

## A Development Methodology Framework of Smart Manufacturing Systems (Industry 4.0)

Moamin A Mahmoud<sup>a,1</sup>, Ramona Ramli<sup>a,2</sup>, Feninferina Azman<sup>a,3</sup>, Jennifer Grace<sup>b</sup>

<sup>a</sup> College of Computer Science and Information Technology, Universiti Tenaga Nasional, Malaysia  
Email: <sup>1</sup>moamin@uniten.edu.my; <sup>2</sup>ramona@uniten.edu.my; <sup>3</sup>ferina@uniten.edu.my

<sup>b</sup> College of Graduate Studies, Universiti Tenaga Nasional, Malaysia  
Email: jennifer\_grace28@yahoo.com

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**Abstract**— Numerous studies have been conducted to reveal the importance of Smart Manufacturing Systems (SMS) or Industry 4.0, but very few studies have been made to answer the question on “how to establish a new SMS” taking into account the required efficiency, reliability, cost-effectiveness, and sustainability that requires pre-implementation planning and assessment. Besides, the discussion on the challenges of SMS adoption is very limited in the literature studies. In particular, the recent configuration models proposed by literature overlooked the pivotal role of robots in any SMS project. Therefore, a clear and concise development framework is needed to provide a better understanding of the development process of a new SMS, which leads to higher adoption of this new technology. To do so, the main objective of this study is to propose a development methodology framework that enables stakeholders to build better SMS capabilities while enhancing the adoption awareness of industry 4.0 among manufacturers. The framework consists of four phases, system and robots’ configuration, smart system components, smart system integration, and evaluation and selection. This study supports the realization of Industry 4.0, particularly in Malaysia. Currently, Malaysia is behind other ASEAN countries like Indonesia and Singapore as the highest growth country in the digital economy. The proposed methodology is expected to support different industries in the adoption of the technology in building a new SMS or evaluating an existing one.

**Keywords**—smart manufacturing; industry 4.0; development methodology; robots.

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### I. INTRODUCTION

Based on the current hype for the fourth industrial revolution globally, manufacturers try to be in the latest revolution, and therefore the competition is getting higher and higher day by day [1], [2]. However, the big question is how they are going to move into the new Industry 4.0 from the current industry with all challenges ahead. Besides that, artificial intelligence plays a significant role in smart factories as machines need to be equipped with human intelligence to be automated [3]. Research has been carried out on the logistics section for smart factories [4], [5]. However, the vital question mark is how effective are the roadmap planned by management to move into this new era. We have technologies such as the Internet of Things (IoT) and Artificial Intelligence (AI), while on the other hand, we have manufacturing systems that are being used in the production lines. The problem arises when management tries to integrate the available systems with the available technologies. Assessment needs to be thoroughly carried out using a simulation method to find out the effectiveness of the

proposed solutions. According to researchers like Esmaeilian et al. [6], manufacturing is ceaselessly advancing from idea improvement to technologies and tools accessible for the generation of products for use or deal.

In recent years, manufacturing has undergone major industrial revolutions in terms of production. First, we had the Industrial Revolution in the 18th century, using steam power for production. Next, we had the Second Industrial Revolution in the 19th century, which was made possible with the discovery of electricity and assembly line production. Thirdly, the Industrial Revolution took place via partial automation using memory-programmable controls and computers. This made way for the use of technology in the manufacturing processes. Now, we are seeing the Fourth Industrial Revolution, which is mainly consisting of Internet of Things (IoT), Artificial Intelligence, and the networking of all systems, which is also best known as the Cyber-physical system (CPS). This has contributed to the automation of the production systems in the Industry 4.0 which eliminates human intervention in most of the processes since it is focusing more on autonomous processes,

in other words, best known as smart manufacturing systems [7]. The modern production industry calls for a new generation of manufacturing systems [8]. Figure 1 below best illustrates the evolution of the manufacturing industry [9].

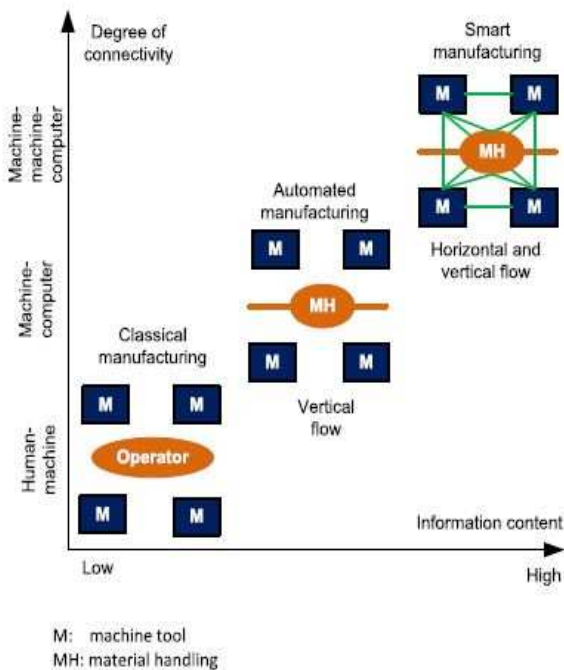


Fig. 1 Evolution of Manufacturing in Industrial Revolutions

As explained by Kusiak [4], the six leading technologies which are being applied in smart manufacturing systems would be Automation and manufacturing technology, Data storage technology, Digitalization technology, Cloud computing technology, Agent technology and Prediction technology as illustrated in Figure 2.



Fig. 2 Technologies in Smart Manufacturing Systems

This study aims to resolve some issues relating to the framework adoption of a smart manufacturing system by proposing a development methodology framework that consists of four phases, system and robots' configuration, smart system components, smart system integration, and evaluation and selection. The implication of this research will be that management could be well informed about the

success or potential pitfalls of their strategy to move into Industry 4.0 based on the framework that will be done through this research and simulation.

Although many research studies were conducted in regards to Industry 4.0, there are still many criteria lacking, such as operational structures, legal organization structures, the cut down of operators' jobs since everything will be automated, and many other things, including the cost and benefit analysis for industries. However, this research mainly focused on the logistics part.

Besides that, if we were to investigate the status of smart factories in Malaysia, we can see that many organizations are already making progress and all the necessary steps to adopt this new revolution. For instance, semiconductor industries such as KESM [10] are making vital plans to make plants into smart factories due to the demand in the industry to produce higher quality products in the automotive field.

The Malaysian government has also been preparing for this fourth industrial revolution beforehand. Based on what was reported in the news in the year 2017, Malaysia is still slow in the pace of adopting this Industry 4.0 compared to other countries like Thailand and Vietnam, which already have Industry 4.0 framework policy. The rate of implementation of Industry 4.0 in Malaysia is still lower compared to other developing countries [11]. One of the main reasons for this is the cost of investment in IT and automation, which makes smart factories possible, is too high if it were to compare to the cost of hiring foreign workers to do the operator job in the manufacturing field [12]. Preparation has already begun for the world of digitalization in the automotive field; however, it indicates that much automation is needed in the future. There are a lot of processes that require automatization in the production line to reduce the time spent and the cost of workforce. Besides, the Malaysian government has also been playing its role in this revolution by providing various seminars regarding Industry 4.0 to government officials [13].

In a seminar held recently organized by MITI Malaysia [13], few matters have been pointed to influence the adoption of SMS such as poor standards and technology. SMS has several impacts, such as productivity, revenue, efficiency, and megatrends [14]. To advance SMS, the leading countries such as the USA and Germany are stressing on multiple key technologies such as the Internet of Things (IoT), Cyber-Physical Systems (CPS), Big data, Cloud computing, Smart Sensors, Smart energy [15]–[20]. Figure 5 shows nine pillars as key technologies to implement SMS [14]. Although research studies conducted on the key technologies would be useful but not adequate to overcome the efficiency challenges of optimal configuration, the need to be determined and assessed before the implementation of a new smart manufacturing [4], [5], [21]. To cope with the problem, the configuration includes three crucial items to be specified, machines/robots' types and quantities, process flow diagram, and essential novel technologies [21]. Accordingly, several configurations would be proposed, and therefore assessing each configuration before implementation is required to determine the optimal one, the assessment can be achieved via modeling and simulation [7], [22]. Wang et al. [4] propose a cloud-based framework to

come up with a self-controlled SMS by integrating multiple technologies such as big data, cloud computing, wireless networks to control physical components such as machines, products, and conveyors autonomously.

Another approach has been developed for evaluation Intelligent Manufacturing Systems with an integration multi-agents' system on architectures of service-oriented [23]. AI applications were proposed to establish Intelligent Manufacturing Systems in China [24]. Similarly, a proposed framework by [5] assists the configuration of Intelligent Manufacturing Systems by determining the manufacturing components. Guideline for SMS configuration using a cyber-physical system (CPS) architecture has been provided [25].

Recent research by Nagadi et al. [21] developed a hybrid simulation-based SMS configuration model using agent-based simulation (ABS) and discrete event simulation (DES), where agents are designed to handle each resource autonomously [30]–[34], which offer resilient for resources to co-operate with each other to fulfill the given task [35]–[38]. Nevertheless, few research studies have addressed the configuration challenge before implementation to provide awareness for stockholders in launching a new smart factory for the benefits of optimizing resources such as cost, time, and machines' utilization. To this end, proposing a configuration strategy to assess SMS before implementation is inevitable; thus, in this paper, we propose a framework that generates smart factory configuration that maximizing capabilities and minimizing wastages.

## II. MATERIALS AND METHOD

In this section, we propose a conceptual framework based on the above-presented research studies. The framework generates alternative configurations, subsequently assess each one, and finally confirm the best of them. It consists of four phases, as shown in Figure 3, system and robots' configuration, smart system components, smart system integration, and evaluation and selection.

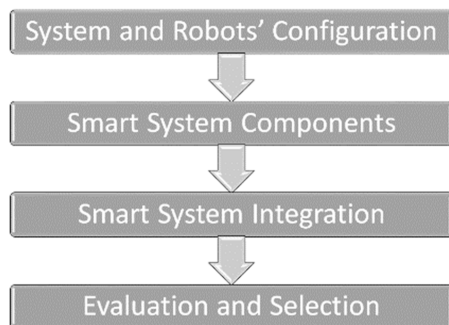


Fig.3 SMS Development Framework

The first phase generates configurations. The second phase determines the smart components of each configuration. The third phase develops the integration model, and the last phase evaluates different configurations and eventually selects one.

### A. System and Robots' Configuration

In this process, data will be collected to determine the configurations of system and robot for a SMS domain, as

shown in Figure 4. System configuration involves four components, machine type, quantity, functionality, and process flow. The type of machines will be specified first, subsequently determine the required quantity of each type. Next, the function of each machine type should be modeled for farther development. Finally, define the production process flow.

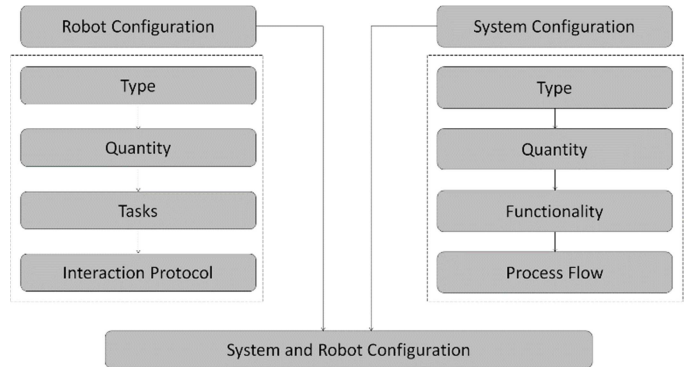


Fig. 4 System and Robots' Configuration

Figure 4 above shows that the robot configuration involves four components, i.e., robot type, quantity, task, and interaction protocol. Robot types such as mobile or static require specification—subsequently, the quantity of each type is determined. Next, the task of each robot is modeled. Finally, it requires to define the interaction protocol between robots and robot with a machine. In this phase, multiple configurations could be defined, and each of them would have a specific configuration, and eventually, only one will be selected and implemented.

### B. Smart System Components

Several innovative technologies could be utilized to develop a successful and efficient configuration model. These technologies are presents in Figure 5. We present them as components that constitute the proposed smart system phase.

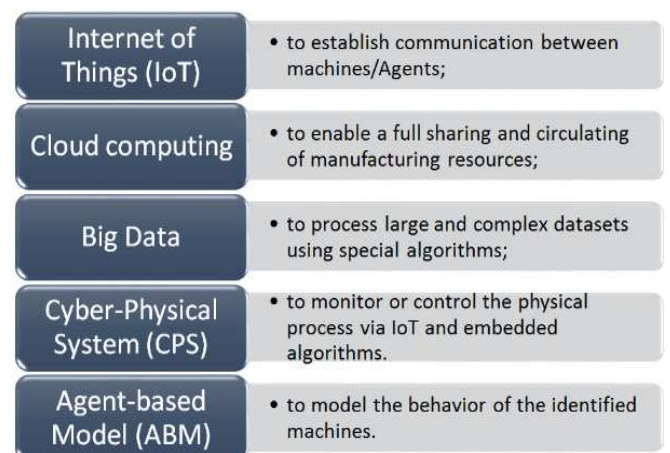


Fig. 5 Smart System Technologies

Figure 6 shows the process model for this phase. Firstly, a configuration will be selected. The configuration contains machines' types, quantity, and process flow/interaction

protocol. Subsequently, the behavior of each machine type will be modeled using ABM. Finally, operate and control the process via the selected technologies shown in Figure 6. The combination of the physical system configuration and smart system components via ABM constitutes the Integration model of SMS.

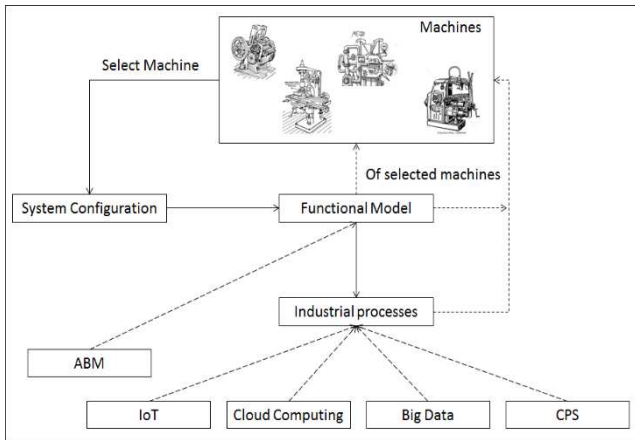


Fig. 6 Process Model

### C. Smart System Integration

The third phase produces the smart system design of a specific configuration; the concept of the digital twin was utilized to develop the Smart System Integration (SSI) model. The SSI model encompasses three layers, unite layer, integration layer, and system layer, each of these layers is associated with development technology. As shown in Figure 7, Unite layer is associated with Agent-based Simulation (ABS) that is broadly used in various domains [26]–[29], [39]–[41], integration layer with the Internet of

Things (IoT), and system-level with Discrete Event Simulation (DES) and Cyber-Physical System (CPS).

The design of hardware and its behavior will be modeled at a unit level using ABS. When all units are designed, the integration between the units will be established using IoT. Finally, the process flow between the integrated units will be mapped using DES and controlled using CPS.

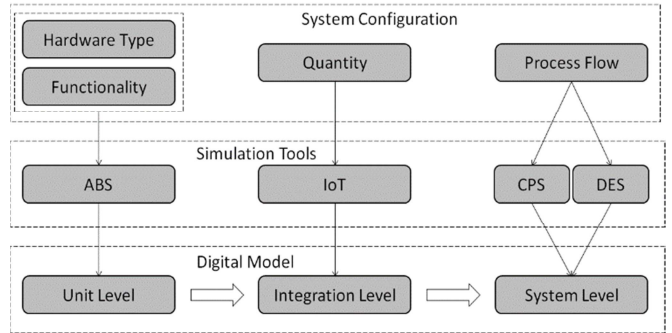


Fig.7 Integration Design

### D. Evaluation and Selection Model (ESM)

This section presents the evaluation and selection model (ESM). The ESM encompasses Primary Configuration (P-Con) and Final Configuration (F-Con). The P-Con will be designed through collaboration between software engineers (SEs) and manufacturing engineers (MEs). MEs determine machines and robot types, quantity, and process flow. After that, the functionality and behavior of each machine will be modeled by SEs using ABM, and the production process flow between machines will be assimilated using DES according to MEs description. Finally, the P-Con will be evaluated through simulation means. If the evaluation result of a configuration is satisfied, it will be selected as F-Con.

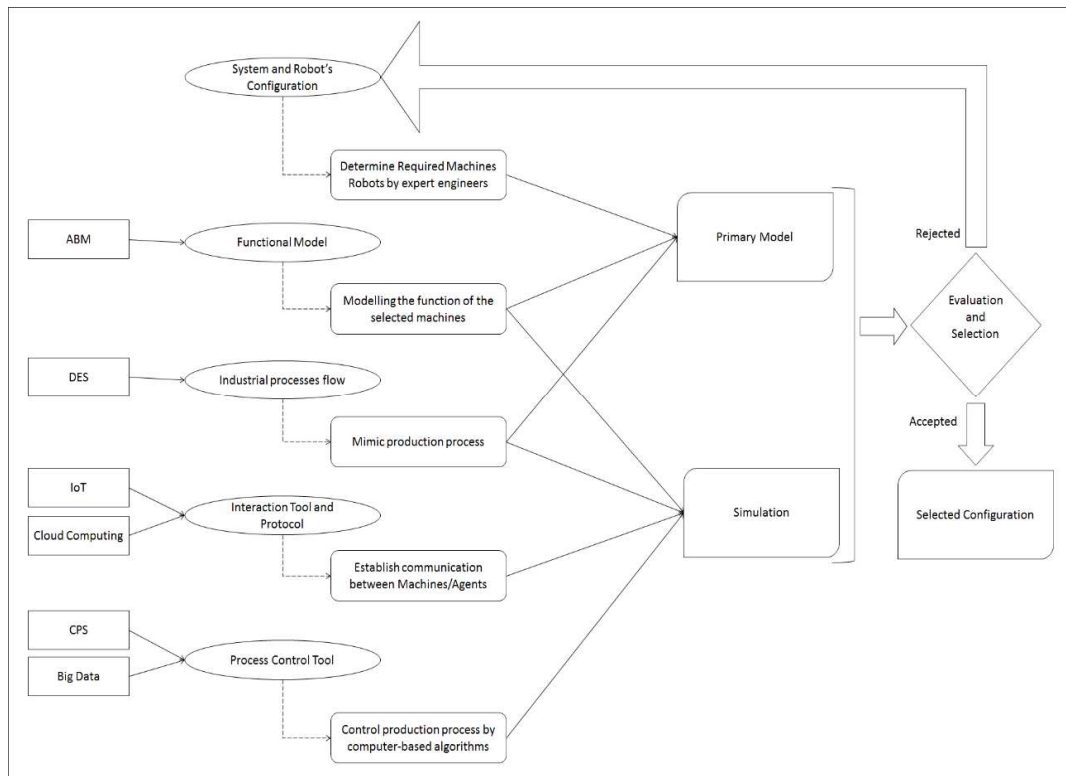


Fig. 8 Evaluation and Selection Model

As shown in Figure 8, Each proposed technology will be in charge to produce an outcome for the ESM, Physical configuration, ABM, and DES constitutes the P-Con, while IoT, Cloud Computing, and CPS in addition to ABM and DES constitute the Simulation, and Finally, the Simulation and P-Con constitute the F-Con. The F-Con can be obtained by measuring several factors through the simulation for each P-Con, the factors are quality, leading-time, cost, productivity, resource efficiency, product customization, environmental impacts. A reconfiguration process will be conducted if one or more factors are not satisfactory.

### III. RESULTS AND DISCUSSION

To illustrate how the proposed framework could be implemented, we present a scenario for this purpose. In this scenario, manufacturing engineers propose multiple configurations for a new SMS, as shown in Figure 9. Each configuration will display data the Machines' Types, Behavior, Quantity, and Process Flow. After that, the System model of each configuration will be produced. The system model will then be evaluated using the predefined evaluation criteria that will be evaluated as High (H), Medium (M), or Low (L). The result of the evaluation will indicate the best configuration.

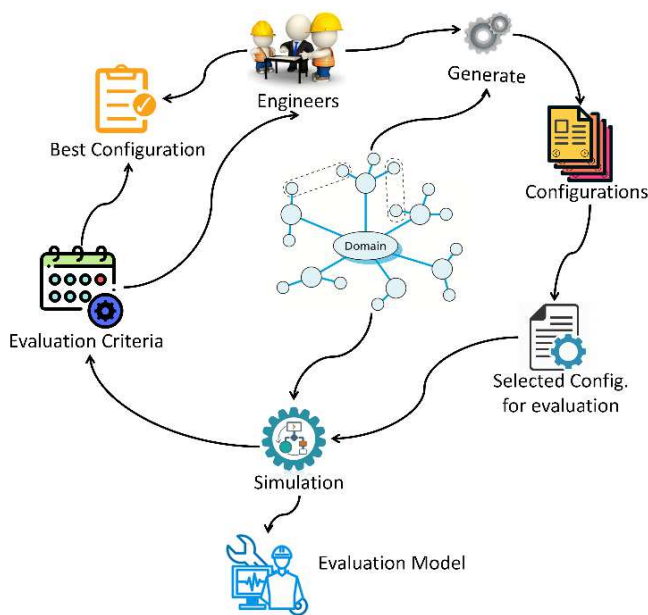


Fig. 9 Evaluation Scenario

### IV. CONCLUSION

The study of development methodology in establishing new SMS is crucial for pre-implementation assessment that leads to more efficient and capable machines whilst optimizing operational cost. Consequently, this paper proposes a development methodology framework that emphasizes the engagement of software and manufacturing engineers all over the process. The framework consists of four phases, system and robots' configuration, smart system components, system integration, and evaluation and selection model. The System configuration involves machine type, quantity, functionality, and process flow. While, the robot configuration involves robot type, quantity, task, and

interaction protocol. The determined and smart system technologies are Internet of Things (IoT); Cloud computing, Big Data; Cyber-Physical System (CPS); Agent-based Model (ABM). The integration model consists of three levels, unit level, integration level, and system level. Each level is associated with development technology.

In the evaluation and selection phase, the model of the selected configuration will be assessed based on seven evaluation criteria, which are quality, leading-time, cost, productivity, resource efficiency, product customization, environmental impacts. Each evaluation criteria will be measured as High (H), Medium (M), Low (L). However, the logical model of the framework is not discussed in this paper. Therefore, in our future work, we shall formulate each phase and subsequently conduct a case study to validate the framework. Besides, the primary model will be assessed on different scenarios to ensure optimal cost and lead-time.

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