Chapter 2
Research Description

The previous chapter laid down the basic road map of the presented research. This chapter builds on the previous chapter, and elaborates the constraints and goals of the presented research. In the presented research, different time notations are used. Section 2.1 presents these notations and their meaning. Based on the previously mentioned descriptions, Sect. 2.2 elaborates the constraints and goals of the presented research. Finally, a summary of the chapter is presented in Sect. 2.3.

2.1 Time: Classification and Definition

In recent years, different technologies and computing power have made advances by leaps and bounds. The technologies and computing power can be employed in numerous ways. Nevertheless, there are different definitions of time that influence the meaning and outcome of the aforementioned technologies and computing power. These definitions of time are defined from the perspective of how the systems respond to situations and user interactions.

A real-time system is defined as a "system which is required by its specification to adhere not only to functional requirement, but also to temporal requirements, often also called "timing constraints" or "deadline" [199]. A real-time system is characterized by speed—rate of execution of intended tasks, responsiveness—ability of the system to adjust to the external changes in the environment and remain alert to incoming events, timeliness—ability of the system to react within the time constraints or deadlines, and graceful adaption—ability of the system to adjust to the internal changes in workload and resource availability [36].

Real-time systems can be classified as hard and soft real-time systems [99]. A hard real-time system has to produce a response to a situation before a specified deadline, usually in a matter of a few milliseconds or less and without human intervention [99, 199]. For the computer science community, a real-time system is a hard real-time system. The response is mostly concerned with maintaining the safety of operators,

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and resources, among others [99, 199]. Furthermore, a hard real-time system is located very close to its environment and is tightly coupled with it [99].

A soft real-time system responds to a situation in seconds or more, and can miss the deadline, i.e., the response can arrive after the deadline [99, 199]. The response time is in the order of a few seconds or more [99]. Additionally, the deadline missed by the system is not critical and operators or users can intervene in the working of the system [99]. A soft real-time system is also known as an online system [99]. In contrast to an online system, an offline system consist of processes that are executed over a prolonged period of time (e.g., days, weeks) and is idle most of the time waiting for inputs.

Nevertheless, the manufacturing community does not classify the time precisely the way the computer science community does. For instance, some manufacturing enterprises consider real-time if response happens within a minute or less [141]. Rather, the manufacturing community uses real-time, soft real-time and online interchangeably. Subsequently, the presented research also does not distinguish among real-time, soft real-time and online, rather real-time and offline terms are appropriately used.

2.2 Research: Constraints and Goals

Manufacturing enterprises can be characterized based on employee count, plant layout, manufacturing processes and production quantity, among others. Likewise, performance measurement is a broad field. The presented research considers specific enterprises and attempts to address the requirements of performance measurement concerning the chosen enterprises. In addition, the presented research focusses on processes internal to a manufacturing enterprise as the enterprise has more influence to enhance its internal processes. Consequently, the following paragraphs will outline the research constraints and goals based on the problem described in Sect. 1.2.

2.2.1 Manufacturing: Enterprises, Processes and Taxonomy

The presented research is concerned with manufacturing, and its processes and activities leading to the manufacture of physical products, i.e., discrete products, in discrete industry. Manufacturing is defined as "the application of physical and chemical processes to alter the geometry, properties, and/or appearance of a given starting material to make parts or products; manufacturing also includes the joining of multiple parts to make assembles products" [62].

The manufacturing enterprises referred to here can be represented by suppliers, SMEs and area or site of a bigger enterprise that deals with the manufacturing rather than assembling. The presented research is limited to the manufacturing of products, which can be a crucial strategy for SMEs. Here, a product refers to a physical

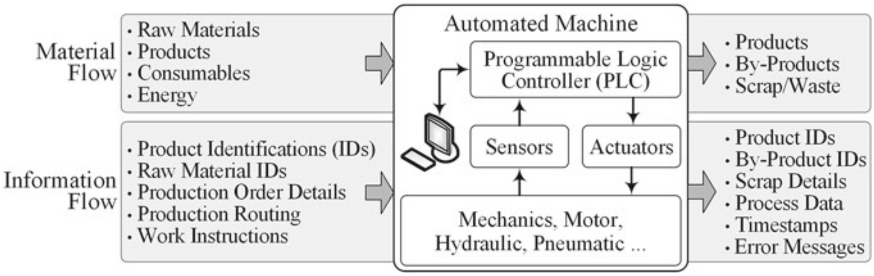

Fig. 2.1 Schematic representation of an automated machine along with the material flow and the corresponding information flow, adapted from [47]

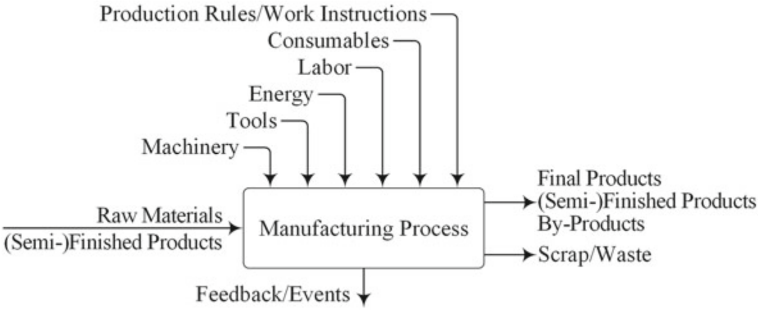

Fig. 2.2 Simplified view of a manufacturing process along with its inputs and outputs, adapted from [62]

individual work unit and not to the assembly of components. These enterprises considered in the presented research rely on automated machines to improve cycle time, reduce manufacturing lead time, improve product quality, and so forth [62]. An automated machine can be schematically illustrated as shown in Fig. 2.1.

The automated machines encompass different degrees of automation—fully automatic and semi-automatic devices [173]. Furthermore, human intervention is required for the control of semi-automatic and manual devices [173]. Nonetheless, the presented research is concerned with machines that are able to provide manual/automatic feedback of manufacturing processes. The feedback can be as simple as denoting the completion of a manufacturing process to a complicated one describing the manufacturing process with the actual process parameters employed.

The conversion of raw materials into (semi-)finished products is realized by a manufacturing process, as illustrated in Fig. 2.2. In contrast to manufacturing processes, there are business processes to manage customers' orders, billing and so forth. In either case, the business and manufacturing processes should consist of value-added activities [37], and should be part of the value-chain [184]. These processes can be belong to discrete, batch processing, and continuous industries [63], and logistic domain (see IEC 62264-3 [123]). A manufacturing process is supplied with product definition information, which specifies the required materials, products and subassemblies; describes the instructions to carry out the manufacturing process; and identifies resources to be employed (see IEC 62264-1 [121]). This information can be part of production routings, manufacturing Bill of Material (BOM) and Bill of Resources (BOR) in discrete industry or recipes in batch processing industry.

Finally, the plant layout of manufacturing enterprises would contain all possible types of resource layouts and material flows, especially in the case of SMEs. The plant layout is dictated by the production variety, production quantity [62] and product specification. There exist numerous plant layouts—fixed-position, process/functional, cellular and product [62]. Nevertheless, the presented research can be employed for different plant layouts.

2.2.2 Enterprise Entities and Identification

Monitoring and controlling of manufacturing processes is indispensable for sustaining a competitive advantage. However from a monitoring and control engineering perspective, the manufacturing processes are imprecise and intangible, which is mainly due to way enterprise members interpret and execute these processes. Thus, it is essential to monitor and control the underlying tangible enterprise entities of manufacturing processes. Resources, manufacturing operations, production/work orders, production schedules, raw materials, products, and quality, among others are a few of the enterprise entities that can be really monitored and controlled.

Nonetheless, it is necessary that the enterprise entities are uniquely identifiable to realize monitoring and control by tagging/labelling them. The unique Identification (ID) and the underlying tagging/labelling can be done virtually or physically using enterprise determined procedures or available standards[1] and guidelines. For instance, a barcode label containing ID can be physically glued onto a product that can be read using the barcode reader attached to the operators' terminals along the downstream processes. Likewise, an automation device can assign a virtual unique identification to enterprise entities, especially (sub-)products and raw materials, which can be communicated with its upstream and downstream machines.

2.2.3 Enterprise Perspectives

A manufacturing enterprise can be viewed from different perspectives—management science, control engineering and computer science. Nonetheless, there exist additional perspectives (e.g., functional and infrastructure), which are considered under previously mentioned three perspectives. These perspectives are essential to address

[1] For more information, refer to GS1 at http://www.gs1.org and Association for Automatic Identification and Mobility at http://www.aimglobal.org.

the challenges existing in the enterprise's internal and external environments, and to assist different enterprise members in performing their duties. The management science perspective is concerned about the health of an enterprise in the short-, medium- and long-term. This might involve strategic planning and the management of operations, and so forth [39].

The strategic plans and objectives are realized by executing the business and manufacturing processes. Here, the strategic plans and objectives are rolled down to the shop floor [109]. Likewise, the feedback in terms of performance metrics is rolled up to top management after the execution of manufacturing processes [109]. In this regard, the management science perspective should be assisted with the control engineering perspective as presented by the (control) engineering community. The feedback loops are based on the concepts of cybernetic controls to monitor and control the manufacturing processes [32, 112, 207], especially by comparing the actual performance metrics and the planned enterprise objectives.

Additionally, the computer science community has proposed the computer science perspective, which is crucial for both the management and control engineering perspectives. This perspective provides necessary information for monitoring and control, and subsequent decision making. Here, an enterprise employs different enterprise applications, like the ERP System, Supply chain Management (SCM) System and Customer Relationship Management (CRM) System.

The monitoring and control of manufacturing processes based on multiple feedback loops stress the importance of financial and operational metrics [112, 207]. Thus, the control engineering perspective is the focus of the presented research, and elaborates methodologies to compute financial and operational metrics during the execution of manufacturing processes. However, it does not address the decision making, i.e., action or reaction component (see Sect. 2.2.6).

2.2.4 Performance Metrics

Manufacturing enterprises are influenced by internal and external situations. However, the enterprises are in a position to effectively control their internal situations [109]. The performance metrics vary from enterprise to enterprise in a specific industry as well as from industry to industry, especially concerning discrete and batch processing industries. Thus, the research addresses the computation of basic financial and operational metrics internal to a manufacturing enterprise, especially concerning manufacturing processes, in real-time. On the other hand, the research does not delve into selection of performance metrics and PMS.

2.2.5 Linkage of Financial and Operational Metrics

Today's manufacturing enterprises compute operational metrics in real-time. In contrast, the financial metrics are calculated offline, which presents a snapshot of a manufacturing enterprise at a particular instant in time. The manufacturing enterprise with a stable high volume and low mix production schedules can afford to use the lagging financial metrics to monitor and control the manufacturing processes. In the aforementioned situation, the manufacturing enterprises are in a position to link the operational and financial metrics. For instance, Overall Equipment Effectiveness (OEE), an operational metrics, can be linked to financial metrics (e.g., profitability) [213].

On the contrary, the manufacturing enterprises are mainly represented by suppliers/SMEs that adhere to low volume and high mix production schedules, and would like to employ leading metrics to monitor and control manufacturing processes. In this situation, many of the operational metrics cannot be easily aggregated/transformed and linked with financial metrics, i.e., requires huge effort and many assumptions to assign information to production orders. Subsequently, aggregation of operational metrics might result in deceptive financial metrics.

The presented research attempts to compute the financial and operational metrics in real-time from the acquired real-time process data and link them, resulting in the conversion of lagging financial metrics into leading financial metrics. For instance, the improvement steps introduced on the shop floor should increase the operational efficiencies and effectiveness, and instantaneously suitable changes should be observed in the financial metrics. Likewise, any managerial decision should suitably influence the financial as well as the corresponding operational metrics.

2.2.6 Performance Management

Performance management should complement performance measurement, and is crucial for sustaining competitive advantage. Performance management is identified as "systematic, data-oriented approach to managing people at work that relies on positive reinforcement as the primary means to maximize performance" [80]. Likewise, performance management, according to IEC 62264-3 [123], is defined as "the collection of activities that systematically capture, manage and present performance information in a consistent framework. This includes utilizing corrective actions to affect operational improvement." The presented research attempts to compute financial and operational metrics in real-time, and present a comprehensive view of a manufacturing enterprise.

Nonetheless, enterprise members need to initiate corrective actions, if necessary, when the manufacturing processes deviate from the planned objectives as indicated by the financial and operational metrics. In addition, the computed metrics can be used to provide feedback to upstream processes, like engineering and sales. Overall, it is necessary to realize multiple performance feedback loops [109], especially within and across the enterprise boundary.

The corrective actions can be reactive or proactive [59]. Furthermore, these actions can be fully automated, semi-automated, or manual. However, it is beneficial to have a semi-automated approach in which few types of actions are automated and remaining actions are initiated by enterprise members. For instance, the action component can also be partially automated based on an event processing paradigm (see [157]). Likewise, improvement, either incremental or innovative, can be initiated to enhance the processes. Apart from the process corrections, efforts might be needed to invest in training of employees to realize higher performance. However, the presented research is concerned with the quantification of financial and operational metrics in real-time, and does not deal with the performance management and the corresponding action components, training of employees, and so forth.

2.3 Summary

Manufacturing enterprises need to monitor and control their manufacturing processes to sustain a competitive advantage. In this regard, performance measurement and management are crucial. Since the mid-1980s, several PMSs have been elaborated. These systems have emphasized the importance of financial and operational metrics, alignment of financial and operational metrics with the enterprise objectives, and inclusion of stakeholders, among others. Nonetheless, PMS are seen from a strategic perspective and do not elaborate about selection and computation of performance metrics. Subsequently, the presented research attempts to address the performance measurement component of PMS.

Section 2.2 elaborated research constraints and goals based on the problems associated with performance measurement presented in Sect. 1.2. The research goals can be summarized as following:

- computation of financial and operational metrics internal to a manufacturing enterprise in real-time;
- linkage of financial and operational metrics in real-time.

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