

Chapter 2

Problem Description and Fundamentals

In the following chapter, the RTE is introduced as an organizational concept for manufacturing enterprises. The presentation of the RTE starts with a broader discussion of RTE's motivations, fundamentals and principles. Further, the emphasis of presented research and status of development in the realm of RTE are presented. Here, the realization of the RTE in manufacturing can be identified as requiring further attention in ISR.

The event-based processing of information, vertical integration of a manufacturing enterprise and real-time alignment of planned and actual manufacturing process execution are recognized as primary requirements for the realization of an RTE. MES is introduced as a contribution of the engineering community towards the implementation of RTE in manufacturing. In addition, CEP is unveiled as an IT building block for the RTE. However, the liaison between MES and CEP requires further attention in research, which is elaborated in this research work.

2.1 Real-Time Enterprise - Organizational Concept for Manufacturing Enterprises

The RTE is a vision to manage an enterprise in (near) real-time. Consequently, its basic principles are integration of (IT) systems across enterprise borders, automation of value creation processes, and realization of capabilities to satisfy individualized customer demands. Even though RTE is not designated for dedicated industrial sectors, methodologies and implementations of RTE in manufacturing have been widely neglected. In the context of manufacturing enterprises, the implementation of an RTE requires the vertical integration of an enterprise and the realization of closed-loop controls in (near) real-time.

2.1.1 Vision, Principles, and Definition

“Time is money” is a proverb whose relevance has actually increased in recent years. The environment of today’s enterprises can be described as dynamic, volatile, and driven by uncertainties [98]. These environmental changes have been significantly pushed by the advent of new (information) *technologies*, especially, revolving around the Internet [4]. Also Gartner, who coined the term RTE [60], is seeing “the effect of inexpensive, powerful telecommunications” [212, 2] and computing power, like Web, e-mail, and so forth, as main drivers for a “shrinking globe” [212, 2]. Besides other factors, these technological developments have affected enterprises’ external environments (i.e., demand and competition) as well as internal (organizational) structures and processes.

Information about products and prices is conveniently accessible via the Internet for (potential) customers, who in turn tend to be less loyal to a certain enterprise [4]. Customer demands have fluctuated more, and at the same time, requested products have to adhere to customers’ *individual* requirements (i.e., mass customization). Actually, the known transition from a seller’s market to a buyer’s market has been intensified [165]. Besides the above mentioned technological progress and altered demand behavior, the *globalization* has led to a boost in the number of competitors, especially, from the developing world. Also, because of improvements in communications and logistics, products can be manufactured and distributed all over the globe. Sometimes, this situation is phrased as “design anywhere, build anywhere, sell anywhere” (cf. [167]). Enterprises are no longer operating as part of a flat and linear value chain [207]; rather, they are connected in a complex and multidirectional *value grid* [119].

These tremendous changes in the global economy don’t seem to represent just a temporary phase [212]. The vicissitudes of markets, customers’ fluctuating behavior, and technological changes are not intermittent, but have to be considered as continual [22]. Unfortunately, the prevalent managerial decision making processes are just supported with historical data, which are often outdated [30]. Besides quality and capability for innovation, time has become a critical success factor and a selling proposition for enterprises [4, 95].

The vision of an RTE addresses the necessity to cope with *time* in a comprehensive way. Gartner’s research has initially defined RTE as “an enterprise that competes by using up-to-date-information to progressively remove delays to the management and execution of its critical business processes” [60, 1]. Therein, it is explicitly emphasized that the usage of *up-to-date-information* is required to sustain competitive advantages of an enterprise. Also, Drobik et al. express the strategic character of the RTE as an on-going endeavor that cannot be completed in a fixed, predefined time frame [60]. In the same direction, Abolhassan states the fundamental and comprehensive approach of the RTE [4]. Hence, the RTE is concerned with internal and external processes [12] encompassing SCM (cf. [11, 133]) and CRM (cf. [11, 132]).

Although the work of Alt and Österle pertaining to RTE is mainly focused on extended enterprises, which integrate information across the enterprise’s edges, and

are consequently denominated as real-time businesses (RTB) [12], it also describes the necessity to coalesce the physical world into the information world [78]. They enunciate the principles of the RTE (or RTB) with the following rules [78]:

- Information created at the point-of-creation (POC) is *immediately*¹ accessible at the point-of-action (POA) for decision making. This requires the realization of *seamless information flows in (near) real-time*. Applying publish-subscribe communication patterns seems to be promising to realize such information flows.
- Information has to be *acquired automatically* at the POC from IT systems (e.g., ERP), programmable logic controllers (PLC) (cf. [138, 141]), radio frequency identification (RFID) chips (cf. [76]), and the like.
- Real-time systems avoid *information buffers*, which are often a result of an inadequate integration of sub-systems.
- There should be no breaks in *semantics* crossing various (IT) systems. Hence, the consideration of standards regarding data semantics is recommended (e.g., ontologies).
- A real-time system has to *select relevant information* that should be made accessible at the POA. Acquired data at the POC has to be filtered, aggregated, and delivered in an adequate timeframe (e.g., seconds, minutes, hours). Thus, only a *significant* subset of all state variables has to be made available for control purposes [148]. Also, Hugos argues that the RTE is “an organization in which specific and relevant information—not just an indiscriminant flood of data—flows continuously to individual people throughout the organization” [120, 1].
- The *decision making* in RTE can be performed at the POA without human interactions or at least with minimum human assistance².

Assuming that decision making aims at accomplishing certain objectives, the above principles of an RTE can be summarized to establish (multiple) feedback controls within and across an enterprise [95]. The application of cybernetics and control theory to information systems engineering has been introduced and taught in ISR for a long time (cf. [75]). Hugos explicitly elaborates the theoretical foundations and principles of the RTE as (i) Shannon’s information theory [233]; (ii) Wiener’s cybernetics [269]; and (iii) Bertalanffy’s and Ashby’s general system theory [21, 120]. Also, Meyer describes the RTE as an organization that integrates sense-and-respond and learn-and-adapt into its processes [183].

Blood mentions that RTE models often focus on the rapid response to events, but lack considering early warnings as an integral part of the RTE [26]. Motivated by a similar re-thinking, Gartner has adapted his definition of the RTE:

Definition 2.1. (Real-Time Enterprise): The RTE monitors, captures, and analyzes root-cause and overt events that are critical to its success the instant those events occur, to identify new opportunities, avoid mishaps, and minimize delays in core

¹ A comprehensive discussion about what is meant by ‘immediately’ (e.g., soft and hard real-time) is given in Sect. 3.4.

² Nevertheless, it is also mentioned in the literature that the incorporation of humans is key to the RTE (cf. [23]).

business processes. The RTE will then exploit that information to progressively remove delays in the management and execution of its critical business processes [176].

This definition accentuates the processing of events for the sake of detection of threats and opportunities. Thus, the (feedback) control within an RTE is preferably *proactive* rather than *reactive*.

2.1.2 Research Scopes, Gaps, and Challenges

By definition, the RTE is entirely influencing an enterprise [4], i.e., its strategies, organizational structures, internal processes, and external interactions with market participants. Nevertheless, ISR revolving around the design of the RTE has concentrated on the extended enterprise. The need to react to changes occurring in the *external environment* of an enterprise is often expressed with vigor (cf. [12, 225]). For instance, Alt and Österle argue that enterprise integration (EI) has focused on internal processes whereas external processes with suppliers and customers have been neglected [12]. Furthermore, they state the aim of ERP systems, like SAP[®] R/3, is the real-time dissemination of information across humans, organizational units, and even enterprises.

Although it is vital and inevitable to *horizontally* integrate an enterprise with its external environment, as mentioned by Alt and Österle, its vertical integration is just as important. The *vertical* enterprise integration across enterprise levels, which is capable of linking planned and actual process execution, can be seen as a prerequisite for the realization of an RTE in manufacturing [95]. In addition to enterprise integration, automation as well as individualization has to be achieved or appropriately addressed in an RTE [78]. The challenges of vertical integration of an (manufacturing) enterprise are summarized in the following paragraphs.

In Fig. 2.1, a simplified model of a manufacturing enterprise is depicted as a triangle composed of several enterprise levels. The enterprise's external environment is delineated as SCM and CRM, and their horizontal integration with the enterprise is denominated in this research work as an extended enterprise³. Extensive research has been carried out to automate and integrate business processes at the tactical level of an enterprise. Primarily, administrative, purchasing, and financial processes are executed at this enterprise level. According to standard VDI 5600, this level is called enterprise control level [255], and it is often supported by ERP systems. On the contrary, actual value creation is performed at the resource level or manufacturing level. The intermediary between the enterprise control level and the manufacturing level is the manufacturing control or operational level, which is in charge of providing a comprehensive control of manufacturing processes. The vertical integration of a manufacturing enterprise is challenging as enterprise levels

³ Contrarily, the term extended enterprise can also be understood as the integration of enterprises in a value network or value chain.

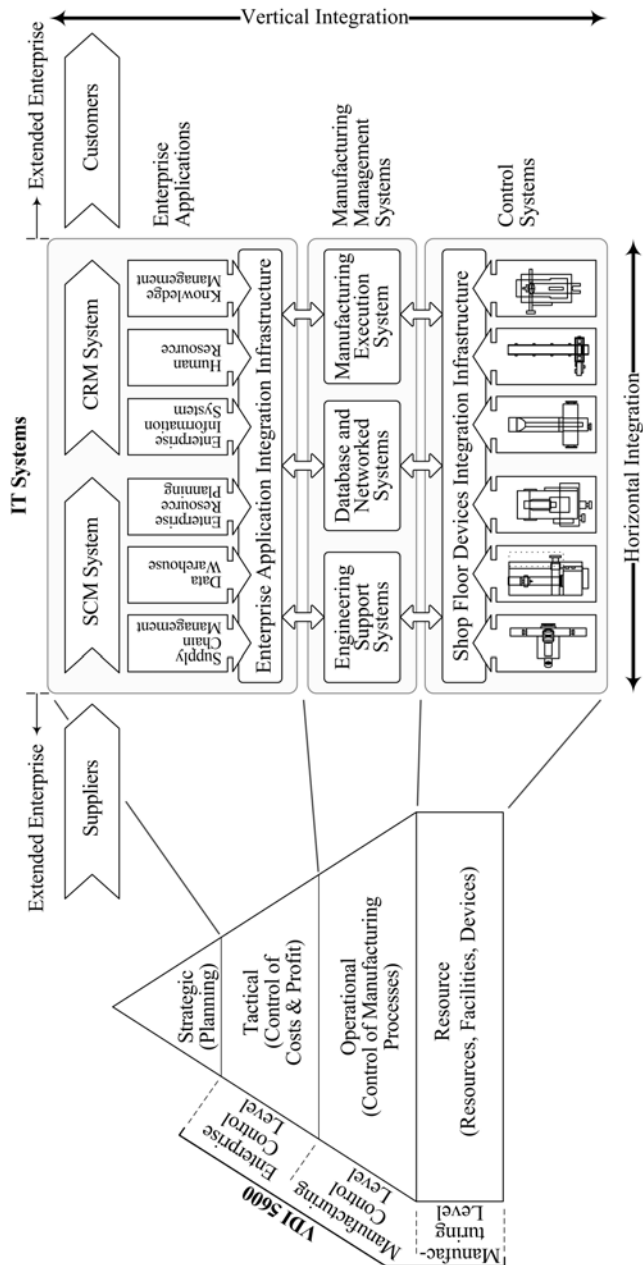


Fig. 2.1 Horizontal and vertical enterprise integration as a prerequisite for the RTE, and some characteristics of IT support at different enterprise levels (adapted from [101, 117]).

are associated with different time horizons varying from (milli-) seconds over hours and days to quarters and years. In other words, business processes located at the tactical level are predominantly executed *offline* whereas manufacturing processes situated at the shop floor level are executed *online*. Briefly, these properties of the enterprise levels result in a semantic and temporal vertical integration gap.

MES are located at the manufacturing control level and try to bridge the vertical integration gap (cf. [255]). However, major problems with respect to MES are reported in the literature [201], primarily, because inflexible and proprietary interfaces between shop floor resources and enterprise applications (e.g., ERP system) impede a seamless (vertical) integration [140]. Therefore, research has been carried out to exploit the SOA paradigm also at the manufacturing level to overcome these shortcomings. Prototypical implementations of SOA-enabled devices (e.g., programmable logic controllers) at the manufacturing level have been examined in EU funded projects (cf. [29, 237]). Nevertheless, further developments are essential to refine and improve these implementations, and to foster their acceptance and dissemination in industry.

In its final configuration, the RTE envisions the integration of feedback controls between POCs and POAs, hence exceeding basic integration of data. Instead, a continual detection and analysis of events, which happen during execution of value creation processes, and a manipulation of these processes by dispatching control commands has to be performed in (near) real-time. The RTE's goal of a comprehensive real-time control of (manufacturing) processes necessitates the examination of (shop floor) events with respect to their administrative and financial context. Logically, the basic vertical integration of enterprise data can be considered as a *necessary condition* of the RTE whereas event processing and (automatic) deduction of appropriate (re-) actions can be described as its *sufficient condition*.

2.1.3 Emergent Enablers

The definition of the RTE (cf. Def. 2.1) does not encompass explicit descriptions of (information) technologies to be employed for its realization [23, 60]. Rather, it is focused on business aspects, where IT is just seen as an enabler for the RTE. According to Fleisch and Österle, the key concepts, which have to be addressed by IT within an RTE, are: (i) integration; (ii) automation; and (iii) individualization [78]. In their solution, the integration of an enterprise has been realized with *EAI solutions*, capable of connecting various enterprise applications, like an ERP system and a product data management (PDM) system, at the enterprise control level. Further, a *portal solution* based on principles of an SOA has been presented to also integrate SCM and CRM effectively [11]. In general, *SOA* is seen as a substantial enabler of RTE as it provides flexible and adaptable infrastructures [11].

In addition, Schulte discusses the event-driven behavior of the RTE and the need for the application of events, messaging, and publish and subscribe concepts at the business level [230]. EDA has been mentioned as another enabler for the RTE

[95]. Moreover, the automatic detection of opportunities and threats, which are inherent parts of the RTE vision, are notably more than a crude analysis of simple events. Simple events originated by manufacturing processes have to be related, e.g., in temporal and causal terms. Hence, CEP is currently mentioned as another technological building block for the RTE (cf. [41, 164]).

2.1.4 Summary and Research Goals

Based on the above mentioned explanations, the current situation with regard to the realization of the RTE in manufacturing can be summarized as follows:

- RTE is a comprehensive concept covering all aspects of an (manufacturing) enterprise. However, research has primarily focused on the topmost enterprise levels and the extended enterprise, but has neglected the vertical integration of an enterprise with its value creation processes at the manufacturing level.
- Available MES solutions address the vertical integration and are indeed considered as enablers for the RTE. Nevertheless, MES still possesses some shortcomings in the interface with shop floor resources [118].
- Further, promising event-driven IT, like EDA and CEP, have been introduced (into the RTE) for administrative and financial enterprise processes. However, a concise framework is missing to link MES and CEP. The application of CEP in manufacturing is currently limited and requires further consideration.

The consequences of the aforementioned situation within manufacturing enterprises are numerous: (i) the *restricted transparency* of value creation processes impedes accurate, consistent and timely decision making processes; (ii) critical (complex) situations cannot be *sensed* in (near) real-time, and hence, necessary *responses* are induced relatively late to overcome or mitigate these situations; and (iii) enterprise-wide *learning* is hindered, and further, *adaptation* is not performed on the basis of experienced facts (empiricism) about the processes' outcome (i.e., quality, performance, maintenance, inventory).

This research work presents a framework comprising a process model and software architecture, which both contribute to the realization of the RTE in manufacturing. The IT part of the framework is based on principles of EDA and CEP, enforcing the vertical integration of enterprise levels and facilitating the introduction of comprehensive feedback controls in (near) real-time. This contributes to the implementation of the RTE principles (i.e., *learn-and-adapt* and *sense-and-respond*) within a manufacturing enterprise. The results presented in this research work have been achieved and experienced during a three-year industrial project with the Ohm & Häner Metallwerk GmbH & Co. KG, Olpe, Germany. This enterprise manufactures high quality aluminum sand castings employing state-of-the-art machinery and a high degree of automation. In addition, further results could be attained during an 18 month research project funded by the Federal Ministry of Economics and Technology (BMWi), Germany.

2.2 Principles and Fundamentals of Event Processing

As the envisioned IT framework is grounded on the EDA paradigm and exploits CEP technology, important principles are outlined with regard to the same. These descriptions are mainly centered on CEP as an innovative enabler for sophisticated monitoring and control of value creation processes. In addition, EDA and CEP are discussed in contrast to their predecessors, and competing and complementary concepts.

2.2.1 *Events and their Processing as a Fundamental Requirement for Business*

Although events are an inherent part of the world, they have not been widely used in business [229]. Oftentimes, one has just dealt with simple events, i.e., has focused on low-level events, like in network monitoring [161]. Higher-level events that can be exploited for monitoring and control of business processes have been neglected, as they have not been supported by IT in a systematic way. The correlation among business pressures, management strategies, information system requirements, and event processing has been delineated by Chandy and Schulte, as depicted in Fig. 2.2 [41]. The demand for a systematic and computerized processing of events is clearly illustrated in the figure.

Obviously, the business pressures already mentioned in previous paragraphs (and listed in Fig. 2.2) have intensified the need for novel management strategies, like RTE. Besides RTE, the agile, adaptive, predictive, zero-latency and event-driven enterprise can also be referred to as having innovative strategies; note that zero-latency and event-driven enterprise are synonymous with RTE [230]. Putting enterprise strategies into practice, one often has to pursue the following simplified steps: (i) recognition and anticipation of threats and opportunities for the enterprise; (ii) development of strategies concerning business, products, and technologies; (iii) (re-) design of the organizational structures and business processes in accordance with the selected strategies (i.e., structure follows strategy); and (iv) implementation of the processes, probably, by employing appropriate IT [87]. Hence, RTE and similar management strategies result in serious consequences for the enterprise's processes and systems. In the case of RTE, they can be summarized as timeliness, agility, and information availability [41]. In technical systems, *timeliness* is often associated with the term (low) *latency*. The meaning of latency depends on the context wherein it is being used. In computer networks, latency is the time required for a data packet to get from a sender to a receiver, which is influenced by, e.g., the packet size, communication medium, and routing [25]. More generally, latency is understood as response time in computer systems, i.e., the time between a request to a system and its response. Similarly, in real-time control systems, delays are described for controlled objects (e.g., a heater) and for controlling computer sys-

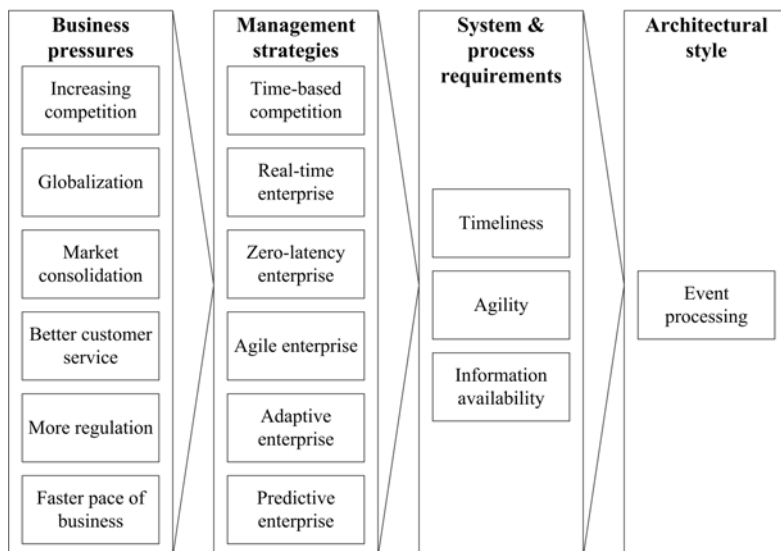


Fig. 2.2 Correlation among business pressures, management strategies, system & process requirements, and event processing (adapted from [41]).

tems (e.g., programmable logic controller). For the latter, the delay (i.e., latency) describes the time between the observation of the controlled object (e.g., measured temperature of the heater) and the push of a derived output (i.e., reaction) from the controlling computer system to an actuator (e.g., thermostat) [148]. Finally, latency can also be defined with regard to event processing systems, where latency is the difference between an event's egress time and its stimulus time (i.e., the time an event arrives at an event processing system) [40]. In a business context, low latency can be considered as the execution of single activities or even orchestrated processes with celerity [41]. In addition, it also connotes timely decision making processes and immediate reactions to events.

Because of turbulences in markets, technological progress, and the like, enterprises strive for flexibility and agility. Unfortunately, there is no consensus about the definition of flexibility and agility [92]. *Flexibility* has been addressed in business process management (BPM), where “process flexibility can be seen as the ability to deal with both foreseen and unforeseen changes, by varying or adapting those parts of the business process that are affected by them, whilst retaining the essential format of those parts that are not impacted by the variations” [227, 17]. Also, flexibility has been considered for manufacturing processes as “the ability of a system to change its behavior without changing its configuration” [267]. In addition, Wadhwa and Rao consider flexibility as a predetermined response to predictable changes, and further, describe the scope of flexibility on single systems [262].

The concept of an agile enterprise was first worked out in the 1990s [57]. Later, a significant number of definitions of *agility* were based on flexibility. Oftentimes, agility is described as flexibility complemented with quickness and speed (cf. [262]). Oosterhout et al. analyze literature pertaining to agility, and conclude that “business agility is the ability to sense highly uncertain external and internal changes, and respond to them reactively or proactively, based on innovation of the internal operational processes, involving the customer in exploration and exploitation activities, while leveraging the capabilities of partners in the business network” [197, 53-54]. Intriguingly, this definition of *business agility* encounters the main aspects of the RTE (cf. Sect. 2.1): sense-and-response to uncertain changes, response in a reactive or even proactive manner, inclusion of processes related to customers, and encompassing partners in the supply chain.

After an investigation of the discourses on flexibility and agility across various research disciplines, agility seems to describe a higher form of changeability. Accordingly, a maturity model for manufacturing system changeability has been described, starting from changeover ability via reconfigurability, flexibility, and transformability to agility [268]. In contrast to flexibility, agility’s scope is on groups of systems, its focus is on responsiveness (i.e., quickness), and it must cope with uncertain and unknown changes, must respond proactively, and control (processes) dynamically [262]. As enterprises and their processes are largely reliant on IT, the discussion on (organizational) agility has also affected the information system’s agility, which can be differentiated into technical infrastructure agility, information systems process agility, and human characteristics [173].

SOA has a high potential to substantially contribute to a company’s agility [8]. This potential can be derived from SOA’s inherent concept of loosely coupled software components, existing standards for implementing SOA-based components, and realization of enterprise interoperability build on top of SOA [202]. Following SOA, EDA has been discussed as a paradigm that leverages events to achieve even “minimally coupled” software components [41, 34]. Events are emitted by event producers (cf. POC in Sect. 2.1.1) and received by multiple event consumers (cf. POA in Sect. 2.1.1), which are interested in the emitted events. The event-driven communication within EDA implies that the software components do not have any preconception about each other. Hence, EDA augments loose coupling and fosters information system agility. However, EDA does not need to be perceived as contradicting SOA, rather as complementing SOA to achieve business agility. Recently, there is a trend to enhance EDA by employing CEP, i.e., analyzing the (causal and temporal) relationships of events [46].

In addition to timeliness and agility, the *availability of information* is considered as an indispensable requirement to attain the vision of the RTE. Voluminous amounts of information have been made available to users in the era of the Internet. Search engines, like GoogleTM, support users searching for relevant information. Similarly, *enterprise search* supports enterprise members to retrieve appropriate documents, like 2D drawings and 3D models of components (products), product calculations, and process plans [100]. Among others, the retrieved information considerably assists knowledge-intensive processes (e.g., offer process) and improves

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