving the necessity to counter the global cost competition with constant and often IT-based product and process improvements (Meyer, Fuchs and Thiel 2009). With respect to this backdrop, *Manufacturing Execution Systems* (MES) are gaining more and more traction in shop floor environments. An MES promises to close the gap between the engineering oriented data acquisition on shop floor level and the economic support provided by Manufacturing Resource Planning (MRP II) or Enterprise Resource Planning (ERP). In theory, an MES merges machine and production data acquisition, staff work time logging, energy management and more, and thereby allows a centralized steering of those components (VDI 2007, MESA 1997). An MES can therefore be in parts seen as a combined data integration and process steering tool. Additionally, state of the art MES include reporting and (simple) analysis features, e.g. for monitoring machine capacities, set-up or lead times or for visualizing related performance indicators with dashboards (Kletti 2007). Because of compliance purposes, MES are often supplemented with integrated data repositories (McClellan 1997; Kletti 2007; Meyer et al. 2009).

As can be seen, an MES covers much of what is subsumed under "Operational BI", although coming more from an engineering angle. However, they still lack some features common in DWHs, most notably a more elaborate data historization and aggregation and advanced analysis functionality.

This raises questions relevant both for system and organizational design:

- Is there an actual need for analytical support in a shop floor environment based on MES data? If not, the core data acquisition and production steering functionality of an MES might very well be sufficient.
- In case there is a need for further reaching analysis functions: Are MES sufficient – or is it necessary to complement them with DWH-based systems?
- Are there complementary strengths of MES and "classical" BI systems that justify an integrated approach?

Coming from an Information Systems perspective, these questions can be condensed to an overarching research question: Is the current information supply for management decision support adequate and in how far do MES or Operational BI systems close relevant gaps in information support? This paper sheds light on this subject in order to motivate a framework for the integration of MES and BI functionality. With respect to the dearth of material on the subject of MES, two subsequent explorative studies have been conducted, the first with a qualitative and the second with a quantitative focus.

In the following sections, the concepts of Operational BI and MES are introduced more in depth and put into context. After a short description of the applied methodology, selected study results are introduced and discussed. The conclusions from the studies led to the derivation of a framework for the integration of MES into BI infrastructures. After a brief outline of the framework the paper concludes with a discussion of the limitations of the studies, a delineation of further research activities, and options to expand the scope of the research.

BI, MES AND RELATED CONCEPTS

The following section discusses relevant concepts in the BI and the MES domains and puts them into context.

Business Intelligence and Data Warehousing

At the core of most BI approaches stands the DWH as the hub for data support. Major contributors to the DWH concept are Inmon (Inmon 2005) and Kimball (Kimball and Ross 2002). The former stands for a strongly centralized, application-independent approach while the latter proposes a more decentralized data management that is bound together semantically by the use of shared dimensions ("dimensional bus"). In practice, pragmatic approaches can also be found where several application-independent DWHs are kept – that are nevertheless semantically compatible with respect to selected excerpts for integrated analysis.

Providing near time, transactional data is one of the most significant modifications of the classical DWH concept (Inmon 1999). To handle the different access profiles, reliability requirements, and update time-frames, dedicated components have been proposed which have become known as "Operational Data Stores" (ODS). An ODS brings together transactional data from multiple sources (Kelley and Moss 2007). ODS/DWH architectures allow to build *Closed-loop* and *Active Data Warehousing* solutions. In Closed-loop Data Warehousing, results from analytical processes are directly fed back into DWHs or operational systems (Brobst 2002). Active DWH systems automatically trigger actions based on defined data constellations. As the respective application scenarios frequently go along with the need for current data, "Active and Real Time Data Warehousing" are often used as a fixed phrase (Akbay 2006; Raden 2003). In Closed-loop and Active Data Warehousing, the DWH becomes a data source for the operational systems.

Active and Closed Loop Data Warehousing are also cornerstones for *Operational BI applications* that aim at binding operational and managerial systems together (Eckerson 2007; White 2006). A widespread application in Operational BI is *Business Activity Monitoring* (BAM). BAM is built upon the idea of providing software for the near-time monitoring of the status and the results of business processes (Golfarelli, Rizzi and Cella 2004; Melchert, 2004; Eckerson, 2006).

The relation of Operational BI to an integrated manufacturing support is salient. Production processes are supported by a plethora of independent, disparate systems (e.g. for scheduling, supervisory control and data acquisition, quality assurance, etc.) each providing relevant data that is needed for operational decision support. With respect to the tight competition and an increasing need for a flexible production, it becomes crucial to bring the different sources together in order to provide a *consistent and comprehensive* data support with an *adequate level of detail*. Only then can process *transparency* be gained. This has to be achieved under consideration of the *timeliness* of the data which is determined by the time span between data gathering and decision making, the *action time* (Hackathorn 2004). At the first glance, an ODS enhanced DWH might seem as the right system here as it is specifically designed for this type of information logistics task. However, a powerful alternative has grown that has its roots in classical engineering minded automation technologies – MES.

MES – Production Process Data

In order to understand the role of MES, it needs to put into the context of IT for the management of production processes. The respective systems are usually structured along three distinct layers (McClellan 1997; VDI 2007):

- the planning layer,
- the execution layer and
- the control layer.

Originally, the IT support in manufacturing was focused on the planning layer: Among the first manufacturing systems developed were *Material Requirements Planning* (MRP) tools which support planning and scheduling processes on the basis of demanded quantities and available resources. Later, *Manufacturing Resource Planning* systems (MRP II) broadened the scope of those systems with an integration of system modules for business units like finance or marketing. Currently, the production planning layer is included in an *Enterprise Resource Planning system* (ERP) that promises an integrated support for all sorts of operational processes of an enterprise. Usually, MRP-II- and ERP-based scheduling and capacity planning is conducted on a macroscopic level that is both long term and product oriented (McClellan 1997; Monk and Wagner 2007; Hossain, Patrick and Rashid 2002).

However, these systems neglect the execution and control layers. Relevant tasks include scheduling and planning on atomic level, real-time process control and active process control. MES attempt to address these layers in an integrated fashion. The origin of the MES lies in the data collection technologies of the early 1980s. Initially, production environments were characterized by unrelated data gathering components. With the rise of integrated concepts like Computer Integrated Manufacturing (CIM), individual tasks were no longer seen as independent but rather as relating to a process. This opened the view for benefits resulting from data exchange. Unfortunately, the CIM concept could not achieve acceptance. A variety of reasons for the failure of CIM has been identified, e.g. unsatisfactory standardization, disappointing applications, and a tendency to misuse of the term CIM for marketing purposes (Kletti 2007).

In the 1990th, the far reaching vision of CIM was replaced by integrated data collection systems that concentrated on defined functional scopes, e.g. production (esp. supervisory control and data acquisition technologies), personnel management (staff work time logging, access control, etc.) or quality control (CAQ etc.) (Kent 1998). Although this pragmatic approach was a step forward, it still fell short of achieving the degree of integration that was needed for a comprehensive process transparency. An MES promises to achieve exactly that by drawing from the semi-integrated functional systems. To avoid the destiny of CIM, standardization committees defined the content of MES, first in USA (ISA 2007) and later in Europe (VDI 2007).

Among the heterogeneous definitions for an MES some commonalities can be found: MES gather and deliver information on shop-floor level to enable a real-time optimization of production processes (ISA 2007; VDI 2007). Beyond that, some authors emphasize that the MES is concerned with the (partly real time) gathering of performance indicators and with mirroring those against predefined targets. The reach of an MES can also touch peripheral areas such as an ERP which might use or feed in data, so that all responsible participants on the value-creation process have all necessary event-based data accessible (Meyer et al. 2009). According to the prevalent opinion, an MES needs an own database solution as the ERP system cannot provide the highly detailed required by production management. This leads to a system that combines data integration, reporting, and data storage for operational decision support – not unlike an ODS.

METHODOLOGY

So far, there is hardly any material that discusses MES in a BI context and with the beginning of this study it was by no means clear whether or how the approaches might fit together. This led to the decision to tackle the subject in an explanatory fashion with a design aiming at hypothesis generation rather than hypothesis testing (Schwab 2005). The overall research process is illustrated in Figure 1.

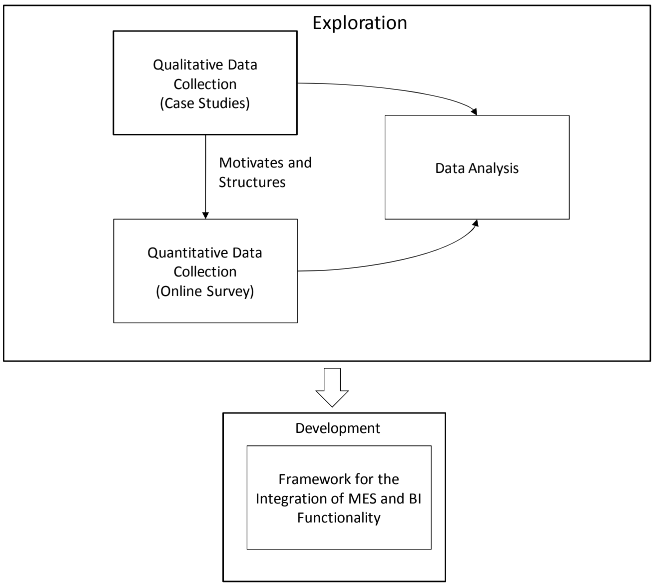

Figure 1. Course of the Exploration

The research was comprised of two steps: First, two case studies (Yin 2009) were conducted for rich insights into real-world production systems with MES support. The data gathering for the cases included on-site-visits, hands-on-system usage, and semi-structured expert interviews (1.5 and 3 hours). The gathered data has been transcribed and systematically evaluated.

The results motivated and structured the second step, a quantitative study in form of an online survey (carried out from September 2009 to January 2010). Among others, the survey addressed types and functions of MES and their relevance for production management. The sample was gathered in a social network of business professionals ("systematic sampling"). Because of the exploratory nature of the study, the results are primarily evaluated by the use of descriptive statistics and chi-square significance testing.

The results from both steps led to the development of the framework for the integration of MES into BI.

Regarding the contents of the study, the framework in Figure 2 was applied when drafting the interview guideline and survey structure. The central research question builds the core of this framework: The role and the relevance of an IT-based decision support. This is seen as the result of the *information supply* provided by the *IT systems* on the one hand as well as gaps in the information supply on the other. Further qualifications come from the relevant business environment and the characteristics of the supported production process. The results from both steps led to the development of the framework for the integration of MES into BI.

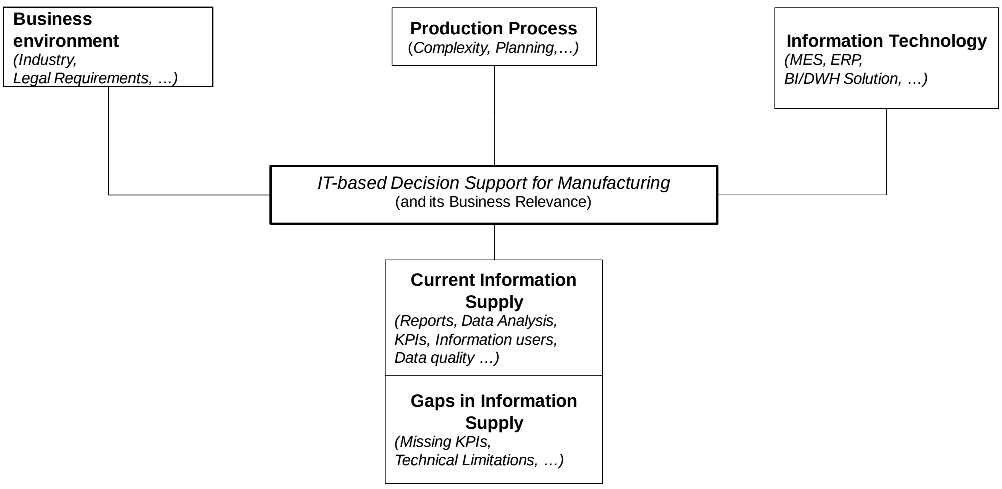

Figure 2. Conceptual Framework

QUALITATIVE EXPLORATION – RESULTS AND DISCUSSION

An overview on the case studies is given in Table 1. As can be seen, the two enterprises in discussion are from the plastics and chemistry and from the automotive sector (engine building) respectively. Regarding the business environment it is noteworthy that both companies had to comply with legal requirements regarding retraceability – which fostered MES data storage.

		Case Study 1	**Case Study 2**
Business environment	**Industry**	Plastics and chemistry	Automotive
	Legal requirements	Retraceability of process data, clean room (medical products)	Retraceability of process data and products
Production process	**Complexity**	Single stage process, high variety of products on one machine	Large number of variants, complex processes, highly flexible manufacturing systems
	Planning	Pull-based, delivery schedule, production to order	Pull-based, production to order
Information Technology	**MES**	MES used as clock counter, detailed scheduling (foreman), so far no analyzes	Bidirectional data flow to control layer (machinery, transport system etc.) Status of production process to ERP system
	ERP system	Production planning and scheduling, detailed scheduling (disposition)	Economic disposition on daily level, process oriented (all shop floors) Production planning and scheduling
	BI-/DWH-solution	Planned data flow MES and CAQ → ERP → BI/DWH	Isolated, plant specific data base for management support
Current information supply	**Reports**	Monthly (production KPIs)	Daily, weekly, monthly reports flexible analyses, break down analyses
	Information user	All related to manufacturing	Foreman, shift supervisor, plant manager, partially middle management
Gaps in information supply		No OEE-indicator, no daily reports No features for process analyses No business oriented analyses in MES	No package cycle analyses Insufficient integration with non-production related systems

Table 1. Case Studies

In the company from the plastics industry the overall complexity of the production system was rather low (single stage process), although the variety of products and the intricate interplay of variable parameters require a deep understanding of the production process. The requirement of providing a suitable information supply is currently only rudimentary met by the MES – which is primarily applied as a clock counter and for purposes of status visualization. The interviewee articulated a clear demand for further reporting and analysis features, being particularly unsatisfied with the flexibility, the timeliness, and the granularity of production data. The current monthly reporting does especially not deliver relevant indicators like the Overall Equipment Effectiveness (OEE) and there is no possibility to trace back root causes or impacts of problems. Also an option to connect technical to business indicators was perceived to be missing. Currently, the respective data can be fed into the company DWH only via an intermediary ERP system. Despite of its shortcomings, the MES is nevertheless seen as a major step forward as it for the first time brought the possibility to get a real-time overview of the current production status.

The issues are concisely summarized in the following statement (translated): "*The current situation, in which the MES data is transmitted to the ERP system [instead of directly inserting it to the DWH] feels like transcribing a phone book.*"

The automotive company provided a stark contrast to this situation. Here, the MES was *by design* tailored to support continuous improvements. This was also an answer to the complex production process that was geared at churning out a high number of variations and flexible reconfigurations. Indeed, the MES was implemented as an integral part of the overall engine plant design. The number of attached and controlled systems was numerous: Machinery, conveyor belts, autonomous transport vehicles, lighting and heating, work time logging, access control, quality management etc. The interviewee emphasized that this type of near-time data integration and immediate process control makes the MES indispensible and cannot be taken over easily by any other system including an ERP system. The integrated data was also used for rule-based event processing, e.g. by automatically informing relevant decision makers in case one of the autonomous transport vehicles got stuck. Moreover, the data was kept in an integrated repository for ad-hoc analysis and reporting. This add-on data base was in fact used like a DWH for production.

However, despite the far reaching support, there were still gaps in the information supply. First, the view was limited horizontally to the supported plant. There was no way to get an equally comprehensive decision support with respect to the whole process chain, e.g. for the management of reusable packaging or for informing the assembly plant of a possible propagation of a material flow disruption originating in the engine production. Second, the data was strictly technically oriented with no option to come to conclusions on the business impact of technical decisions, e.g. for relating material flow decisions to the overall production planning or to evaluate the cost consequences of production flow decisions. The interviewee was skeptical if this type of usage can ever be conducted with an MES that is by design not built for handling business data.

The cases indicate that an MES needs to be seen as the preferred choice for data integration and process steering in a manufacturing environment – and that a DWH-based system can by no means replace the MES with its battery of highly specific interfaces. There are also good reasons to provide means for data collection, data aggregation and flexible analysis as the first case shows in a negative and the second in a positive way. The reach of an MES seems to be limited, though, both horizontally and vertically.

The second step of the exploration took a wider look at this. It specifically looked at MES function use and the satisfaction with the functionality, the impact of an MES on the quality of the information supply, the achieved process transparency as well as on the possible business relevance of those benefits.

QUANTIATIVE EXPLORATION – RESULTS AND DISCUSSION

In the online survey, a total of 1790 experts of controlling, production, logistics and IT of all industries were contacted, 560 of which stated the survey and 302 completed the survey to the last page. This represents a response rate of 31%. Figure 3 gives an overview on the industries as selected by the respondents who answered this question.

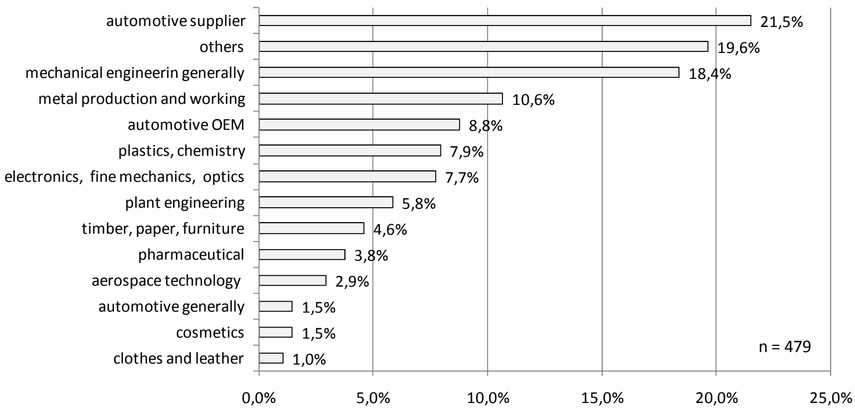

Figure 3. Industry of Participants

96 of the survey participants stated to apply an MES[1] – usually in addition to established systems for production support ERP or PPS systems. The results justify treating MES as a separate system class that at its core brings data gathering and integration features: When asked for the concrete functions included in their MES product, about three quarters of the respondents named product or machine data acquisition. However, with respect to its role as a data analysis tool the results deviate from the literature: Only 36 (58%) checked out that "analysis functionality" (cf. Figure 4). These results lead to the conclusion that many MES are by no means full-fledged management support tools.

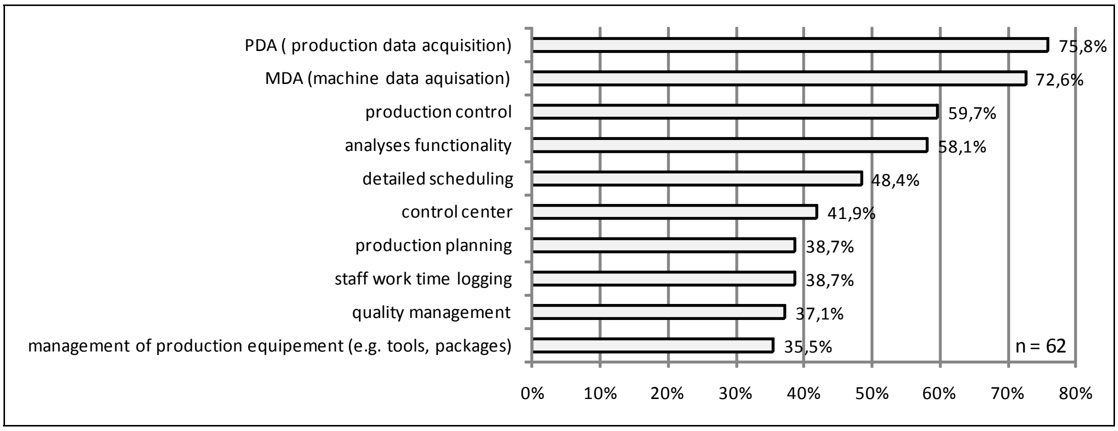

Figure 4. MES Functions

Interesting are the results on the actual usage of data analysis by those 36 respondents (Figure 5): Although the analysis of production data is rather the rule than the exception, a majority of the users either circumvents or complements available MES features (mostly by the use of spreadsheet or ERP software). Obviously an MES is not perceived as a sufficient analysis tool.

The data also sheds some light on possible benefits of an MES: 62% of the participants claimed to have achieved a higher process transparency, 39% observed a more consistent data, and 39% perceived an enhanced information supply. Although these benefits are admittedly highly interdependent, the data still indicates that the data capturing and integration is perceived to be valuable.

These immediate effects also lead to higher performance with respect to business indicators: Better asset utilization was stated to be higher after the MES introduction in 42% of the questionnaires, a reduction of lead times in 41% and an increase in product quality in 40%. The immediate and the business benefits correlate: Significant are the Chi-Square-Values between the consistent data base and the reduction of lead times (p=0,015), the consistent data and asset utilization (p=0,07) as well as between increased transparence and product quality (p=0,088). It will be left to hypothesis-testing oriented studies to confirm or reject the preliminary conclusions that arise from these results.

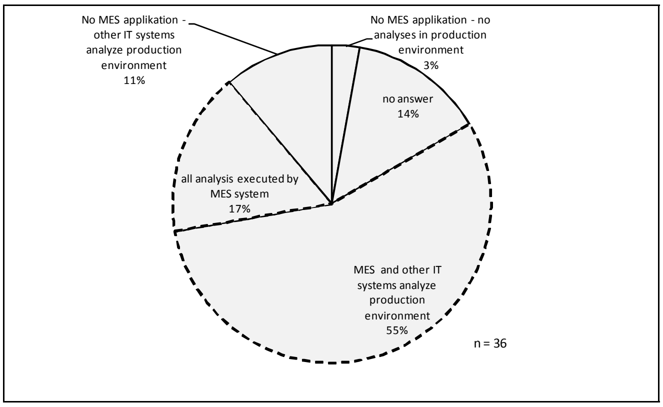

Figure 5. Data Analysis and MES

[1] This includes participants who did not answer all questions, leading to a varying N.

CONCLUSIONS – A FRAMEWORK FOR A COMBINED APPLICATION OF MES AND DWH

The results of both studies indicate that MES indeed has a relevant impact on production performance and that it is used for tasks that would usually be attributed to Operational BI – data integration, event processing, and a subsequent data storage and analysis. At the same time, the MES can obviously not fully fill the role of a classical BI infrastructure. In the next step this leads to the derivation of an IT-framework that can only be shortly outlined here. Within the framework, two layers are considered: the *shop floor layer* and the *business layer*.

Shop floor layer

The survey illustrates that the functionality of the MES that are used in practice are aligned to users on operational and tactical levels (machine operators, foremen, plant management) – data acquisition and production control functions dominate. This is the bases for a time-critical decision support based on machine statuses with performance indicators usually relating to time and quantity dimensions. The decision support on shop floor level therefore depends on production wide real-time data on ongoing processes. The splash of predefined machine interfaces and machine control programs an MES needs to bring can be seen in the automotive case. Furthermore it has to be acknowledged that, depending on the number of production machines, a huge amount of process events permanently has to be captured and analyzed. Those requirements match to actual MES. It is a fallacy to assume that an all-purpose Operational BI based on a DWH/ODS could easily replace such a system. It needs to be pointed out though, that the MES on shop floor layer might be complemented with a local data repository for production specific analysis and reporting (e.g. regarding tool abrasion over time, material flow efficiency).

Business layer

The IT support on the second layer, however, aims at increasing business performance by integrating *complete processes* as well as by enriching technical indicators with economically data. The first point adheres to business wide process data integration. The requirements thereby differ from those on the shop floor analysis layer:

- The data usually only needs to be “right time” and not “real time” in a narrower sense.
- The data has to be aggregated and enriched with economic indicators.

For those purposes, an ODS that feeds events and indicators back to the shop floor level in a closed-loop approach seems to be the right choice. Eventually, there are valid reasons to further propagate the seemingly technical machine and production data to a DWH where it can be used for combined analyses (e.g. to analyze the effects of production related choices on the customer and financial side). This makes it necessary to define conformed dimensions (e.g. based on product and machine master data) between the different systems.

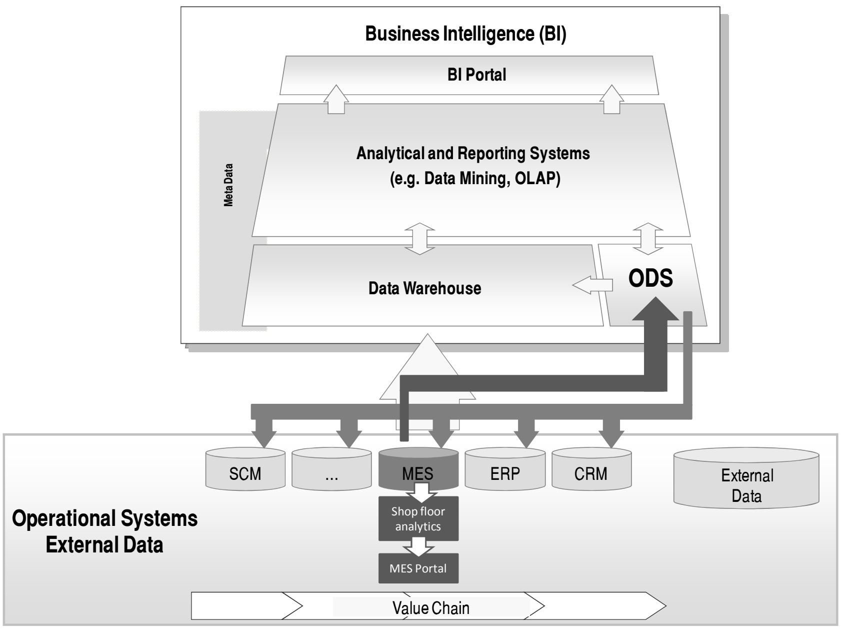

Figure 6. Framework for the Integration of BI and MES

DISCUSSION AND OUTLOOK

As the results of both studies indicate, MES are indeed conceived to be part of a decision support infrastructure – albeit limited to the immediate plant environment they were originally conceived for. They enable a consistent provision of decision data that is relevant for reporting and analysis features. An MES very much takes over the role of "an ODS for manufacturing". By either built-in features for data storage and analysis or adding a separate data repository (as in the automotive case), the MES turns into a DWH for manufacturing.

But just as a classical DWH-based Operational BI system is by no means a replacement for an MES with its variety of interfaces and dedicated features for production steering, an MES is not designed for a comprehensive managerial support in the context of manufacturing. This has immediate practical implications: In order to fully utilize the business potential of the data gathered with an MES, both organizational and technical integration measures are necessary. The derived framework takes these results into account by adding a process-spanning ODS and DWH layers on top of the MES. The compatibility of the systems needs to be ensured by complementary organizational measures that balance a division of local responsibilities for the MES and a central BI competency center.

Due to the explanatory nature of the study and the selection of questionnaire participants, the presented results are by no means to be taken as final evidence but rather as the motivation for an initial structuring of the field. This especially applies to possible causal relationships between system features and benefits.

The study nevertheless opens an array of research questions, with the concrete role of near-time data integration from areas beyond manufacturing being of particular relevance. Also, the conclusions need further validation and detailing, e.g. for pinpointing the business potential on higher management levels. Eventually, the derived framework needs to be translated into a concrete design based on a design oriented approach.

Regardless of all the open questions, the results clearly underline the relevance of the subject. The integration of MES into BI not only opens the door to a new field of BI applications but also shows a new path towards melding technical and business oriented systems.

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