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Intelligent Manufacturing System Configuration and Optimization Considering Mobile Robots, Multi-Functional Machines and Human Operators: New Facilities and Challenge for Industrial Engineering

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Abstract: The combination of multi-functional machines and mobile robots supports the emergence of highly flexible intelligent manufacturing systems (IMS). In this kind of manufacturing system, some machines must stay fixed at previously established positions (heavy equipment) but some types of multi-functional machines (small flexible equipment and mobile robots) can stay in one position for one or several periods and change their position for others periods, or change permanently their position in the shop floor. Moreover, using mobile robots allows performing transportation and operation simultaneously. This possibility may change the decision processes and manufacturing system configuration, calling into question the existing decision methods in strategic, tactical and operational levels. This paper concerns the specific production systems in which mobile robots operate in the same shop floor and at the same time with conventional and multi-functional machines and humans. This kind of production system is more sophisticated than conventional manufacturing chain (as cellular manufacturing system) and can decrease the reactivity time and new products can be quickly introduced (as for dynamic cellular manufacturing system). However, the configuration and optimization of this kind of system is very different from conventional production systems. In this paper, in one hand, the advantages of this kind of system and then several difficulties and challenges from operation management and industrial engineering point of view in configuration, organization, planning and optimization of IMS is discussed and developed. As a first step it is considered that localization is a key issue in the highly flexible intelligent manufacturing. Several approaches exist for outdoor localization, but indoor localization is an open problem. In this work, it is presented and discussed the highly flexible intelligent manufacturing system and the indoor localization. *Copyright ©2015 IFAC.*

Keywords: Intelligent Manufacturing System (IMS), production system configuration, planning and optimization, localization, mobile robot, dynamic cellular manufacturing system.

1. INTRODUCTION

The development of new generation of more flexible and agile production systems was required to satisfy customer requirements in terms of variety, quality and response time. In a highly competitive environment, manufacturers will adopt the strategy of offering a new product as soon as possible the wish by the consumers to have such product has been detected. This strategy requires the companies to have a much more flexible production system and more responsive, the Intelligent Manufacturing Systems program (IMS, 2014) is the most relevant answer today. In this program, the following possibility is pointed: some heavy equipments (i.e., numerical control machine tools) must remain at pre-established positions, while the position of others can change dynamically (i.e., mobile robots). The mobile robots are able to ensure the realization of simple and/or complex operations as well as transportation (Tavares et al., 2011). There are many international research projects related to design of machines and robots

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for IMS such as: Automated Imaging Screening and Data Capture, Economics of Model-Based Manufacturing, Energy Efficient Manufacturing, Sustainable Supply Chain Management, Virtual Manufacturing, etc. (IMS, 2014). Thanks to important research and amazing progress in microelectronics and mechatronics engineering, as well as computer science and artificial intelligence, several companies developed excellent mobile robots, that are ready to use in production systems. A steep increase in the use of this kind of equipment in factories and manufacturing systems for operations and transportation has been observed. However, few research focus on challenges and methods related to the configuration and organization of these manufacturing systems. Additionally, as it will be shown, indoor localization is an open issue.

Dramatic advances in robotics and automation technologies will be even more critical with the next generation of high value-added products based on high performance and flexible equipment with embedded computers, sensors and microelectronics asking high tech micro- and nanometer products, the manufacture by human operators is no longer a viable option. According to data from the IFR (International Federation of Robotics, 2014), the number of robots in worldwide industry is increasing with 9% annual average since 2008 and 12% in 2013. According to the same source, the annual increase of 12% will continue at least until 2017. This increase rate is significantly higher in China ($> 50\%$ per year), as in some countries with low cost human resources. According to a study conducted in 2013 by nine prestigious United States universities, entitled “A Roadmap for US Robotics” (Christensen, 2009), it is expected that with the new generation of mobile robots and manufacturing systems, a new product can be configured into mass production in 24 hours in 2018, 8 hours in 2023 and 1 hour in 2028. The robots are becoming more sophisticated and inexpensive. They will be able to perform highly uncertain operations and even learn just by watching the movements of a human operator. These forecasts show the importance and necessity of academic research on the various configuration and organizational issues of production systems.

The ability to have mobile robots capable of replacing human operators on repetitive and strenuous activities can either be very promising. This opportunity can offer operators the possibility to focus on operations with more aggregated value (inspection, quality control, innovation in the production process, etc.), but also can reduce the total production cost. Moreover, this is a great opportunity for operators to expand the scope of their knowledge, to be more innovative and evolve more easily in the system. Unfortunately, if the manufacturing system is not correctly designed then, it can completely demotivate operators and drastically reduce the agility. Therefore, in the design and configuration of these manufacturing systems, decision processes and existing organizational methods must be changed, if they are still applicable, or new methods must be invented and developed to integrate these new opportunities, criteria and constraints. These adaptations or innovations in methods may occur at all levels, from strategic and tactical up to operational and real time decisions. In addition, knowing that human operators and their interactions with mobile devices are essential in the manufacturing system agility, a purely technical, economic and quantitative approaches certainly cannot bring adequate solutions. Therefore, it is necessary to complete the technical, economic and quantitative approaches with social and cultural criteria and constraints, as well as integration of managerial and organizational solution. Such integrated approach can be called as global approach, and it will allow the development of methods and tools with support for configuration and organization of the production system. The global approach must be technically, economically, socially and organizationally efficient while human operators remain motivated.

The main problems in design and configuration of traditional manufacturing systems are, at first, the identification of (1) resources, machines, tools and operators (respecting availability and skills), (2) the space for a target production level and (3) the suppliers and outsourced resources. Secondly, the location of equipment in the workshop must be addressed while taking into account their interdependencies and their impact on the overall performance of the internal supply chain. The difficulty of this location is that the choice of the position for heavy equipment is difficult to change, while the needs and justification of this position can change rapidly (Amiri-Aref et al., 2013b). Thirdly, to remain successful, approaches for planning and scheduling of activities must be adapted to be able to integrate the new constraints while providing the best solutions in allowed calculation time (Al-e Hashem et al., 2013).

This paper is structured as follows. Section 2 details the new challenges for the next generation of manufacturing systems. Section 3 details the indoor localization that plays a key issue in the implementation of the next generation of manufacturing systems. Section 4 has some conclusions and future works.

2. NEW CHALLENGES FOR INDUSTRIAL ENGINEERS

Despite the important benefits, involving innovative organizational and management practices, there are researches with specific solutions. There is no research with the broader view that this research addresses. In the past, problems of location and assignment in manufacturing systems were studied by considering the existence of a single mobile robot (Amiri-Aref et al., 2013a,b). However, some important research issues remain to achieve the necessary configuration and organization of such manufacturing systems. Specifically, it is necessary to restudy several methods on three decision levels (strategic, tactical and operational) by considering the simultaneous existence of mobile robots, flexible production facilities and human resources, as well as the accessibility of real time information.

2.1 Strategic Level Decision

The inclusion of mobile robots allow an increase in flexibility and performance of the manufacturing systems, and consequently they will be more competitive in the existing market. The new performance will certainly influence the supplier selection. Some services that were previously