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Citation for the original published paper (version of record):
Salunkhe, O., Fasth Berglund, Å. (2020)
Increasing operational flexibility using Industry 4.0 enabling technologies in final assembly
IEEE Transactions on Communication Technology

N.B. When citing this work, cite the original published paper.

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Increasing operational flexibility using Industry 4.0 enabling technologies in final assembly

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Abstract— The Manufacturing industry is facing major with growing competition and increasing demands from customers. This presents new challenges for companies, especially with final assembly operations to cope with these changing scenarios. One way to cope with these changes and respond to increasing demands is to enhance operational flexibility. Operational flexibility can be influenced in many different ways. One way is to enhance the source of operational flexibility. This enhancement can be done using Industry 4.0 enabling technologies. This paper presents various Industry 4.0 enabling technologies that can be used as a tool to increase operational flexibility in final assembly. The technologies presented in this paper are based on proven examples of their application in either final assembly or for increasing flexibility.

Keywords—Final Assembly, Operational Flexibility, Industry 4.0, SIILab

I. INTRODUCTION

Final assembly operations are often affected by the manufacturing uncertainties, changing customer demands and increased customization [1]. Highly competitive and globalized markets are pushing companies to be more flexible in their operations. An effective way to respond to these changes and prepare for uncertainties is to establish and maintain optimal level operational flexibility in final assembly. A efficient way to achieve and maintain operational flexibility lies in technological and managerial response [2]. With the emergence of new technologies under Industry 4.0 umbrella, new tools and methods are made available for managers to achieve substantial level of operational flexibility in final assembly. This paper focus on the technological response. Technological innovations such as Industrial Internet of Things, Cyber Physical Systems, Big Data Analytics, Arguments and Virtual Reality, 3D printing, cloud computing, edge computing, collaborative robots applications are considered as Industry 4.0 enabling technologies [3], [4]. A list of such tools with proven application that can be used to influence the sources of operational flexibility are presented in this paper.

Aim of this paper is to identify proven Industry 4.0 enabling technologies for increasing operational flexibility in final assembly. The details of this process and structure of the paper is as follows, section II provides the theoretical background of industry 4 technologies and operational flexibility sources. section III presents the methodology for literature review used to find Industry 4.0 enabling technologies followed by results in section IV and discussion V. Article ends with conclusions and future directions.

II. THEORY

A. Industry 4.0

The term Industry 4.0 was coined in Germany as a part of a government initiative for digitalizing manufacturing industry and widely referred as the beginning of the fourth industrial revolution [3]. This initiative was followed by other countries throughout the world by launching similar initiative with different names such as Smart Industri in Sweden, Industrial Internet Consortium (IIC) and Smart Manufacturing in USA, Made in China, Made in Denmark, Smart Industry in the Netherlands and Robot strategy in Japan[5]. A recent review on Industry 4.0 and related technologies suggests its growth in terms of research and application in academia and industry [6][7]. Industry 4.0 enabling technologies are at the forefront of providing solution to increasing production challenges caused by inconsistency in market demands and high customization. Industry 4.0 enabling technologies consist of technologies and innovations that are highly reliant on information and communication technology (ICT) and are bridging the gap between the cyber and physical world.

B. Definition of Operational Flexibility

Operational flexibility is most widely considered as the ability of system to react to changing environment and represents the culmination of the effect of other common type of flexibility such as machine flexibility, volume flexibility, product flexibility, process flexibility [8] [9]. Some common operational flexibility capabilities include its ability to respond to uncertainty[10], increase efficiency[10], ability to expand operations[11]. Capabilities and flexibilities that form operational flexibilities are interconnected. For example, the result of increased workforce flexibility will increase operational flexibility by raising the ability to rotate workers in the work stations [12], this will also lead to the capability of the final assembly to manufacture different product variants resulting in product flexibility [1]. Studying individual flexibility with its affecting parameters in final assembly will lead to a narrow-focused approach without considering the larger impact on overall operational
flexibility of final assembly. Thus, the focus on this paper is to consider source of operational flexibility in final assembly and provide Industry 4.0 enabling technology as a tool to influence these sources. Based on major review on operational flexibility by Yu et.al [8] and Jain et.al [9] sources of operational flexibility are presented in the table I.

**TABLE I. SOURCE OF OPERATIONAL FLEXIBILITY**

<table>
<thead>
<tr>
<th>Source</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td>System design and layout [9], system integration [8]</td>
</tr>
<tr>
<td>Machine and Equipment</td>
<td>Types of machines [8] and equipment [8]</td>
</tr>
<tr>
<td>Operator training and skills</td>
<td>Training and skill development of operators for assembly operations [8]</td>
</tr>
<tr>
<td>Information and Knowledge transfer</td>
<td>Assembly support in form of instructions [2]</td>
</tr>
<tr>
<td>Production Control</td>
<td>Production operations and process control [8] [13]</td>
</tr>
</tbody>
</table>
| Material and Logistics    | Efficiency of Material handling and supply chain [14] [9], Quality and Delivery | Quality control and on time delivery [9] [14].

**III. METHODOLOGY**

The purpose of this research work is to identify Industry 4.0 enabling technology that can be applied for introducing or increasing operational flexibilities in final assembly and suggest a framework for application. This paper uses Systematic literature review [15] with the aim of retrieving and analyzing existing literature on industry 4.0 technologies and its impact on flexibility. Systematic literature review is followed by deductive research approach [16] for identifying key technologies helpful in introducing or increasing operational flexibility in final assembly. The keyword string used in this article is presented in figure 1. The systematic review process is presented in figure 2. Articles that included Industry 4.0 as a buzzword have not been included in the review. Scopus and Web of Science databases were used for retrieving relevant literature. Only journal articles were considered in this study. Articles from 2009 onwards are included in the search.

**IV. RESULTS**

A. Infrastructure

Internet of Things (IoT) is an ecosystem of connected devices consisting of both physical devices and software components with the ability to exchange data turning these connected devices into smart objects [17], [18]. Traditional assembly systems heavily rely on pre-determined assembly sequence which often come with requirements such as high inventory costs and few flexibility opportunities. Use of IoT offers the possibility to dynamically optimize assembly sequence in production systems [19]. Such opportunity offers assembly systems the ability to assemble wide range of products with low changeover times as the connected devices and smart systems make sure correct material is made available at correct station when required [20], [21]. Another benefit of IoT helps in increasing productivity and efficiency through smart and remote management of facilities by use of sensors, real time data analytics and optimized decision-making assisted by artificial intelligence [18]. Operational flexibility in final assembly can also be increased by making changes in the infrastructure by introducing production modules. Benefits of modular and assembly systems is presented in [22]. These modules with capabilities such as autonomy and intelligence [23] can act as a plug and play device for enabling cyber physical production systems [24]. Such devices offer the flexibility of moving physical resources around different workstations according to the requirements. Their plug and play capabilities eliminate the need for reprogramming thus offering greater flexibility.

B. Machine and Equipment

Smart machine and equipment with the capabilities of a cyber physical systems (CPS) offer capabilities such as reconfigurability and automatic integration. CPS is based on convergence of connected machines and intelligent networks.
which facilitates smart automatic control of processes [25] and provide necessary intelligence for identifying products and processes [26]. Cyber-physical systems drastically reduce the integration of an existing and new machines in production by removing the need for reprogramming usually required while deploying new products [27] leading to increased flexibility. This elimination is based on self-configuring systems inspired by artificial intelligence and smart sensors [28]. CPS also affects the production system design and the system architecture. The traditional top down centralized decision-making architecture is replaced by more modularized, decentralized and agent-based architecture [23]. This type of modularized architecture has a positive impact on among other things increase in flexibility, productivity and performance of the production system [29] [22]. Humans are responsible for over 90% of final assembly tasks in final assembly [30]. Any introduction of robots in such processes requires higher degree of safety and security for operators. Collaborative robots offer such safety and security [31], [32]. Apart from taking over tedious and unergonomic tasks from human operators, robots also assisting humans in final assembly tasks such as pick and place operations [33][34]. With robots taking over the repetitive tasks, human are flexibility to carry out other task thus increasing over flexibility and efficiency of production system [35].

C. Operator training and skill development
The need to manufacture different products leads to the requirement of highly flexible work force [36]. Operators are required to assemble products which differ in design and or assembly sequence. This change not just leads to unnecessary strain on operators but also end with quality problems. High turnover of workforce also hinders the prospects of achieving highly flexible workforce. Emergence of Industry 4.0 and has consequently led to development operator centric technologies characterized as Operator 4.0 [37]. The operator 4.0 typology classifies operators with different Industry 4.0 enabling technologies. Strength from Exoskeleton, information from virtual and augmented reality, wearables to monitor health and support from personal assistants are enabling necessary support for operators towards accomplishing their tasks in a smarter and simpler way [37], [38]. The use of augmented reality (AR) and virtual reality (VR) for skill development operators is also increasing. Use of AR and VR in machine setup operation, collaborative work, assembly support is presented in [39][40]. Large companies are faced with a challenge in training of new workforce. A training system based on AR and VR is presented in [41][42][43]. AR and VR is also used for studying production processes [44] which can further be used for identifying operational flexibility potentials.

D. Information and knowledge transfer
Proper information on assembly operations is necessity for operators. The way information is provided plays an important role in flexibility of operators in final assembly. Traditional methods such as paper-based instructions will not be helpful for operators when they are moved from their regular station they stop looking at the instruction eventually when enough skills are acquired for assembly. In such cases, digital instructions are instruction provided via AR glasses are helpful not just for operators making them more flexible in their work tasks. Lean information tools can also be used for providing information to operators in digital format [45]. Such tools provide managers with necessary tool to increase operational flexibility. On a system level, It is important to assess the requirements of production systems before implementing any technology for increasing operational flexibility. Maturity assessment for implementing Industry 4.0 is a good way to assess specific areas for competences and knowledge sharing possibilities that can increase operational flexibility [7].

E. Production control
Final assembly operations are managed and control by production managers. The managerial decisions play a very important role in handling the most important and most flexible resource in final assembly, the operators [46]. Providing managers with efficient tools such as a Programmable Manufacturing Adviser [46] and an AI based job allocation tool [47] will help them efficiently handle the work force and increase flexibility in final assembly.

<table>
<thead>
<tr>
<th>Source of operational flexibility</th>
<th>Industry 4.0 enabling technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production System Infrastructure</td>
<td>Internet of Things (IoT) as backbone for vertical and horizontal integration [17], [18]</td>
</tr>
<tr>
<td></td>
<td>Autonomous and Intelligent modular systems [23][22].</td>
</tr>
<tr>
<td></td>
<td>Self-adapting, plug and play system based on CPPS [24]</td>
</tr>
<tr>
<td>Machines and Equipment</td>
<td>Cyber-physical Systems [48], [49]</td>
</tr>
<tr>
<td></td>
<td>AI based reconfiguration of low-level automation [50]</td>
</tr>
<tr>
<td></td>
<td>Collaborative robots[33][34]</td>
</tr>
<tr>
<td>Operator training and skill development</td>
<td>Operator training for complex assemblies using AR and VR [41]</td>
</tr>
<tr>
<td></td>
<td>Wearables for operator support [51]</td>
</tr>
<tr>
<td>Information and knowledge transfer</td>
<td>Instructions via AR glasses[39]</td>
</tr>
<tr>
<td></td>
<td>Industry 4.0 based Lean information tool[45]</td>
</tr>
<tr>
<td></td>
<td>Industry 4.0 maturity index to assess competences and enable knowledge sharing[7]</td>
</tr>
<tr>
<td>Production control</td>
<td>AI based Job allocation to operators [47]</td>
</tr>
<tr>
<td></td>
<td>Programmable Manufacturing Adviser [46]</td>
</tr>
<tr>
<td>Material and logistics</td>
<td>Use of Automatically Guided Vehicles for material handling [52]</td>
</tr>
<tr>
<td></td>
<td>Cobot mounted AGV</td>
</tr>
<tr>
<td>Quality and Delivery</td>
<td>Artificial intelligence and Machine Learning based quality assurance[53][54]</td>
</tr>
</tbody>
</table>
Material handling is a very important function of final assembly. Correct and on time delivery of material is essential for function of final assembly. An automated and reconfigurable material handling process increases the flexibility in final assembly[52]. Use of automated guided vehicles (AGV’s) offers the functionality of automation and reconfiguration. Some advantages of AGV’s are their ability to choose shortest distance for material delivery[55] and possibility to automatically provide material handling directions. This eliminates the necessity to reprogram delivery vehicles and the ability to remotely provide delivery instructions contributes towards increased flexibility in final assembly.

### G. Quality and Delivery

High quality and on time delivery are not just important factors but a necessity for any business. In final assembly, these parameters are equally important not just from a performance perspective but also flexibility perspective. With high involvement of humans and machines, there is a possibility to get wrong quality and miss deliver times. Industry 4.0 enabling technology such as AI and machine learning based solutions can help in assuring high quality and on time deliver[53][54].

### V. DISCUSSION

A holistic approach in required for increasing operational flexibility in final assembly. A closer look at the seven sources of operational flexibility mentioned in this paper will reveal the interconnectivity in between these sources. Each source of flexibility has the potential to influence the other source of operational flexibility. It will be beneficial for companies to think in the holistic way while investing in such a tool. It should also be noted that the Industry 4.0 enabling tools mentioned in the paper will an impact beyond the specified sources and increment in operational flexibility. For example, introduction of IoT platform will enabled the possibilities of system wide data collection and dissemination for better overview this combined with plug and play devices will enable a complete cyber-physical production system setup. With operational flexibility already established, the company can offer wide range of products and services based on this advance setup and flexibility.

The high contribution of human operators in final assembly system makes them the most important characteristic that influences the flexibility of final assembly. Their ability to switch tasks and change roles enables a level of flexibility any automation technology is yet to match. The tools mentioned in this paper will support them in their daily tasks resulting in enhanced capabilities of operators and increase in skills. Highly skilled and well-trained work force enables higher degree of flexibility in final assembly. Based on these capabilities, the companies will be able to offer different variants of products and services to compete in global markets. The human factor must be considered while applying any Industry 4.0 enabling tool in final assembly.

The application of new technology also comes with new challenges. Industry 4.0 enabling technologies are based on communication tools and protocols which are very sensitive in terms of cyber security. Any breach of this network can lead to system wide shutdown of machines and other resources which depend of the network. Companies must have robots cyber security and defense team to secure their networks and provide constant safety from the cyber-attacks. There will be a requirement of new competence to setup and handle the functioning of Industry 4.0 enabling technologies in final assembly. Companies have to think though these requirements before adding any new technology.

### VI. CONCLUSION

This article presents Industry 4.0 enabling tools to enhance operational flexibility in final assembly. Source of operational flexibility are identifies and acquired from various major reviews of operational flexibility and flexibility in manufacturing. These sources are then match with a corresponding Industry 4.0 enabling technology found via a systematic literature review. These Industry 4.0 enabling technologies have the capability to influence and enhance the source of operational flexibility resulting in increase in operational flexibility of final assembly. This is discussed in results section. The holistic benefits and challenges are presented in discussion.

This paper uses proven application of Industry 4.0 enabling technology in increasing flexibility of final assembly. Though their application is proven, their economic impacts are not studied. This presents opportunity for further of research in this area. The application presents in this paper enhance the operational flexibility in final assembly, this enhancement needs to be further quantified for economic implications.

**ACKNOWLEDGMENT (Heading 5)**

This research has been carried out within the framework of research project Demonstrating and Testing Smart Digitalization for Sustainable Human-Centered Automation in Production funded by VINNOVA, the Swedish Governments Agency for Innovation Systems. Their support be gratefully acknowledged in this this work.

**REFERENCES**


