# Chapter 2
# An Integrated Business Intelligence Framework

## Closing the Gap Between IT Support for Management and for Production

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**Abstract** Information Technology (IT) support in the manufacturing sector has reached a watershed with digital components beginning to permeate all products and processes. The classical divide between "technical" IT and "business" IT begins to blend more and more. Data from design, manufacturing, product use, service, and support is made available across the complete product lifecycle and supply chain. This goes hand in hand with the diffusion of sensor and identification technology and the availability of relevant information streams on the customer side—leading to unprecedented amounts of data. The challenge is to purposefully apply emerging BI concepts for a comprehensive decision support that integrates product and shop floor design phases, the steering and design of operational industrial processes, as well as big and unstructured data sources. This chapter brings those pieces together in order to derive an integrated framework for management and decision support in the manufacturing sector.

## 2.1 A New Role for Business Intelligence in the Manufacturing Sector

Globalization, scarcity of natural resources, complexity, and the powerful rise of the BRICS economies are the biggest challenges for the leading industrialized countries. For these nations, the major tasks for the next 20 years will be securing versatile production capabilities, resource efficient engineering environments, and a consequent time-to-market delivery of highly sophisticated industrial products [1].

In order to cope with these challenges, engineers are concentrating their research activities on complex concepts like the "Digital Factory" or "Intelligent Production Systems" as well as on introducing a variety of systems for steering and controlling their specific, production oriented operational processes. The main objective of these measures is to fully digitalize and integrate all processes of the product lifecycle and across supply chains [1]. In these contexts, large volumes of data are

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generated and stored within the IT infrastructures that support engineering, production, and logistics. The integration of this technical-oriented data with management support information, however, is still unsatisfactory. An integrated strategic, administrative, and operational control and a comprehensive managerial decision support still promises relevant untapped business potential. This article focuses on this topic. It extends and adapts the BI framework by [28] that has been introduced in Chap. 1 and derives an integrated framework for closing the gap between management- and production-oriented IT support.

## 2.2 Reshaping the BI Toolset

The more comprehensive the BI-based decision support becomes and the closer it is linked to the actual (and in the realm of manufacturing: *physical*) business processes, the more questions arise regarding requirements for an augmentation of classical BI-systems. Required are pertinent components and concepts for defining the interplay between the evolving BI landscape and existing operational application systems. Additionally, striving for a detailed understanding of processes leads not only to an ever increasing volume of data of both structured and unstructured nature but also to volatile use profiles and workloads.

In the following, existing concepts dealing with these developments are introduced. These are later contrasted with available systems for the support of the product lifecycle in the manufacturing sector.

### *2.2.1 Operational BI and BI and Business Process Management*

The diffusion of BI into operational and tactical management layers has been discussed under the label "Operational BI" (OpBI) [17, 38]. The term OpBI is problematic because it does not clearly distinguish between the realm of BI and that of operational systems. In fact, some examples given by vendors appear to be rather manifestations of an insufficient operational support than of an innate need for new BI applications. If there already is a mature IT landscape in place—as in the manufacturing industry—the claim of a better operational decision support needs to be thoroughly substantiated [32]. This does not mean that OpBI is without merits. BI-technologies come into play when they can exert their strengths: Integrating large volumes of data from various sources, refining them for the purposes of decision support, and presenting the results in a comprehensive fashion.

This is also why OpBI is so closely related to the connection between business process management and BI—an area where the aspect of integration clearly comes into focus. There are various facets of this, which are covered in different, partly overlapping concepts [27].

A widespread example for viable OpBI is the area of Business Application Monitoring (BAM). In this case, data from various sources is combined in near-real-time to process-level key performance indicators (KPIs) and visualized via operational dashboards (e.g. on the status of open orders, delivery processes etc.). BAM applications are often embedded in broader concepts for Business Process and Business Performance Management, which aim at providing a consistent base of indicators across process steps and managerial levels [22, 42].

An approach that goes beyond the mere presentation of refined data is "Process-centric BI". Here, next to data, analytic *functionality* is embedded into operational systems in order to enable operational staff to conduct analysis on operational data [11]. The term "Embedded BI" goes even further. It denotes the application of BI functionality to process data from local repositories [30]. In this case, however, the specific contribution of a BI system is not obvious.

While the discussed OpBI concepts are directed towards an inclusion into running processes, *Business Process Intelligence* (BPI) has a more strategic momentum. BPI is concerned with the analysis of data on process instances for purposes of uncovering and optimizing the underlying process structures and models [16, 23, 38]. An example for a BPI application is process mining where operational log files are used for the extraction, enrichment, and evaluation of as-is-process-structures [44]. Another option for BPI is tailoring existing BI analysis tools (OLAP, reporting) [9, 14]. This, however, makes it necessary to extract, store, and handle data on the *process logic* rather than just on the *process results*, i.e. the order of activities and the related constrains need to be traceable. The concepts developed for this include the introduction of a respective "Process DWH" that is designed for such an analysis [47, 50]. Examples for relevant sources of process data in the realm of manufacturing are the Manufacturing Execution Systems (MES) or systems which allow an automatic tracing of objects, e.g. based on RFID technology (cf. Sect. 2.3).

### *2.2.2 Big Data, Cloud BI, and In-Memory BI*

Collecting relevant data for the in-depth analysis of processes and activities on the operational layer leads to data repositories with sizes beyond those of ordinary DWHs. The relevant data can come in various forms—structured machine and sensor data, semi-structured reports form quality testing, feedback e-mails from customers, product evaluations on web pages, discussions in social networks, etc. Performance bottlenecks have always been an issue in BI that required an arsenal of strategies on multiple levels [10]. Nowadays, however, data volumes reach a level that classical relational technologies cannot efficiently handle anymore. This topic is currently summarized under the rather unspecific term *Big Data* [26, 37]. It can be dealt with in various ways, which can in parts also be applied in combination.

One approach, particularly suited for conglomerates of semi-, and unstructured data ("polystructured data"), is to apply database technologies that relax the strict scheme requirements of relational data bases as a trade-off for a better distribution of the data processing tasks and a higher query performance ("NoSQL"—not only

SQL). Examples include key-value stores, document stores, and extensible record stores [12, 45]. Contemporary NoSQL BigData repositories are particularly suited for parallelizing data aggregation and analysis task and for utilizing large clusters of computing infrastructure. While their eventual role in the domain of BI remains yet unclear, Big Data stores seem to be particularly interesting as *data sources* and as components for pre-processing the semi- or unstructured contents residing within those sources. Their applicability as full-scale replacements for a business-oriented DWH is limited however, as they are *by design* not meant to guarantee full consistency at all points of time ("BASE" model—Basically Available, Soft state, Eventual consistency).

A second strategy for dealing with large data sets that is intensively discussed is to apply "In-Memory data base" solutions. In-Memory solutions are tailored for handling larger volumes of data in the higher layers of the memory hierarchy, i.e. Random Access Memory (RAM), processor cache, and processor registers. Combined with pertinent data structures (e.g. a column-based instead of row-based storage of data base tables) this can lead to significant gains in query performance, e.g. in OLAP solutions [40, 41]. Implementations can particularly be found in specific DWH and/or OLAP appliances. The suitability for OpBI solutions is palpable—which leads some authors to the conclusion that in the future managerial and operational enterprise systems will rest upon a (re)unified data socket that is realized in an in-memory fashion [40]. While such a scenario is most probably only viable in a limited set of environments, the assumptions illustrate the increasing overlap between the operational and the managerial systems and the relation to questions of performance.

An alternative to a high-end in-house BI infrastructure is the import of services based on Cloud Computing approaches, i.e. internet-based services that can ideally be deployed in an ad-hoc manner, scaled dynamically with changing demand based on virtualization technologies, and be used in a pay-per-use model [39]. The application of Cloud Computing approaches to the domain of BI ("Cloud BI") can be an answer to issues of volatile workloads and of unpredictable requirements on the information generation and access layer [4, 46]. One source of such requirements is the unpredictable demand for BI on mobile devices ("Mobile BI")—where the rapid succession of innovation cycles quickly renders investments in specific components worthless (among others: mobile clients for various platforms, user and device management, security settings, etc.) [5]. The subject of mobile BI also gains relevance with the trend towards OpBI—an *in-process* decision often goes along with the need for an *on-site* decision, e.g. on the premises of the customer, in a distribution center, or at the shop floor.

## 2.3 Source Systems for BI in the Manufacturing Sector—Developments

The level of IT support in manufacturing is currently taken to a new level. This development can be broken down into three interdependent trends: First, activities across the product lifecycle are increasingly connected via digital networks. Second, identification and sensor technology is increasingly embedded into the physical environment and attached to objects ranging from transportation equipment, material, Work-In-Progress (WIP), up to machines, vehicles, and buildings [20]. Third, there is an increasing amount of semi- and unstructured data available for analysis (cf. Sect. 2.3). All this provides an increasing foundation of interrelated data that can be utilized for decision and management support. Injecting this data into BI systems is fruitful from two perspectives: First, integrating data on technical processes and business outcomes enables a more purposeful planning and steering at operational and tactical level (OpBI). Second, it allows for the provision of in-depth insights that can be used for strategic decisions.

The following sections detail the developments regarding the IT support within the product lifecycle, the relevance of sensor and identification technologies, and the role of semi- and unstructured data sources.

### *2.3.1 IT Systems Within the Product Lifecycle*

Industrial companies are characterized by developing, designing, and manufacturing physical goods. While technological leaders create more and more complex products that are sold in bundles with non-material extensions like services and maintenance, the actual products are still of a *physical* nature and require intricate development and manufacturing processes in which expertise from several domains needs to be brought together [18, 35]. For example, technical goods are regularly composed of mechanical engineering, software- and electronic-based components, as well as fluid or electric power modules. Each of those domains comes with specific tasks and needs specific IT support. Three examples illustrate this: CAD systems, simulation, and production control. As for CAD, mechanical design, electronic design, as well as the fabric layout planning all apply Computer Aided Design (CAD) systems to build Digital Mock Ups (DMUs) [48]. The concrete functionality and data models of those CAD systems, however, strongly vary depending on the tasks they have to fulfill. This has the consequence that industrial businesses use several types (and brands) of CAD systems in parallel, often one per domain. Another example is simulation: The development and manufacturing of high-end products contains specific tasks like finite element simulation for strength calculation purposes, the simulation of product functionality or manufacturing planning. Each of those tasks is supported by its own specific IT-system [19]. In consequence, industrial businesses use a broad variety of heterogeneous IT systems. A third example is production control: Manufacturing is increasingly digitalized with numeric control systems, digital actors and sensors [3]. Specific steering and control tasks lead to specific IT systems. For example manufacturing execution system (MES) are increasingly used for the collection of machine and sensor data for right time control and steering tasks [31]. Those systems have to fit to the kind of manufacturing processes and tools. Therefore, even here industrial businesses apply separate MES in different manufacturing environments.

Taking into account that most industrial businesses act as global players, the IT infrastructure regularly gets more heterogeneous with different plants brining in their own IT systems depending on their size and functions.

In summary, the points mentioned above are leading to heterogeneity of the IT system landscape. And so far, business-oriented systems like ERP and CRM systems have not been considered: Even in medium-sized industrial businesses, it is common to find a large number of respective IT systems. This results in relevant product, process, and machine data being distributed across industrial businesses. It is indispensable for a holistic decision support purpose to collect and semantically integrate this data.

### *2.3.2 Identification and Sensor Technologies*

Embedded, wirelessly interconnected, and mobile IT components that jointly provide new types of IT services have been discussed under the heading of "Ubiquitous Computing" (UC) for quite a while among scholars [36, 49]. It was the attention that has been given to the technology of "Radio Frequency Identification" that eventually propelled the diffusion of viable business applications of UC [20, 25]. RFID is applied in a variety of applications, yard management, theft prevention for tools, up to tracking product flows in production. A crucial development has been the diffusion of standards, esp. the "Electronic Product Code" (EPC) family of standards which not only covers codes and physical interfaces, but middleware platforms, and services for data exchange across enterprise borders [15, 24]. Originating in the retail sector, EPC is also increasingly applied in the manufacturing industry. Beyond its initial focus on identification, RFID can be augmented by sensor technologies, measuring environmental states such as temperature, humidity, acceleration, strain etc.

Direct effects of the application of RFID and sensor technology result from the automation of data capturing activities and encompass cost savings, faster availability of data, data quality improvements, and an avoidance of various mistakes and inefficiencies that result from erroneous manual data input. More interesting are the information effects that are an indirect consequence of the real-time data availability and the potentially higher resolution of automatic measurements of the presence, the identity, and/or the state of objects. This can even enable complete new ways of conducting processes or designing products (transformation effects) [7].

From the view of decision support, the new data enables not only a real-time process steering but also an *ex-post analysis* of process instances—particularly if objects are identified on item level [6, 13]. Among others, this allows process analysis on shop floor level, e.g. if WIPs or transportation material (cases, pallets, containers etc.) are tagged with pertinent RFID transponders and tracked with systems like MES. In case of EPC-based applications, the definition of a globally unique identifier like the EPC code even fosters data integration and analysis across enterprise borders. This is of particular interest in the realm of SCM, e.g. for pinpointing root causes of loss, faults and damages, for identifying and analyzing routing options, or for evaluating lot sizes or transport modalities.

Another relevant development towards a UC manufacturing environment with a BI impact results from the increasing degree of network-attached and IT-controlled "smart" machines and the trend to collect, distribute, and archive machine data in digital form.

UC data can enter the realm of BI either indirectly via operational systems (material management systems, warehouse management systems, SCM, ERP, MES, PPS, etc.). Or it can bypass this layer by being fed more or less directly into the DWH environments (after going through basic filtering and data transportation steps with specific "edge ware" and middleware). Either way, UC data can become a rich source for insights for both the steering and iterative adjustments of processes as well as for the design of new ones.

### *2.3.3 Unstructured Data*

The discussed digitization of the shop floor leads to a large amount of structured data, e.g. sensor data [3]. However, numerous sources are not as structured and therefore not readily processable by BI applications. Examples include reports, emails or plain text documentations. Even the results from BI-based analyses are usually at some point translated into an unstructured form (e.g., a PDF file) for purposes of distribution or archival—the handling of these procedures is still considered unsatisfactory in many larger organizations [2]. Even more challenging are non-text representations of information, e.g. pictures from optical sensors or drawings, which are also needed for decision support, esp. within engineering tasks.

This leads to the requirement of coupling "classical" BI infrastructures for management support with systems that are specifically designed to handle, refine, and analyze semi- and unstructured data. In general, the semi- and unstructured data is either integrated into the information access layer (e.g. by the means of interlinked documents), integrated into the data support and information generation layer by processing (existing or extracted) meta data or distributed via components from the domain of knowledge management for knowledge storage and distribution [3].

## 2.4 Extending the Scope of Integrated Decision Support

In the following section, business scenarios are presented that highlight the potential of integrating the data sources discussed in section three—under consideration of the concepts and technologies introduced in section two. This leads to a BI with a much broader scope: First, product, process, and shop floor design phases are explicitly considered—necessitating dedicated product and process DWHs. Second, process steering and management become part of BI, which leads to components for OpBI and BPI. Third, large and unstructured data sources are considered in more analysis scenarios.

### 2.4.1 Including Product and Shop Floor Design Phases

Within the industrial product creation process and the subsequent phases of product usage and recycling there are several decisions with strategic implications. For this reason it is advisable to devote attention to the decision support within the product lifecycle. The following two exemplary management tasks will explain the typical decisions contained in the product lifecycle and the resulting information demand that needs to be covered by BI.

*Management of Engineering Regulation and Standardization*

The management of engineering regulation and standardization is usually part of the role of *Knowledge Engineers* (KE). KEs e.g. have to deal with identifying relevant engineering knowledge, acquiring that knowledge, and encoding it as input for knowledge or expert systems, construction rules, (construction) scripts, or templates. A primary task of these engineers is the acquisition and association of (fragmented) information in order to regulate construction with the objectives of coming to a holistic view on the relevant information [21, 43] and to implement a permanent active learning organization [29, 34]. These are prerequisites for the support of a "design for X" approach (e.g. design for assembly, design for logistics, or design to standards). As most business strategies require more than one "design for X" commitment (e.g. simultaneously demanding design for cost, design for quality, and design for assembly), these commitments are very often conflicting: Reaching a higher quality level (design for quality) requires a trade-off with the reduction of costs (design for cost). The KEs therefore have to figure out the impacts of changes across different commitments, if possible based on historical data. Examples of the data that needs to be collected and integrated for this includes actual geometric data and its history of changes (as stored in CAD systems), data on actual and historic assemblies, e.g. with respect to the reuse of parts (stored in PDM/PLM systems), non-financial KPIs (e.g. timeliness) from different manufacturing sites (mostly extracted from MES), plan, actual, and historical data about resources in production (from PPS-systems), or budged and actual financial key performance indicators from ERP systems.

*Maturity Stage Level Management*

Maturity Stage Level Management (MSLM) is important in the context of manufacturing engineering, quality management and lifecycle management. A core task of MSLM again is the acquisition and association of (fragmented) information—here aiming at reporting a certain maturity stage concerning key figures (e.g. warranty costs, loss claims) under consideration of different views (e.g. manufacturing site, region of use, and kind of defect), areas of responsibility (e.g. part managers, module managers, project managers), and hierarchical levels. The goal of MSL managers is to permanently enhance the maturity stage of products [33]. The information demand of MSL managers includes actual and historical data from different business units as well as heterogeneous external data sources (e.g. market data). Examples include geometric and feature data, a history of changes (from CAD systems), actual and historic assemblies (from PDM/PLM systems), quality data (from quality systems), documents and spreadsheets, plan, actual as well as historic financial data (from ERP systems), data concerning customer satisfaction, e.g. complaints (from CRM systems), as well as external data form retailers, service or repair shops about failures and repairs.

There are many tasks in the product lifecycle with similar characteristics like product and project management, management of product variants, or manufacturing engineering management: They all require information from the whole lifecycle and the plethora of applied systems contained within.

### *2.4.2 Including Process Steering and Management*

Forerunners in applying both BI-based process management approaches in industrial environments can be found in the areas of logistics and SCM. This is not surprising, given the fact that the core concepts of those functions are characterized by an overarching process view. A process DWH, potentially filled automatically by UC technologies, can be used both for tasks of steering and of analyzing. A relevant complication for such scenarios comes from the cross-border nature of many of those scenarios and the need to quickly include and exclude partners, react to changing transportation and inventory strategies, consider modification of business models, and temporary demand for advanced analytic functionality (data mining, simulation, predictive analytics). From this point of view, logistics and SCM also illustrate the potential of Cloud BI [4].

*Steering of Product Flows*

Providing comprehensive information on product flows is a task that is heavily characterized by integrating and aggregating data from a variety of involved partners (manufacturers, second, third, and fourth party logistics providers, wholesalers, retailers) and their respective systems. Ideally, the status of a supply network (e.g. inventories, number, location, and status of moving goods and vehicles, service levels, throughput times etc.) can be accessed without manual or semi-manual data capturing and integration effort in adequate accuracy, correctness, and timeliness. This way it becomes possible to react to unexpected events (e.g. unavailable routes, losses and damages etc.) and to find solutions (e.g. alternative routes, re-directing oversupplies to retail outlets that face an Out-of-Stock situation etc.). Such scenarios are both relevant for the internal logistics of a single enterprise as for complete Supply Networks [6, 8, 13]. These are also examples for Operational BI.

*Analyzing Process Structures*

Interlinked with the (ad-hoc) steering is the step of uncovering patterns behind already observed events and of pinpointing root causes of reoccurring issues—a prime example for the application of BPI solutions (cf. Sect. 2.2.1).

Applications include the identification of problematic product configurations that lead to problems during transportation, identifying transportation routes that can be linked to quality impairments, or bottlenecks causing decreasing cycle times. This type of BPI application requires not only pertinent analysis tools but also data on both process logic (for tracing back problems) and on business results (for evaluating the problem impact). Here, a higher granularity of the data corresponds with the ability to adequately narrow down cause-effect-relationships. Again, scenarios can be found both in internal (production) logistics (where esp. an MES can act as a rich source of relevant and interconnected process data) and in broader SCM approaches (which, however, requires object traceability, e.g. based on RFID technologies) [8, 32].

### 2.4.3 *Including Big and Unstructured Data*

Decision support within various tasks in industrial businesses typically needs to consider both economical as well as technical aspects—with the latter often coming in extremely detailed and high-dimensional form (e.g. geometric data). Usually, the respective types of analyses also require the consideration of information that is only available in a semi-structured or unstructured form, e.g. service reports that sketch technical and geometric specifications in quality protocols or technical drawings. A comprehensive framework for BI in the manufacturing sector therefore needs to include both: an integrated presentation interface to connect structured and unstructured data as well as analytics of structured descriptions (meta data) to unstructured files. Given the sheer volume of the resulting data repositories and the need to also include Internet data for the reconciliation of decisions with customer and market trends, the potential of an inclusion of In-Memory and Big Data technologies (possibly Cloud-based) is salient.

*Decision Support Based on Data from PDM and PLM Systems*

Many PDM and PLM systems are based on meta data centric file systems. They handle drawings, DMUs, or reports as *files* that are managed by their meta data. Diving deeper into the processes of the digital firm, increasingly often simulation and virtual reality methods are used for testing and enhancing product features. Those methods typically generate large quantities of data—with large portions being unstructured or semi-structured. Typical analytics regarding PDM data, simulation data, and data from the customer side are explorations on the degree of customer satisfaction. Therefore, web analytics are increasingly used in social networks and use groups.

*Optical Methods in Manufacturing and Quality Monitoring*

The same applies to more and more widespread optical methods in manufacturing and quality monitoring. Process monitoring based on high resolution image processing leads to quickly increasing volumes of both structured and unstructured data, which both have to be integrated in decision support concepts to conduct lifecycle oriented root cause analysis e.g. for analyzing

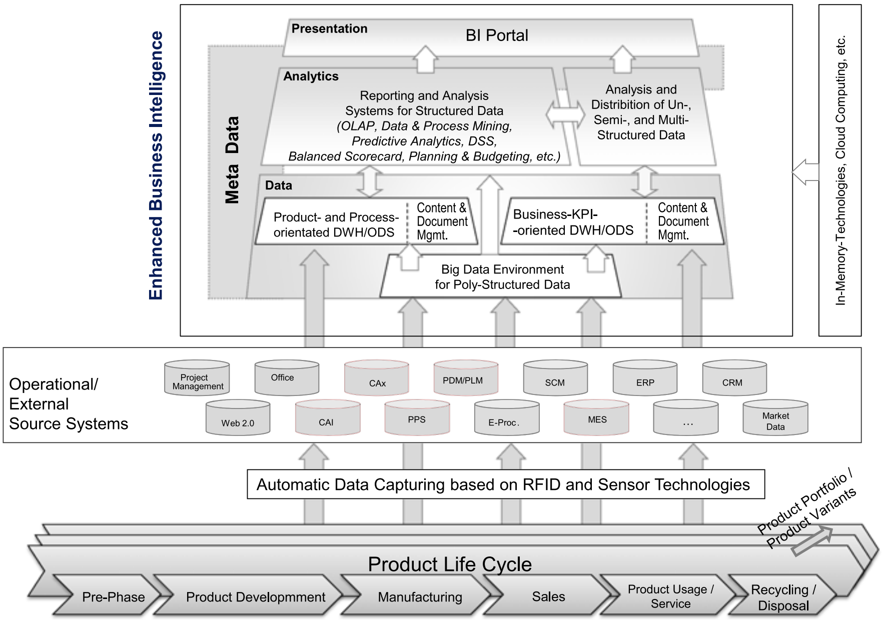


**Fig. 2.1** Enhanced business intelligence architecture

failure driven warranty cost in maturity stage management or engineering management.

## 2.5 An Integrated Framework

Summarizing the previous insights, BI can unlock benefits in the manufacturing sector by bringing together technical and business-oriented information in a comprehensive decision support. This is on the one hand relevant at the operational and tactical level for the design and steering of processes. It is on the other hand of interest from a strategic perspective, as a holistic and in-depths view on these contents enables to uncover new decision options and a better understanding of the potentials and limitations of certain decisions.

This requires changes to traditional BI architectures. A resulting architecture framework is depicted in Fig. 2.1.

In more detail:

*Data Support Layer*

To support the decisions mentioned above, data has to be extracted both out of business and technical systems. For example, product feature data can be found in DMUs, while process logic information can e.g. be gained from MES, SCM, or directly gathered from UC systems. Within the enhanced framework, the data sources therefore encompass IT systems from the complete product lifecycle. Due to the need to store additional data formats, structures, and models with distinctive use and access profiles, the data support layer is extended by additional data warehouses, esp. for product oriented and technical data (product DWHs) and for data on process logic as required by BPI applications (process DWHs). Some of the relevant data directly streams in from sensors on the shop floor. This, as well as unstructured data from inside and outside the enterprise, leads to real time and Big Data requirements that complement the data support layer.

*Information Generation, Storage, and Distribution Layer*

The Information Generation, Storage, and distribution layer needs to include tools that are capable of analyzing the newly categories of data (polystructured data, process data)—leading to the need to build connections to NoSQL and Big Data components in the Data Support Layer. This goes along with the requirement to design pertinent data models.

*Infrastructure Options*

As they open up or prohibit application options, new infrastructural options (e.g. In-Memory or Cloud Computing) for coping with the aggravated performance requirements and the increasing volatility of the solutions, need to be included in the framework.

As this overview indicates, an industry-specific BI architecture that incorporates and adapts various new trends in BI and consequent might unfold competitive advantages. However, as many of the discussed concepts are still evolving and so far only implemented selectively and rudimentarily, the architecture framework can only function as a starting point that cannot replace a comprehensive company-specific evaluation. Furthermore, many open questions need to be addressed on the research side as well, e.g. questions on how to balance out trade-offs when choosing between Cloud-based Big Data services and in-house In-Memory solutions, or when comparing the use of established operational systems (like PLM or MES systems) and integrated DWH based solutions for various decision scenarios. Furthermore, a full-fledged integrated product DWH brings various challenges regarding the integrated data models, the data visualization, and the interplay with the process and "classical" business KPI DWHs.

However, tackling these issues might be highly valuable—particularly for enterprises in turbulent, complex, and global environments. Here, the capability to come to a thorough understanding of the business and to respond in-time to unexpected challenges can have consequences for the sustained survival of the enterprise.

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