Chapter 6
Industrial IoT Projects Based on Automation Pyramid: Constraints and Minimum Requirements

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Abstract The industrial sector requires to improve the quality of processes to increase competitiveness. In addition, interconnectivity has seen a huge development based on teamwork related to hardware and software, which is the basis of Industrial Internet of Things (IIoT) vision. In this context, the automation pyramid concept defines the integration of relevant technologies, based on several hierarchical levels of automation, that working correctly together can improve the quality of processes without high-end hardware and software requirements. Therefore, it is important to clarify the relationship between all levels of automation in the IIoT context, emphasizing that the backbone of the IIoT is the optimal design and implementation of hardware and software based on real constraints for particular users; in order to increase the level of effectiveness and competitiveness. This chapter presents the real constraints for IIoT projects related to the state of the art of each level of automation of the automation pyramid. It also proposes the general minimum requirements necessary to develop an optimum IIoT system. These minimum requirements will promote the use of optional hardware and software to relax the design and implementation of IIoT projects based on cost-effectiveness analysis. Finally, the minimum requirements proposed and the detail description of the log-

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ical topology for IIoT projects can be used as a roadmap to increase the industrial competitiveness based on efficient use of resources.

Keywords IoT · IIoT · Automation pyramid · Constraints · Cost-effectiveness · Competitiveness · Logical topology · Monitoring flow · Control flow · Optimal design · Minimum requirements

6.1 Introduction

Nowadays, interdisciplinary projects have been of much interest in several sectors of the society. For example, cybernetics is an important field which supports the research and innovation of health sciences, the mechatronic systems support a number of industrial sectors, renewable energy technical proposals support many activities, and all of these projects require efficiency management. In particular, the Internet of Things (IoT) is a current interdisciplinary field where everyday objects (e.g., lamps, refrigerators, smartphones, computers, among others) are connected via the Internet either through open or closed channels (e.g., wireless connection or copper cables, respectively) in order to share relevant real-time information between them or to send information to a central unit—all this without direct human intervention [1, 2]. Thus, a huge amount of information is shared and concentrated to monitor particular parameters to facilitate the analysis and decision making based on the desired performance, and also, to create important opportunities for people [3, 4].

Considering the aforementioned, the industrial sector related to products and services has adopted the IoT discipline to improve their own processes or resolve particular issues, which leads to resource and time savings. Thus, IoT applied in the industrial sector permits to improve the quality control, supply chain traceability, general supply chain efficiency, manufacturing processes, management systems, among other important advantages. Therefore, when the IoT concept is applied to industries, it is called Industrial Internet of Things (IIoT), also known as Industry 4.0 or I4.0. In fact, IoT and IIoT concepts share features such as permanent availability and intelligent devices connected in similar architectures and automation logic, which use particular standards for industrial, domestic, personal, and metropolitan applications. However, an IIoT system intends to support the industry competitiveness while the IoT system intends to increase the comfort level of people (although the personal competitiveness may be related to the personal comfort level) [5–7]. Also, any automation system proposal, including IoT and IIoT, can be represented using the automation pyramid concept, which establishes five hierarchical levels (field, control, supervisory, planning, and management) that describe how the technology is being integrated into several applications, mainly for industrial applications [8].

The general purpose of the automation pyramid is to create a well-defined automation system according to the particular activities and performance required. However, the theory described by the automation pyramid is very general, i.e., it is common to find high-end hardware and software at different automation levels. In particular, the main problem is not the automation pyramid description, but the partial technical and management interpretations of particular users, which are, generally, industries with high acquisitive power. These industries carry out a rough analysis of the hardware and software needed for particular processes and services to increase their competitiveness, which means that systems with more or fewer capabilities than necessary will be acquired. In this case, the problem is hypothetical because the high acquisitive power permits a slight lack of technical and management information so that the negative effects can be minimized by the general profit. However, the scenario presented can be an important problem for industries with low or reduced acquisitive power. Sometimes, these industries analyze, in depth, the projects that involve hardware and software to improve the competitiveness using the minimum technical and management requirements. Clearly, the above mentioned does not generalize all the industries around the world, but in our opinion, it is an adequate approximation.

This chapter explains the real constraints that should be considered when designing and implementing an IIoT system in order to establish the minimum hardware and software requirements for each industry, which means important support to adequate the process to increase the competitiveness of users in particular conditions.

The chapter is organized as follows. Section 6.2 describes in detail the automation pyramid and the state of the art of the hardware and software used at each automation level to determine the particular real constraints in the IIoT context. Section 6.3 describes the minimum technical and management requirements to improve competitiveness. Finally, Sect. 6.4 presents the conclusion.

6.2 Automation Pyramid: Description, State of the Art and Constraints

To achieve the chapter's objective, it is important to define each level of the automation pyramid (see Fig. 6.1) to establish the requirements needed for IIoT applications.

- The first level (*Field level*) involves the basic instrumentation required for the physical work necessary for the automation process, for example, sensors, actuators, and other devices. In this case, these instrumentations are in direct contact with the process and, in general, can be defined as "dummy" (i.e., not smart) infrastructure.
- The second level (*Control level*) is considered the first smart level of the automation pyramid since it requires the information generated by the *Field level* infrastructure in order to make smart decisions. At this level, many control electronic devices can be used according to particular technical requirements and work area characteristics. For example, programmable logic controller (PLC), remote terminal unit (RTU), among other devices with the corresponding monitoring.
- The third level (*Supervisory level*) describes all the activities related to data acquisition from remote locations to perform high-level supervision and control from a unique location. These automation levels mentioned are commonly classified as *Operational Technology*.

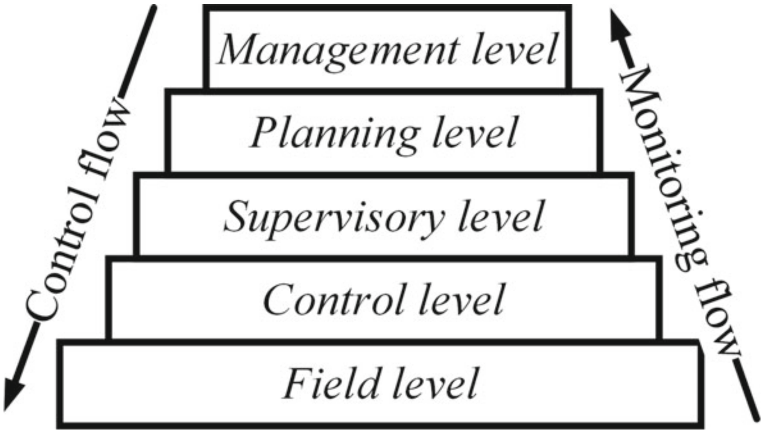

Fig. 6.1 Automation pyramid levels

- From the fourth level, we begin using the *Information Technologies*. Thus, the fourth level (*Planning level*) uses systems to monitor the complete processes of industry from the initial step (i.e., raw material supply) up to the end step (i.e., final product). In this case, articulated planning, that relates to manufacturing and management processes, is required. The manufacturing processes report to the *Planning level* the actual situation based on the interaction between the first three levels. It is important to clarify that the *Planning level* uses the information of all the production lines involved in an industry. This information is needed to make smart decisions related to required material, shipment plans, maintenance schedule, among others.
- Finally, the fifth level (*Management or Enterprise level*) is the highest automation level that integrates the monitoring and controlling of all the activities of the industry, such as all manufacturing processes, sales, purchases, and human resource details. Currently, some modifications or reductions to the automation pyramid have been proposed based on the fact that some particular tasks can be performed at various levels. However, the essence of the industrial automation model proposal remains constant.

In the following sections, we discuss, in some detail, the five levels of the automation pyramid.

6.2.1 Field Level

In this section, the basic task for the *Field level* instrumentation is presented, and based on that real constraints are shown. In addition, the state of the art is shown and analyzed considering the basic tasks and constraints. Thus, all the instrumentation used in the first automation level must be sensitive to all signals needed for a particular industrial process, such as indoor/outdoor weather conditions at the industry. This sensitivity means that the sensors produce an observable signal (mainly, electrical signal). In this point, the real industrial needs of each user have to be considered to determine the optimum instrumentation choice. Regarding the actuators, the technical capacity of each one is the principal constraint. Since the actuators and sensors are designed using different physical and technological backgrounds (i.e., electric, pneumatic, hydraulic, electromagnetic, mechanical, chemical, among others), it is important to evaluate the capabilities and interoperability between them. Therefore, the real constraints are highly related to the parameters and technical features according to the quality level desired by the industry. Thus, the first real constraint for IIoT at the lowest automation level is to clearly determine the quality desired for the process and services in order to choose the optimum sensors, actuators, and manufacturing machines. Clearly, this quality level is established from the highest automation levels and the *Field level* only focuses on contributing to guarantee the quality. In general, the minimization of errors and waste is desired to maintain or increase the quality and competitiveness, which means to clearly define the real constraints related to the parameters for the first automation level. Thus, the real constraints related to the quality and competitiveness are presented and defined as follows:

1. **Response time**: it describes the speed of the sensors, actuators, and manufacturing machines to do corresponding tasks. The principal trade-off regarding this statement is that the dynamic business process imposes the response time permitted so as not to delay shipments based on a particular order time and avoid overfilling the inventory.
2. **Precision**: it is related to accuracy. It describes the closeness between measurements. Thus, the entire infrastructure has to maintain adequate precision to optimize production efficiency, reduce the use of resources, and increase quality [9].
3. **Accuracy**: it describes the closeness of the sensor measurements, the action of the actuator, and the manufacturing activities that have to maintain a standard value close to the desired and designed value. Without ensured accuracy, it is difficult to ensure the quality of products or services.
4. **Intraoperatively**: it is related to compatibility between devices and brands in order to work together. In particular, compatibility means that different hardware and software can broadly share information and connection techniques to make an IIoT project more robust.
5. **Extra resources**: this considers the internal and external technical and operational support, maintenance, spare parts according to the lifetime of the element, equipment or machine, etc.
6. **Energy efficiency**: it is related to the use of minimum energy to perform an activity with the required quality of service. As support to industrial sustainability, this constraint is primordial since it procures an equilibrium related to the conventional sustainability concept and, in addition, among the other constraints.

All the real constraints mentioned are inputs to a cost-benefit analysis to determine the optimal resources that will be needed or used in the IIoT system. Based on the

Table 6.1 State of the art of field level

Real constraints	Scientific and technical contribution
Response time	Time-sensitive networking [20], advanced algorithms [21], novel designs [22], wireless actuators [23]
Precision	Novel clock synchronization architecture [24], multilayer architectures [25], high-precision prediction modeling for sensors [26]
Accuracy	Advanced localization algorithms [27], distributed collaborative control [25], sampling and filtering to increase the accuracy of heterogeneous data [28]
Interoperatively	Reconfigurable smart sensor [29], optimizing mobile sensor and coverage [30, 31], novel middleware for connecting multiple devices [32]
Extra resources	Cross-layer infrastructure and cloud service [33], adaptive components for extra capabilities [34]
Energy efficiency	Novel codesign [35], cooperative industrial sensor [36], dense low-power sensor network [37], data centers use [38], optimized energy efficiency based on time-switching receiver design considering the maximum transmit power and the minimum harvested energy per user [39]

real constraints mentioned, a vast amount of technology exists which intends to cover the constraints. Next, a state of the art is presented to improve the performance or solve particular problems (see Table 6.1). However, a cost-benefit analysis is always needed because, perhaps, some state-of-the-art technologies are not required. If a nonintelligent and nonoptimal decision is made at the *Field level* considering the real constraints mentioned, all the higher levels of IIoT systems based on the automation pyramid will be affected, and so, quality and competitiveness will be decreased.

6.2.2 Control Level

All the input and output signals used at the *Field level* are received and transmitted by control units implemented at this level. These signals are used to make smart decisions about the production process at the lowest level within the industry. In general, some constraints mentioned for the *Field level* can be considered at the *Control level*, however some principal trade-offs and issues can be present in the devices and systems used at this level that impose particular constraints. In particular, PLC, RTU, distributed control systems (DCS), among other technical options, are suitable, although it is very difficult to distinguish the optimal uses with respect to each one. Therefore, the real constraints for IIoT systems at the *Control level* are highly related to the real constraints of the devices used at this level and the competitiveness parameters of each industrial user. Next, some constraints are listed:

1. **Analog or discrete process**: it considers the real actions performed by the industrial process. An analog process requires high-speed processing, which means generally high costs, while in a discrete process, a lower processing speed can be

tolerated. Although both analog and discrete signals are simultaneously embedded in industrial processes by high-speed analog-digital converters.

2. **Control techniques**: it is based on classical or modern control theories. Each production process requires particular control capabilities, controller, compensator, controller tuning, among other important actions to improve its performance. Thus, an analysis is required for each particular production process before selecting the control unit that satisfies the performance of the control parameters.
3. **Production information**: it describes not only the required control action but also the technical production information regarding all controlled devices for an individual or collective processes working together. This information can be reported and used as a first fire wall to detect and avoid future problems related to productivity. In this case, access to information at a remote location based on an Internet connection is highly desired.
4. **Scalability**: it refers to the amount of input and output signals that a device can handle and process. In the same context, it is related to the capability to handle other devices at the same automation level and at the lower level.
5. **Processing architecture**: it is related to the processing units used individually or jointly to increase the performance of the processes. For example, processors and field-programmable gate arrays (FPGA).
6. **Power consumption**: it describes the power consumed by a control unit in order to perform particular processing. Specifically, there is a direct relation between the complexity processing speed for the control algorithms and the power consumption parameter.
7. **Security for enterprise domain**: it refers to the security options to protect the information generated based on the production process. This information can be used by higher automation levels and so, affect the complete business operation.

According to the speed of the industrial processes, some devices are suitable for real-time applications. However, the response time of the second level is highly related to the response time of the first-level devices, and more importantly, to the required production time. In this respect, an important aspect is the lifetime of the devices used at the *Field* and *Control* levels. For the second level, devices with a long lifetime of 5–10 years are usually considered, while lifetime at the first level is relatively short. This condition imposes an important financial analysis when the IIoT systems are designed. Table 6.2 shows the state of the art related to each constraint mentioned.

6.2.3 Supervisory Level

In general, according to the analysis performed by a particular automation level, considering the higher levels, more information related to the overall industrial process is generated, and at the same time, more control information is required for the lower levels. Thus, at this level, the unified information regarding all the process of lower

Table 6.2 State of the art of control level

Real constraints	Scientific and technical contribution
Analog or discrete process	High-resolution industrial monitor [40], improved electronic circuits, and transmission lines for high-speed I/O [41]
Control techniques	Nominal deterministic finite-state automaton-based model of the PLC control process [42], multicontrol distributed levels [43], optimal distributed elements control [44], output feedback fault-tolerant control and predictive compensation strategies [45]
Production information	Nontime-sensitive and time-sensitive data handled by fog computing and cloud computing [46], data logger and data archiving cloud storage for centralized data processing [47]
Scalability	scalable hardware/software architecture for multi/many-core PLCs [48], shared connecting areas (data aggregation and service cooperation) to connect divergent devices [49]
Processing architecture	Parallel programmable controller based on FPGAs [50], multi/many-core PLCs to reduce the scan cycle time [51], wide variety of processors such as Arduino Uno, Arduino Yun, Intel Galileo Gen 2, Intel Edison, Beagle Bone Black, Electric Imp 003, Raspberry Pi B+ and ARM mbed NXP LPC1768 [15]
Power consumption	low-swing global interconnection [52], power management for individual devices based on a powered center device [53], optimized communication protocols [54]
Security for enterprise domain	Mechanism to detect, analyze and remedy attacks [55], open source PLC modified to encrypt all data [56], calculating the uncertainty characterization of the PLC system [57], shifted time redundancy for error detection and correction [58]

levels (first and second levels) is needed in order to perform overall supervision and control in accordance with the productivity and the general performance parameters related to competitiveness. For these tasks, a supervisory control and data acquisition (SCADA) system is commonly used. In fact, the responsibility of the *Supervisory level* is to cover the communication between the *production* and the *management* levels (from the third to fifth level). For example, manufacturing operation management (MOM) system and manufacturing execution systems (MES) permit to control the production process performed at lower levels. These systems (MOM and MES) are described in the next section. Thus, the *Supervisory level* has important requirements that impose real constraints in order to communicate and control the lower automation levels and receive information from higher automation levels. Among the more important constraints, we have the following:

1. **Resilience level**: as aforementioned, *Supervisory level* is the medium level, so permanent use is required. Therefore, resilience level constraints mean that the downtime has to be minimized (or ideally, avoided).
2. **Connectivity performance**: the bandwidth and latency parameters are important to establish adequate communication between the devices and the systems of the lower levels with the other systems of the higher levels. Reduced bandwidth and

high latency can produce business decisions in nonreal time that affect productivity and competitiveness. In addition, availability is the primary requirement for connectivity performance, so local/remote access and monitoring are needed since the supervisory actions cannot be interrupted.

3. **Real-time processing**: it describes the processing speed related to the information rate in transmission and reception. It is important to clarify that real-time processing is somewhat subjective, i.e., the real concept should impose parallel processing. However, the real-time processing parameter is established considering the speed of the business model that involves all the automation levels.
4. **Secure access and confidentiality**: these define the access rules according to the risk level for a particular or overall industrial process. In fact, not all supervision processes need these features. In particular, unidentified interfaces, fire wall management, unknown services provided by third-party software, logical and physical configuration mismatch, and extended access to SCADA systems are potential vulnerabilities.
5. **Well-defined thresholds and keys**: these are required for all lower automation processes because this automation level performs supervision and control activities based on the acquired data. In particular, the key concept describes the important aspects that can be related to the other constraints mentioned, for example, authentication for users and systems at different levels, mutual communication ensured, among others.

The state of the art for the real constraints discussed above is now shown in Table 6.3.

6.2.4 Planning Level

This level needs enough information about different topics related to the complete business system, i.e., production information and internal/external management information. This information is required to plan the production, manage and track the resources (material, people, tools, time), which are necessary to make specific or general schedules related to quality control and generation of reports used to make smart business decisions.

It is clear that, at this level, mathematical models based on a learning method using data management are highly required. In particular, the MES technique helps to optimize productivity based on strictly real-time tracking and monitoring of all resources. In fact, sometimes the MOM system is considered the intermediator between the *Supervisory* and the *Management* levels. Next, some real constraints are presented and described according to the relationship with the other automation levels. Table 6.4 presents the state of the art related to the *Planning level* constraints.

1. **Monitoring features**: these are related to the historical statistical analysis and real-time data to determine the clear performance of the industrial processes,

Table 6.3 State of the art of supervisory level

Real constraints	Scientific and technical contribution
Resilience level	Wireless sensor and actuator networks embedded into conventional supervisory systems to improve the dynamism, redundancy, fault tolerance, and self-organization [59]
Connectivity performance	Harmonize the standards to improve interoperability [60], optimize performance based on load data analysis [61], classify the type of information to be transmitted through the network to handle the operations in order to optimize the throughput network [45]
Real-time processing	Hardware-in-the-loop techniques and software integration [62], tracking states estimator for fast-rate processes and slow-rate supervisory system [63]
Secure access and confidentiality	Modern intrusion-tolerant protocols integrated to conventional systems [64], monitoring of available Internet-connected devices to avoid cyber attacks [65], multilayer cyber-security based on multiple attributes analysis [66], secure authentication protocols [67, 68]
Well-defined thresholds and keys	Impact of SCADA data accuracy on real-time processes [69], accuracy improvement based on frequency analysis [70], advanced and robust machine learning for robust thresholds calculated based on statistics [71]

Table 6.4 State of the art of planning level

Real constraints	Scientific and technical contribution
Monitoring features	Offline and online analysis using statistical process and complex event processing models [72], oriented to provide useful information to the users of the manufacturing service provider, manufacturing service consumer, manufacturing service operator, among others [73], novel techniques used in the virtual factory concept [74]
Information kinds	Centering much information to improve the sustainability in industrial operations scheduling [75, 76], a great amount of concentrated information digitized increases the need for optimization techniques so as not to create a bottleneck for competitiveness decisions [77]
Basis of decision	Simultaneous and deterministic execution of control algorithms based on open-knowledge-driven [78], data mining techniques to improve the speed and robustness of processes [79], predictive scheduling based on hybrid control architectures [80], algorithms that use information from public cloud, private interenterprise cloud and manufacturing cloud regarding inbound/outbound logistics and mainstream processes to make smart decisions [20]

quality of service and products, and overall optimization. Sometimes an offline analysis is sufficient since the data variability is not extremely fast.

2. **Information kinds**: these refer to very large volumes of different kinds of data regarding manufacturing and management processes. These data are centralized and analyzed and considered as input signals to the complete business system. Thus, all information must be correctly processed and presented in the user interface without considering the information kind.
3. **Basis of decision**: it is related to the model used to produce output signals based on particular input signals. It is important to keep the rules well defined and available for a process of continuous improvement. Thus, proactive monitoring permits to make smart decisions.

6.2.5 Management Level

At the top level of the automation pyramid is the *Management level*. Recall that the lower automation levels perform particular tasks and, in general, higher levels monitor and control the lower levels considering the particular real constraints and requirements. In the same essence, the *Management level* uses all the information regarding the lower levels, i.e., it has a full view of all operations within a company, although it also requires external information. This action allows efficiency to be promoted based on continuous improvement processes and thus, improve quality, which leads to an increase in competitiveness. To perform these activities, ERP (enterprise resource planning) is commonly used since it allows to increase the productivity based on the information available (databases) at the same platform in order to save time and reduce costs. In addition, ERP systems allow the use of business intelligence tools to determine the actual enterprise status. The most important constraints and state of the art (see Table 6.5) related to this level are the following:

1. **Response time**: it is related to the time required to make smart decisions at the top automation level. It is clear that the response time is not the same as for the lower levels. In this scenario, the response time at this level highly depends on the dynamic of the market. Also, the connectivity status is highly related to the response time. In particular, connectivity is related to the interconnection capacity of the applications, software, hardware, and platforms used at this level, not only for communication with lower levels but also to communicate with the external infrastructure.
2. **Infrastructure for integration**: this is based on software, hardware, and databases needed to monitor and control in an integrated manner at all lower automation levels. If many platforms are used based on an in-depth technical analysis, a low integrated level is highly possible and, therefore, the decision-making process can require a lot of time with high uncertainty.

Table 6.5 State of the art of management level

Real constraints	Scientific and technical contribution
Response time	Optimal update policy for the industrial database [81], prediction of cloud capacities for unstable service demands based on some algorithms to reduce service delays [82]
Infrastructure for integration	Technical support for the expansion of applications in the cloud for processes inside and outside the industry [83], optimized cloud and enterprise application integration based on cloud service bus [84], customized design of software for enterprise based on particular features [85], transformation of workloads using public/private/hybrid clouds [86]
Security	Analysis of critical success factor related to compliance, network, and security based on strict modeling [87]
Data accuracy	Component-level asset granularity to obtain specific and timeliness information required [81, 88], enterprise cognitive computing industrial applications in order to make complex decisions based on an ambiguous business context [89]

3. **Security**: this is extremely important because all the lower levels (inside the company) depend on the decisions taken at this level. In addition, information from outside the company (e.g., finance, accounting, human resources, sales, purchasing, payroll, etc.) cannot be available for arbitrary personnel.
4. **Data accuracy**: it is referred to the fact that all the lower automation levels send different types of information (related to manufacturing, human resources, finance, processing time, among others) to higher levels. Finally, complete or partial information is stored and used by the top level according to the operational rules established. Thus, degradation of accuracy based on particular problems at different levels of automation is possible. Therefore, data accuracy is highly required to make smart decisions according to industry reality.

Finally, the IIoT constraints (relating to the five levels) as already mentioned can be related to the conventional management theory for organizations, where four stages (control, direction, organization, and planning) are commonly used, as Fig. 6.2 shows. In fact, the IIoT system explained using the automation pyramid is a cybernetic system approach for industrial business management, which means that some challenges presented in the context of conventional management are very similar to the IIoT systems. Clearly, there are also some relevant differences between them, mainly those related to hardware and software [10].

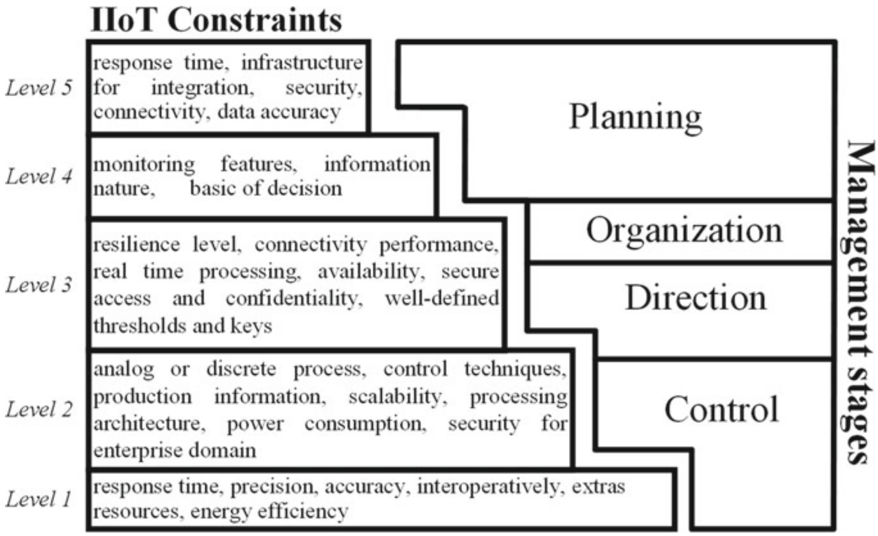

Fig. 6.2 Automation pyramid levels

6.3 Minimum Requirements for IIoT Projects

Currently, IIoT projects can be analyzed using the conventional automation pyramid. However, the cloud computing technique and high-end hardware and software are suitable options that work through the Internet and impose a conceptual modification of the physical topology automation pyramid to a logical topology automation pyramid. Thus, all actions performed by each automation level must still be performed, but now it is possible to use the Internet to generate a local/global link considering static/dynamic data and services provided by different systems (see Fig. 6.3).

In particular, monitoring and control flows are still used, only security cross-layers are added between conventional automation levels. Although there are some IIoT architecture proposals that involve multilayer related to data acquisition, business logic, identification, classification, communication, and control activities [10, 11]. However, the minimum requirements are not yet considered for these architectures.

Therefore, the minimum requirements are not completely related to the available high-end hardware and software because this means that the IIoT projects are not available for small and medium companies. In fact, the minimum requirements are associated with some particular industrial features to reach a particular competitiveness level using IIoT technology at the same time, which is related to specific costs, e.g., a cost-effectiveness analysis (CEA) for IIoT project is required to analyze the desired industrial competitiveness. In order to clarify, the complete minimum requirements are related to the overall performance regarding the hardware, software, cost, and effectiveness for a particular IIoT system to reach wanted competitiveness. Thus, the minimum requirements are proposed as follows:

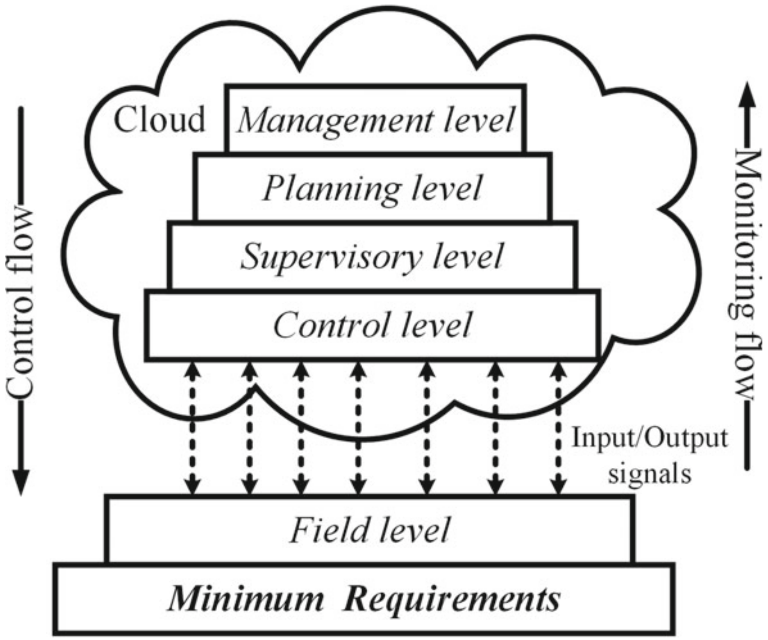

Fig. 6.3 Proposal logical topology for the automation pyramid

1. **Well-defined internal and external industrial processes**: these are important for the industry to clearly define the internal organizational structure. The clear definition involves all the internal processes related to all the automation levels. Also, for higher automation levels, external processes are required. If a company does not fully define the processes, the IIoT project will be an impossible task since the high-end hardware and software cannot fix the management mistakes related to the internal/external organization. In this context, the size and kind of the enterprise/company do not matter. In fact, there are small companies with well-defined processes while other large companies do not give such importance.
2. **Well-defined parameters for each hypothetical automation level**: in general, each internal/external process must have particular important parameters as input and output data to perform their particular tasks. Next, these parameters have to be classified and assigned to particular automation levels according to what was mentioned in the previous sections (i.e., characteristics and real constraints of automation levels).
3. **Well-defined intraoperatively features and communication processes between hypothetical automation levels**: an overall and well-defined process considers intraoperatively between all the stages of the process based on sharing features and a communication process to share information. Thus, control and monitoring information flows are defined. If a company has a well-defined particular process, but this process cannot communicate and understand with other processes, the IIoT project will have a major problem.

4. **Well-defined lean production based on a systematic method for waste minimization**: also called lean manufacturing, where the primary objective is to reduce all waste in the production processes related to internal and external industrial processes. In other words, it is not possible to make an overall IIoT project considering the automation of waste, i.e., firstly, waste minimization is a requirement. In order to do that, information, material, and personnel flows have to be ensured [12, 13].
5. **Competitiveness level desired**: another requirement before the implementation of an IIoT project is the competitiveness level desired to reach when the IIoT system is implemented. In fact, this requirement may be the most difficult to establish and measure by the company, since the parameters to measure the competitiveness level are established according to the mission and vision of the company. Usually, the industry does not consider this requirement based on a low uncertainty related to the IIoT marketing. However, it is important to clarify that not all IIoT projects implemented ensure an increase in the competitiveness level when the planning project does not consider these parameters.

In general, the minimum requirements mentioned can be described using, e.g., the Toyota house philosophy [14]. Thus, the minimum requirements establishment is the first step in order to plan an IIoT project as shown in Fig. 6.3, where the basis of the novel automation pyramid is the aforementioned requirements. On the other hand, the minimum requirements and real constraints mentioned impose effectiveness related to the competitiveness level desired at the cost related to the wanted competitiveness. Therefore, any company that intends to begin an IIoT project have to consider the cost-effectiveness analysis (CEA).

Figure 6.4 shows a graphical cost-effectiveness analysis where the parameters mentioned are related (i.e., competitiveness and cost). Thus, there are four scenarios as follows:

- competitiveness increase requiring more cost
- competitiveness increase requiring less cost
- competitiveness decrease requiring more cost
- competitiveness decrease requiring less cost.

In particular, the ideal scenario is when an IIoT project considers all the minimum requirements and real constraints to increase the competitiveness with a lower cost, which is highly desirable. However, another scenario close to the ideal is to reach the desired competitiveness with a higher cost, which means that a depth evaluation is needed to reduce the cost. In order to clarify, sometimes IIoT projects have a strongly reduced probability of success because the proposed high-end hardware and software do not take into account the minimum requirements and real constraints, and thus increasing the cost and decreasing the IIoT effect, i.e., reducing the competitiveness. These IIoT projects are most likely to be abandoned or rejected.

Considering the aforementioned, an important minimum requirement is also the financial situation and investment budget that the company considered necessary to increase its competitiveness.

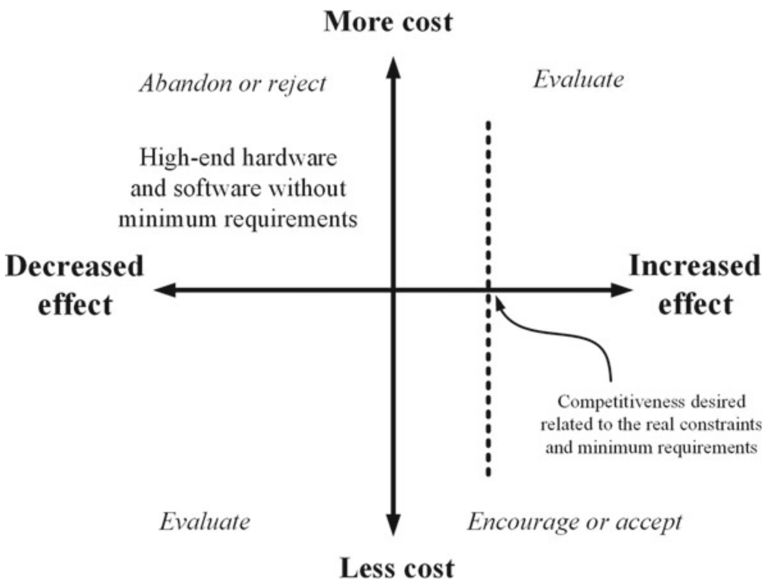

Fig. 6.4 Cost-effectiveness analysis for IIoT projects considering minimum requirements

What has been previously mentioned imposes minimum requirements for the hardware and software used in IIoT projects in a logical topology for the automation pyramid. It also considers the real constraints related to each automation level. For example, the hardware and software classified as *Commercial Off-The-Shelf* (COTS) and low-cost programmable controllers are the available options for *Field* and *Control* levels. Commonly, these options use freely available easy-to-use programming software. However, these options must be analyzed using the real constraints, as mentioned in Sects. 6.2.1 and 6.2.2, according to the particular needs of the industrial processes and the required competitiveness level.

Depending on the competitiveness level desired, some parameters of specific devices should be analyzed in depth, such as clock speed, bus width, system memory, supported communication, development environments, programming language, and connectivity [15]. Regarding the three higher automation levels (*Supervisory*, *Planning*, and *Management*), there is a large amount of multipurpose software with outstanding flexibility and connectivity performance between others platforms [16–19]. Also, these options have to be analyzed using the real constraints as mentioned in Sects. 6.2.3 and 6.2.5.

In order to further explain, some tasks performed at the higher automation levels are defined based on internal and external industrial rules (e.g., warnings, thresholds, operational and manufacturing management, planning information about all the business industrial model, external information related to the customers, among others), so it is difficult to be specific about these tasks.

6.4 Conclusion

Nowadays, the roadmap for the implementation of an IIoT project is not clear at all. Although the IIoT paradigm is a highly attractive topic for research as well as for applications for the industry and academic sectors, it mainly refers to particular research lines, e.g., improvement of the technical performance, integration level, security, and management issues. Thus, the misconception that the IIoT directly increases the competitiveness of any industry without performing a complete analysis of the pertinence is the most important factor to reduce the probability of success of any IIoT project.

This chapter has presented the conventional automation pyramid and its relation with the IIoT projects. A summary of the state of the art and the real constraints related to conventional automation levels has also been provided. The aforementioned helps to determine the minimum requirements needed for any company in order to implement an IIoT system to increase the competitiveness level. In fact, increasing the competitiveness of any company is the main objective when an IIoT system is implemented for the supply chain.

It is evident that if the competitiveness is not increased based on a previous formal cost-effectiveness analysis, an IIoT system proposal is not suitable for a particular application. Hence, conventional management and industrial techniques/tools should be used first to improve competitiveness relating to the IIoT system planning.

Additionally, the minimum requirements needed to begin the analysis of a potential IIoT project are proposed and defined. Thus, well-defined internal and external industrial processes, clear parameters for each hypothetical automation level, detailed intraoperatively features and communication processes between hypothetical automation levels, implementation of lean production based on a systematic method for waste minimization, the establishment of competitiveness level desired, and the financial support are the minimum requirements defined.

In this context, the use of the business process management maturity (BPMM) model is highly recommended to determine the maturity of the organizational process. Consequently, the maturity level can support the decision of whether an IIoT project should or should not be started.

Our future work involves the investigation of a clear roadmap to implement IIoT systems in the industry (or any particular company) based on well-defined stages, real constraints, and minimum requirements to determine the probability of success regarding the competitiveness level desired.

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