Design and Integration of Automation Systems with Manual Operation: Small and Medium Enterprises issues

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Abstract.
Today it is more and more mandatory for all commercial companies to comply with the principles and methodologies of Industry 4.0 and to achieve the related capabilities protecting their competitiveness and taking a leading-edge position on market as regards technologies. Specifically, the whole production and sale system must achieve the fundamental characteristics of Industry 4.0 approach, but specially the manufacturing companies must also change and update their management procedures, internal organization, resource training, assets and all production process to keep safe their current business capacities. This evolution process is even more critical for Small and Medium Enterprises (SME), that traditionally tend to be conservative and to protect their way of operation, usually characterized by a low level of automation. The work presented focuses on the design and integration of a semi-automatic welding cell of train bolster in a SME which is currently realizing a project aimed to the acquisition of Industry 4.0 capabilities, with special focus on manufacturing processes. Among them, one of the most important is the production of welded-steel critical structures, that the Company supplies to prime manufacturer of railway rolling stock systems. The experience gained during the activity, the criticalities due to the integration processes and the adopted design methodologies are here described. The work has been carried out consistently with the Systems Engineering principles, starting from the requirements elicitation and analysis to the systematic approach for the design and integration activities.

Keywords: Industry 4.0, Internet of Things (IoT), Design Methodologies, Systems Engineering, CAD, Welding process.

1 Introduction

To keep up production standards and the whole sale system, companies must achieve the four following fundamental characteristics of Industry 4.0 [1]:

- Vertical integration between all hierarchical levels of the value chain
- Horizontal integration between all the players in the supply chain
- End-to-end design that links all the phases of product conception, production and distribution
- Technological integration

The manufacturing companies must also change and update their management procedures, internal organization, resource training, assets and all other production process components to safe their current business capacities [2]. Therefore for SME, traditionally tending to be protective towards their way of operation, these changes might be critical. The digital transformation process is involving all business realities, be they large, medium or small. This transformation deeply reshapes organizations which, called upon to take up the challenge linked to new technologies, must innovate the processes, the management of information flows and often their business models. The fourth industrial revolution [3] and its technologies have undoubtedly contributed to this evolution; these last ones are an essential element for new factories or in general for smart businesses.

The transition to the Industry 4.0 paradigm is determining a new product supply logic. Manufacturing is no longer a mere process to obtain the product but becomes a service available by different actors. Factories are no longer static and immutable, they become modular and can be rearranged depending on the order [4]. The long and laborious product research and development activity is now enriched with Big Data analysis reducing the over time, increasing product quality and customer satisfaction. In the vast nomenclature of Industry 4.0, the concept of "cyber-physical systems", in short CPS [5], is the one that probably arouses the greatest astonishment and is among the least known. Industry 4.0 aims essentially to maximize the adaptability of Europe as a production site in general and of individual production plants. Ultimately, the aim is to maintain international competitiveness, jeopardized by countries with low labor costs and countries with emerging markets. In this scenario, the present work is focused on the experience gained with the design and integration of semi-automatic welding cell of train bolster assembly, activity developed in close collaboration between the School of Engineering of Basilicata University, the Department of Industrial Engineering of University of Naples Federico II, Department of Engineering and Architecture of Trieste University and PROMEC Srl.

In the following paragraphs the conceptual design of the semi-automatic welding cell will be explained. The reasons that led to this mixed configuration, the functional diagram of the cell and the flow of information that the different stations exchange with the central server will be presented in detail. All that has been developed according to the principles of the Industry 4.0 and through the Systems Engineering approach [6].

2 Motivation and Objective

PROMEC is a SME that is currently realizing a project aimed to the acquisition of Industry 4.0 capabilities, with special focus on manufacturing processes [7]. Among them, one of the most important is the creation of welded-steel critical structures, that the company supplies to prime manufacturer of railway rolling stock systems (i.e. trains, vehicles and other major components).

The welding process is a critical task due to:

- the high safety requirements that parts shall comply [8];
- the consideration that – as well known – welding is a Special Process;
- very binding inspections and traceability requirements [9];
- the large amount of workmanship that the process currently employs (almost all the process operations are traditionally not automatized but realized by qualified workers);
- the high grade of geometrical complexity of the product, combined with low production rates.

For these reasons it seems very difficult to make innovation in this specific area. Nevertheless, the company has bought a robotized welding cell, trying to automate as much phases as possible, but the largest part of them (about 50%) will remain necessarily manual. Due to this it has become mandatory integrate the robotic cell with manual processes. Some tasks (part positioning, tack welding, Non-Destructive Tests) could be performed by one or more operators while other ones (as welding of heavy joints) could be realized by the robot, always respecting the sequences provided by the work schedule/work order. In any case, it has been mandatory for the design to guarantee the automatic acquisition (through the Company Information System) of all the parameters and information (planned and actual) that must be reported in the Manufacturing and Control Plan (MCP). The MPC resumes and certifies characteristics and values of the whole manufacturing process of each part, ensuring the total compliance to the Quality and Safety Requirements of the part itself.

3 Material and Methods

This work has been carried out following the Systems Engineering approach which allows to understand how systems fit into the larger context of day-to-day life, how they behave, and how they are managed. This process has an iterative nature that supports continuous learning and improvement; indeed, it involves looking at a problem in its entirety, considering all the facets and all the variables relating social and technical aspects.

As a matter of fact, Systems Engineering and Industry 4.0 imply the implementation of technological advances (in some cases already used in the traditional manufacturing system) in a way that gives birth to a fully integrated, automated, and optimized production flow, also defined as Smart Manufacturing [10]. Adopting a SE approach allows for the requirements elicitations (e.g. quality and safety requirements) from the early stage of the design and it provides the techniques for the Verification and Validation process [11], representing a key phase for the approval of the welding operations [12]. The aim of the work concerns the integration of the existing technologies into real business contexts and not only mere technological installations in the manufacturing process. The integration of these technologies and approaches in SME is the critical point of the development process since typically, the environment of SME has a low level of automation with processes not very structured. Sometimes the knowledge about the critical manufacturing process (be technical, logistics, commercial etc.) oversees few employers or operators and it is not managed by enterprise information system. In these industrial contexts it has become difficult to have a good traceability of materials and processes state along the entire manufacturing process [13]. The focus is on specific macro phases of production regarding welding. Therefore, in addition to the traceability of the material, the designed cell guarantees, as an information output, other essential data such as: operator traceability, welding parameters, processing start and end time, current and voltage values. The expected results will be to facilitate the production flow and above all to control it in the manual phases, which nowadays does not occur. With the design of a semiautomatic welding cell combined with a robotic welding cell, an attempt has been made to overcome all the problems relating to the transmission and compliance with parameters and data.

Very often, in a working day, structured over several shifts and with different operators, the directives imposed by a welding procedure specification (WPS) are not properly respected because they are subject to variations, based on the evaluations of the single operator; these problems can be overcome using an appropriate data control and management architecture. The robotic cell has been integrated with a "manual welding cell"; both cells cooperate for the manufacturing of the welded component. In this configuration the manual tasks carried out by the operators are integrated with the tasks of the welding robot. Fig. 1 illustrates schematically the layout of the two cells, both in the simple configuration and in a more evolved form (manual cell and robot cell).

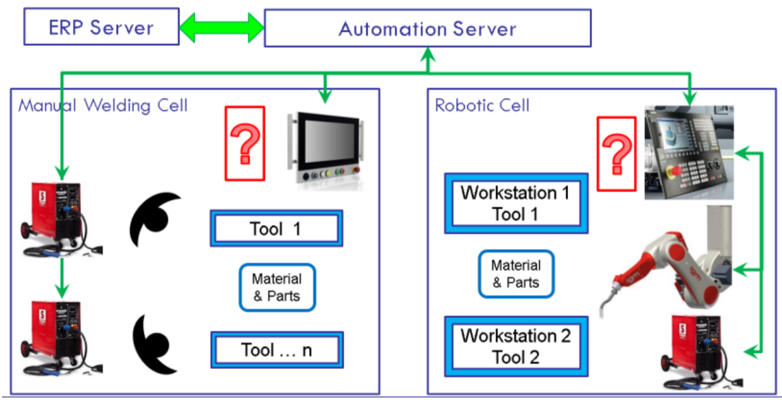

Fig. 1. Functional scheme of the Integrated Welding cell.

In this communication flow the voltage, the current and the wire speed are transmitted. There is a forward feed that lists the parameters to use, and a feedback that records the ones used. The kinematics between the unit and the robot is defined, the control unit is thus able to control everything and provides all the necessary information. If the robot were the only one to oversee the welding phase, we would already be in a situation of industry 4.0, but at present not all information is collected. Both cells are managed by a control unit exchanging information with the Automation Server. The control units manage the cells working areas and the related inputs which can be materials, tools and operators. These units manage the access in working areas in two different ways: it can be physical, by an access barrier, or consists of a series of photocells detecting or acquiring welding data, in direct connection through a port with the welding machines. According to SE approach this architecture assures the traceability and control, also in real time, of the process parameters both for manual and robotic tasks. For our project concerning the train Typical Moving Bolster, the cell must be equipped to perform two of the five welding phases plus all the control phases. The Fig. 2 schematically illustrates the data flow expected to be managed, the flow chart has been superimposed on the layout, previously presented, to highlight separately the characteristic data of each cell.

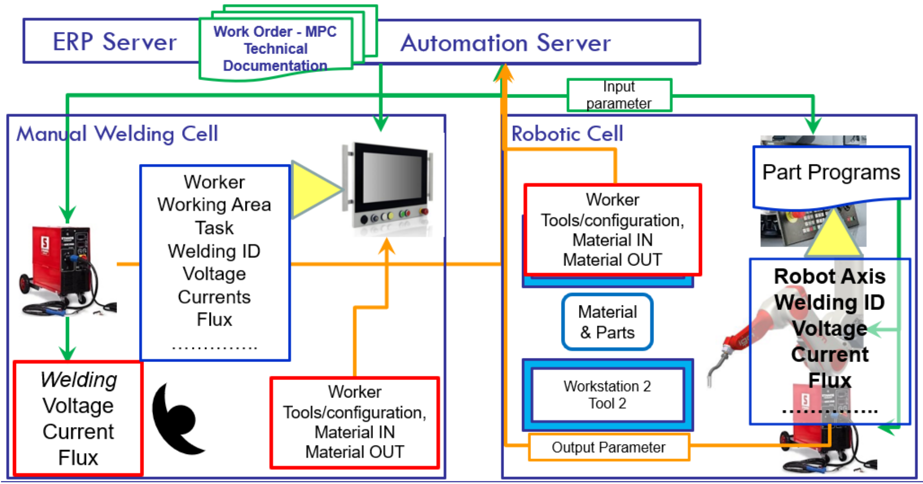

Fig. 2. Information flow between central server and workstations

Work Order, Technical Documentation and MCP data are to be considered shared (fully or as much as necessary) between ERP and Automation Server; the green connectors indicate the flows to and from the Control Units and/or the work cells, while those in orange return to the automation server from devices also different from the Control Units themselves. The large yellow arrow indicates the extraction of the aggregated data received from the automation server for sending to the various devices in the field, while the red boxes list the parameters that will need to be detected. To understand in detail what information the server needs compiling and updating the MCP, a typical one made in PROMEC was analysed.

4 Case Study

Currently PROMEC is dealing with the modernization of both its organization and manufacturing assets to protect its competitiveness and to achieve new market opportunities. Two years ago, it launched a program aimed to introduce significant modifications in the management and realization of all its processes maximizing the implementation of the principles of Industry 4.0 in its production. One of the most important manufacturing programs is a train *Typical Moving Bolster* (TMB), shown in Fig. 3.

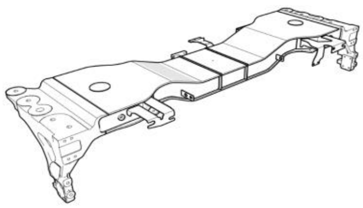

Fig. 3. Typical Moving Bolster

The TMB is a typical welded assembly, used as intermediate element linking the bogie and the train body shell. It is very important to allow the required degree of freedom between the two parts, transmitting in a suitable way the forces. TMB runs stably on both straight and curved track; it absorbs vibration generated by track irregularities and minimizes the impact of centrifugal forces when train runs on curves at high speed. The production flow of a typical TBM order has been analysed for understanding how resources are located and what is the technological level of the individual production steps Fig. 4.

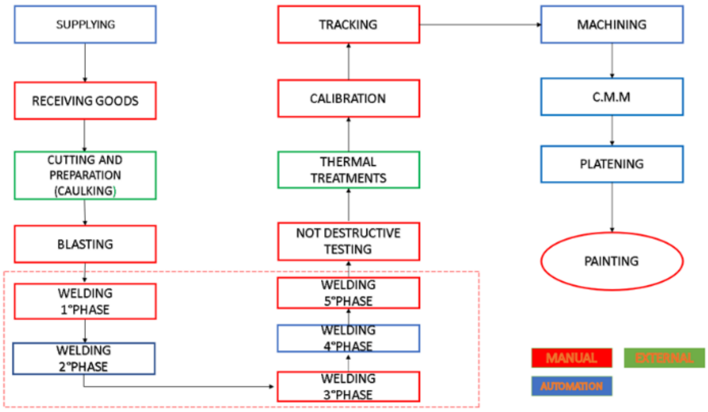

Fig. 4. Complete TBM production flow diagram

schematically represents the manufacturing process performed in PROMEC for a TMB fabrication. It must be highlighted that such kind of process is characterized by a significant alternation of automated and manual phases. In order to achieve the optimal integration between manual welding phases with robotic welding operation and maintaining at the same time unaltered the production flow, the following steps have been carried out: collection of a series of information and parameters on the manual operations not currently considered; integration of all information for the whole cycle until the MCP is automatically completed [14]. According to SE principles, the concept design of work cells has started from the collection of the information (parameters and needs) related to the welding operation and from the reporting of such information into functional requirements. This stage builds the guidelines for the next design stage as well as for the verification and validation activity. Using the layouts provided by the robot manufacturer, the overall dimensions have been considered to adapt the cell with the space available in the company and integrate it with the semiautomatic cell.

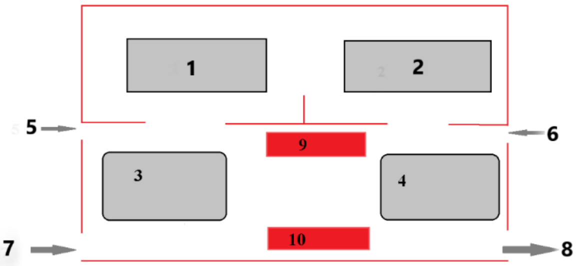

Fig. 5. Final Layout of the two cells

Considering the subdivision of the process phases, the available area has been analysed and implemented to optimize the construction of two cells. Fig. 5 shows the production flow and the logistic organization of the available space. The areas indicated with the numbers 3 and 4 are part of the manual welding cell in which the first welding steps, the bolster checking and verification before authorizing the subsequent phases, the welding and finishing of certain parts are carried out. The areas indicated by the numbers 1 and 2 represent the two robotic stations, in which the two phases of welding of the central body with the closed box are performed. The arrows 5 and 6 represent the two independent entrances for operators equipped with badges (without which they would not have access to the cell), while arrows 7 and 8 indicate, respectively, the input of the semi-finished pieces and the exit of the welded components. The semi-finished pieces entering the cell, in the form of kit, are identified with a code that is transmitted to the cell control unit and then to the servers. The areas labelled 9 and 10 are reserved for the quality control. According to the flow described in Figure 5 and the available area in the PROMEC context a detailed layout of the robotic and semiautomatic welding cell has been developed Fig. 6.

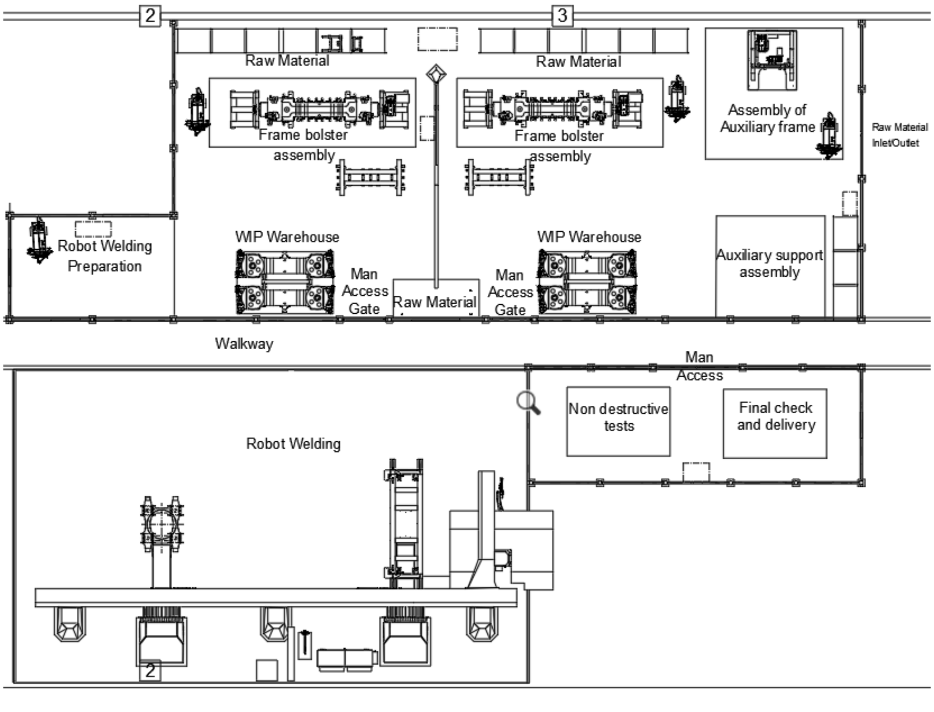

Fig. 6. 2D layout of the two cells

The final design of the two cells is visible in Fig. 7. The entire working area has been modelled in virtual environment (Fig. 7) [15].

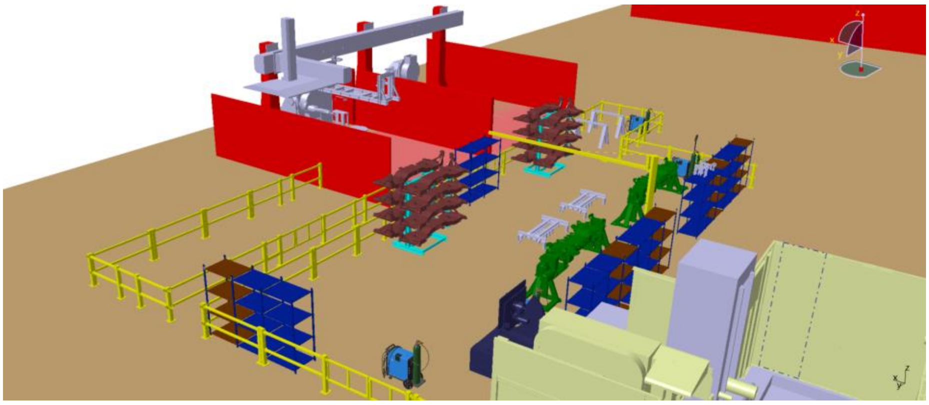

Fig. 7. Working area in Virtual Environment

For the detection of data on machines not equipped with processing units, the use of appropriate sensors (relative low cost) connected directly to the cell control unit is envisaged. Even if the robotic cell has a central unit for the data ex-change, an additional unit which communicates directly with the automation server and therefore with the ERP server would be helpful.

This architecture enables a dense network of data exchange in real time, which allows to gather excellent results with a view to saving time and reducing errors. This architecture helps in saving materials, in more reliable and economic management of their traceability, in the automatic compilation of MCP and all manufacturing documentation. The interface with the company management (ERP) allows the pre-processed production plans to be distributed in the factory; the orders progress in real time are returned via control terminals to the ERP management system, which also updates materials and finished products warehouse. The efficiency of the new production process is significantly improved compared with the previous one and it represents a big step forward from the industry 4.0 point of view.

5 Conclusion

The design and development of an innovative architecture for a semi-automatic welding cell in a SME based on main principles of Industry 4.0 has been presented in this paper. The new architecture, based on IoT and human-robot cooperative environments, leads to a time saving in the product completion and a greater interaction between human and robotic work with excellent results in terms of final product quality. Furthermore, the new architecture allows to know and store previously neglected information, such as the welding machine's working parameters, the beginning and end of the welder's working hours and useful information for the automatic compilation of the manufacturing and control plan. All that contributes to an increased quality of the production processes and products since all the parameter related to them can be managed and controlled on time. This method, allowing the storage and the management of the industry knowledge, will bring also numerous benefits on process planning for sub-sequent orders. The semiautomatic welding cell is now under construction, the cell can guarantee the management and traceability of the information related to the welding process. The approach here described does not allow for the global automation of the welding process, this aspect could be a limitation of the potential benefit of the Industry 4.0 approach but on the other hand the work developed demonstrate its feasibility in not structured industrial context. The authors are aware a test activity to finalize and validate the approach is needed, the experience gained in a real context highlighted the issues related to the implementation of design approach and design solution in industrial context, due to the constraints related to the product and process complexity.

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