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SOFTWARE-IN-THE-LOOP TECHNIQUE: AN APPROACH TO SUPPORT RECONFIGURATION OF MANUFACTURING SYSTEM

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ABSTRACT

Reconfiguration is one of the demands in most of manufacturing industries in order to support unpredictable global business market and to fulfill the various types of customer needs. A virtual commissioning is used as a tool to verify the control system in a simulation environment before the real system is developed. One of the techniques in virtual commissioning is Software-in-the-Loop (SIL). The benefits of SIL technique is it can estimate the real state of control system during the simulation stage. This paper presents the understanding of the SIL technique by using an implementation of the simulation based control system to support the reconfiguration of a manufacturing system. The result of the demonstration shows that the SIL technique has a potential to be used as a tool to configure the reconfiguration of the manufacturing system eventough the reaction time is slightly longer compared to the system simulation.

Keywords: software-in-the-loop, simulation, reconfiguration, manufacturing, system.

INTRODUCTION

Nowadays, manufacturing industry is one of important industry and made a large influence in country's economic growth. It is now moving forwards to adopt the reconfigurable manufacturing system for their production lines in order to support the rapid changes market due to globalization. According to UNIDO (2012), the growth of the manufacturing output is increase about 30% with fluctuation of the growth rate between -10% to 5%. This statistic has proved that manufacturing industries cannot depend on the steady market demand any longer.

For the solution of the problem, a new system needs to be designed in order to respond a sudden change of the market requirements. At the level of the industry's shop floor, this translates to industrial automation and control systems that quickly respond to change while maintaining stable and efficient operation. Given the high degree of automation in modern manufacturing systems, industrial automation and control systems have become central to factories' responsiveness, and arguably the key to competitiveness.

However, the technology e.g. advanced robotics and computer numerical control that has promised to improve competitiveness has also increased the complexity of this problem: modern industrial systems are by nature, distributed, concurrent and stochastic. The result is often a collection of 'islands of automation' that lack the necessary integration for truly responsive behavior. Without adequate control, these systems can display a 'fragility' that is disastrous in the unpredictability modern shop floor environment.

Many researchers have identified the necessity to develop novel manufacturing paradigms in order to achieve these requirements. The quasi-standard of rigid, hierarchical control architectures in today's industry has been unable to cope with the new challenges successfully, since the production schedules and plans are known to become ineffective after a short time on the shop floor. Established production planning and control systems are therefore vulnerable to abrupt changes and unforeseen events in production processes and do not allow a real-time computation of sophisticated decision models (Scholz-Reiter and Freitag, 2007) (Monostori *et al*., 2006) (Valckenaers and Van Brussel, 2005) (Koren *et al*., 1999).

Reconfiguration concept has been introduced in order to support this unpredictable market changes. Reconfiguration of manufacturing system allows changeable functionality and scalable capacity (Koren, 2006) by physically changing the components of the system through adding, removing or modifying machine modules, machines, cells, material handling units and/or complete lines. Most of manufacturing companies realize about the important of the reconfiguration, however Automated manufacturing systems are still not able to cope with unexpected events and situations adequately. Therefore It is therefore necessary to combine the advantages of automated systems and information communication technology (ICT) with the cognitive capabilities of common human workers.

Support by the improvement in ICT, simulation is increasingly used in every phase of the manufacturing system life cycle (VDI3633, 2010) due to the limitation of mathematical-analytical methods in analyzing the wide range of time-dependent and random system values, and the highly networked interactions manufacturing systems. The latest state-of-the-art simulation software offers hardware integration which makes the inclusion of a real control system in simulation environment possible. This type of simulation is known as simulation based control system.

This paper presents the results of simulation based control system in performing Software-in-the-Loop (SIL) technique to support the reconfiguration of a manufacturing system. It is structured as follows: Section 2 will present the state of the art of reconfiguration in manufacturing system. Section 3 will present the state of the art of simulation based control system continues by outcome of simulation based control system study. An exemplary implementation will be describes in Section 4 and it conclusion and challenges will be listed in Section 5.

RECONFIGURATION

Heisel and Meitzner (2006) states that reconfiguration is an advance term from configuration. It has a modification of structure, functionality, capacity and technology that allow adding, removing or modifying the specific process capabilities. The objective of the reconfiguration is to support the sudden change of the market requirements and also to change the engineering technology related to manufacturing system and production machines to improve the functionality for quick respond to product changes, adaptable to diversification in demand, cost-effective and sustaining profit by increasing productivity.

The idea of the reconfigurability is to change the engineering technology related to manufacturing system and production machines to improve the functionality for quick respond to product changes, adaptable to diversification in demand, cost-effective and sustaining profit by increasing productivity.

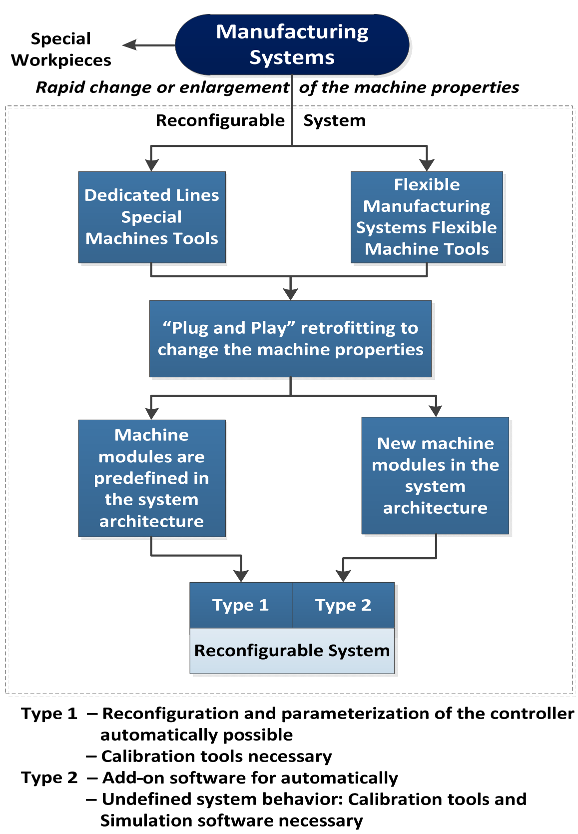

Figure-1. The type of configuration and reconfiguration system. Source: (G. Pritschow *et al*., 2012).

In fully understand about the reconfiguration, the characteristics of reconfigurable that can be identify which is convertibility (purpose for functionality changes), scalability (plan for capacity changes), modularity (elements are modular), integrability (interfaces for rapid integration), customization (flexibility limited to part family) and diagnosability (design for easy diagnostics) (Makinde *et al*., 2014). Customization, scalability and convertibility are critical reconfiguration characteristics. While modularity, integrability and diagnosability allow rapid reconfiguration (Koren and Shpitalni, 2010).

There are two types of reconfigurable systems can be classified. Type 1 consists of machine modules,which are pre-defined in the system architecture,whereas Type 2 has machine modules, which are not designed for the system architecture (Figure-1). For the last one, an automatic reconfiguration process is not possible (G. Pritschow *et al.*, 2012). The Figure-1 shows about the type of configuration and reconfiguration system.

The reconfiguration can be distinguished into two components which are physical and logical configuration. Figure-2 shows about the components in the reconfiguration.

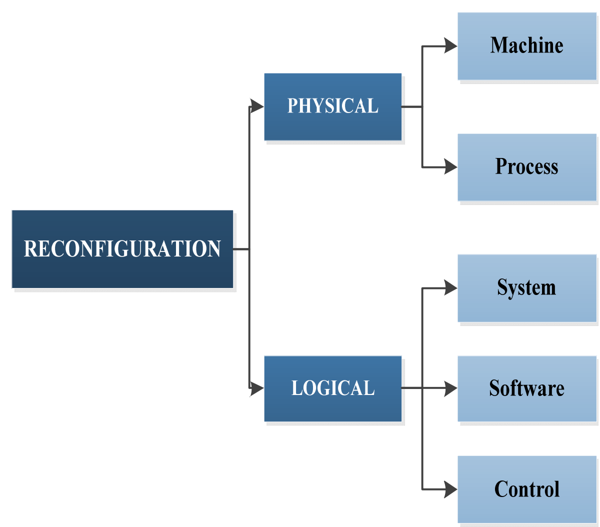

Figure-2. Reconfiguration component (Mr. Braj Krishna and S.C. Jayswal, 2012).

According to Mr. Braj Krishna and S.C. Jayswal (2012), the physical configuration covers about the machine and the process of the machine. It t is include the design and material that needed to develop the hardware of the system. For the logical configuration, it is about the system, software and control include the types of the Programmable Logic Controller (PLC) and ladder diagram used to activate the system controller. Both the physical and logical configuration must comprise with each other in order to have a completed reconfigurable manufacturing system (Koren and Shpitalni, 2010).

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SIMULATION BASED CONTROL SYSTEM

In a world where complexity, dynamics, and change dominate, it becomes vital to understand systems behavior and the parameters that affect performance. This is particularly true in the development and operations of production systems; activities in themselves characterized by complexity and change.

To represent, analyze and evaluate this complex, dynamic reality, the need for simulation has long been recognized. Simulation in particular has been applied to various aspects of production since the 1960s. The introduction of computers in simulation made possible to analyze more complex problems and the 1990s in particular saw the possibilities of simulation expand as a combined result of software development and reduced cost of computing power.

Based on Figure-3, there are several types of simulation such as Finite Element Method Simulation, Material Flow Simulation, 3D-Graphical Simulation and Kinematics Simulation. Depending on functionality and area of application, these simulation types differ from one another. Simulation based control system is the extension of simulation which provides analysis, description and evaluation capabilities of process systems, and is able to generate control logics code out of the simulation.

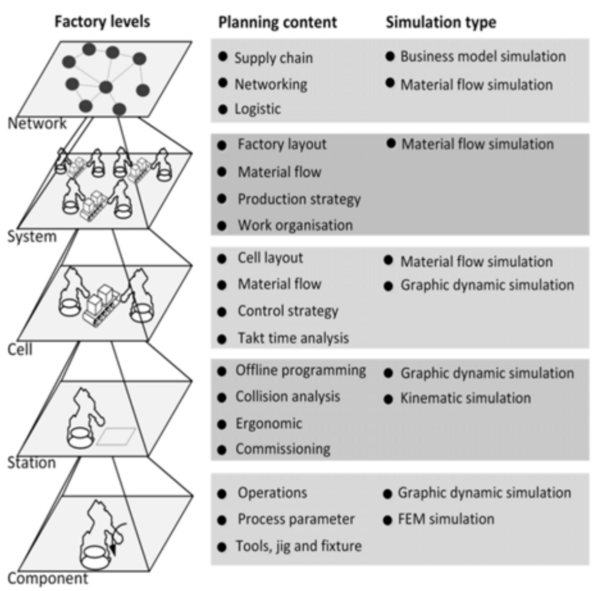

Figure-3. Simulation type in manufacturing factory (Abdul Rahman, 2013).

The latest state-of-the-art simulation based control system offers OPC integration. OPC is the acronym for Object Linking and Embedding (OLE) for Process Control and it is the most widely used vendor-independent specification for communicating control system products, normally drivers between field equipment and control or human interface devices. OPC has and is still developed by the OPC Foundation. The OPC server, which is vendor specific, is connected to the manufacturing control system (Ling *et al*., 2004).

This OPC connection makes the inclusion of a real manufacturing control system in a simulation possible. A simulated machine or process can thereby be controlled in the same way as it would be in reality. This has allowed the commissioning of a manufacturing system to perform virtually (Abdul Rahman, 2013). Virtual commissioning is a testing of the control system that can be done during the development of the system without wait for the system to be built. In other term is the system used a simulation interface in a hardware integration. The example of the simulation software that commonly used in manufacturing system is ARENA (Hoffmann *et al.,* 2010) , DELMIA, Automation Studio and Programmable Logic Controller (PLC) (Seidel *et al*., 2012).

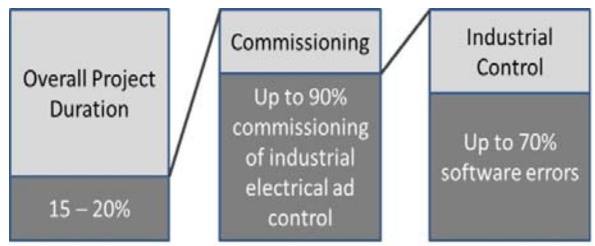

Figure-4. Contribution of control software to project delay **(**Wünsch, 2008).

According to Hoffmann *et al*. (2010), the benefit of the virtual commissioning is to reduce and debug the correction effort during the real commissioning include the process of planning, design and programming. This is also can reduce the time and cost saving for introducing a new system or product (Ali, 2012). Based on the Figure-4, it shows about the time consuming that has been done by Zäh and Wünsch (2005). The result shows the commissioning takes about up to 15 – 20 % of the overall project duration. Up to 90% is for the commissioning of the industrial electrical and control system which up 70 % of time is incurred by software error.

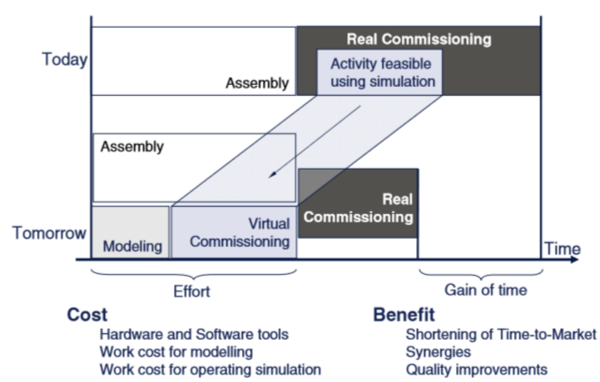

Figure-5. Virtual commissioning process (Reinhart and Wünsch, 2007).

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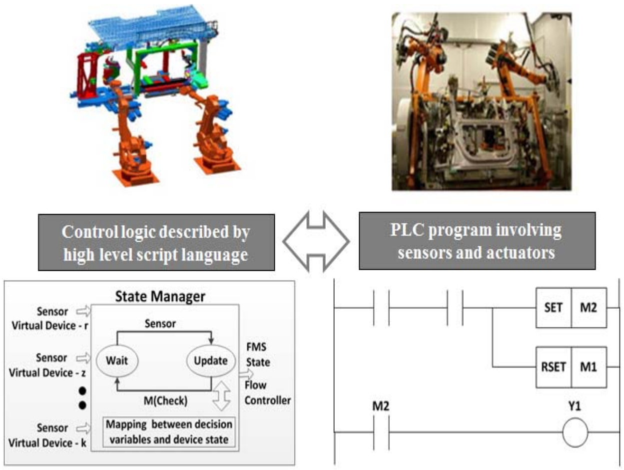
In order to develop a virtual commissioning, a virtual prototype is used for the commissioning of control software in parallel to the manufacture and assembly of the particular production system (Reinhart and Wünsch, 2007). Figure-5 shows the virtual commissioning process compared to a common commissioning process.

Eventough virtual commissioning will lead to shortening of time-to-market and improvement of the quality, extra works are required for modelling and operating simulation. Not only that, converting the simulation language to a control system language is also necessary since simulation based control system is based on control logic that has been described by high level script language while control system language mainly involves Programmable Logic Controller (PLC) program that has sensors and actuators as one of their main electrical components (Figure-6).



(a) (b)

Figure-6. A gap between Simulation based control system (a) and real manufacturing control system (b) (Lee and Park, 2014).

According to Hoffmann *et al.* (2010), there are four basic systems configuration. The first is real plant and real control system. This system is can be called as a traditional system since it testing in the real commissioning only. The second is simulation plant and real control system. The system is a soft-commissioning system that also can be called as Hardware-In-The-Loop (HIL). A virtual commissioning is build first before the real plant is developed. The third is real plant and simulated control system. The real plant is developed first and then the simulation is used. The last system is simulation plant and simulation control system. This system is a complete system in virtual commissioning. The Figure-7 shows about the possible ways to conduct commissioning process.

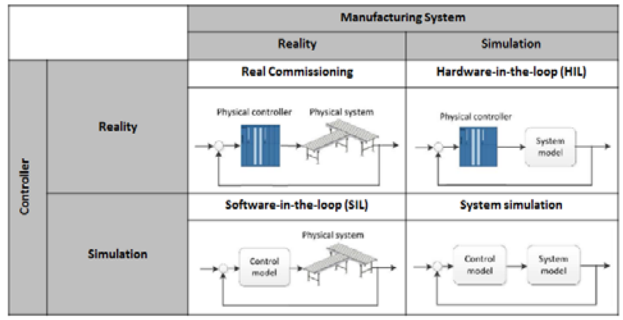


Figure-7. Possible ways to conduct commissioning process (Abdul Rahman, 2013).

In Virtual Commissioning, there are two approaches to build a virtual prototype for control software (Reinhart and Wünsch., 2007) which are HIL and SIL.

Hardware-in-the-loop (HIL)

HIL is defined as a parts of the system by simulation models while a physical or mechanical component is linked with the simulation computer in a closed control circuit (VDI4499, 2011). It is an effective platform to develop and test the complex process system (Bullock *et al.,* 2004). The real-time capability is one of the important requirements in the HIL simulation because it reacts with an event that has a specific time frame.

Software-in-the-loop (SIL)

In the SIL technique, a simulated control system model is used whilst connected to the physical system (VDI4499, 2011). The developed control algorithms run in simulation environment on a development computer, in simulation time or in real time, depending on the requirements. The control algorithms are connected to the physical system. According to Meister *et al*. (2008), there are several benefits by using SIL which are allows the system internal state estimate to the real state. Besides that, SIL can observe and relate the measured parameter to identify the effective system.

IMPLEMENTATION EXAMPLE

In the interest of testing and verifying the functionality of the SIL technique to support reconfiguration, the behavior of SIL technique and system simulation a PLC-controlled assembly system is compared in order to prove that the control model developed for system simulation can be used directly to control the physical system through SIL technique. The selected assembly system consists of a closed loop conveyor system and four workplaces (Figure 8). The material flow system is built with six linear single drive belt conveyors connected to each other in a closed loop topological structure. All of these conveyors have the same speed of approximately 0.2m/s. Eight lifters to change direction is used at each intersection to perform two closed loop flows.

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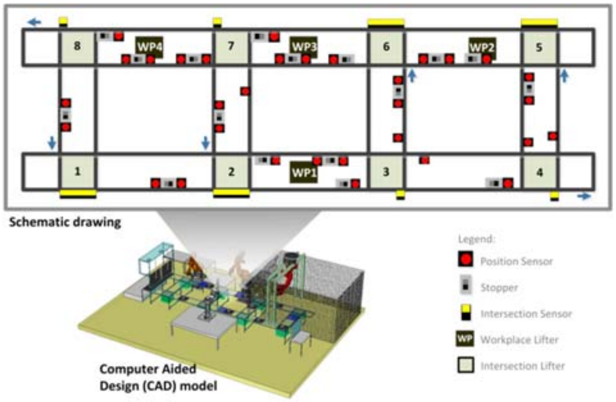

Figure-8. Possible ways to conduct commissioning process.

Architecture

Application-oriented integration of three software programs is used in realizing this approach (Figure-9). The software programs are material flow simulation, software controller, and OPC Server. OPC server-client architecture is used as basis for this connection which required all of the software to supports OPC standard.

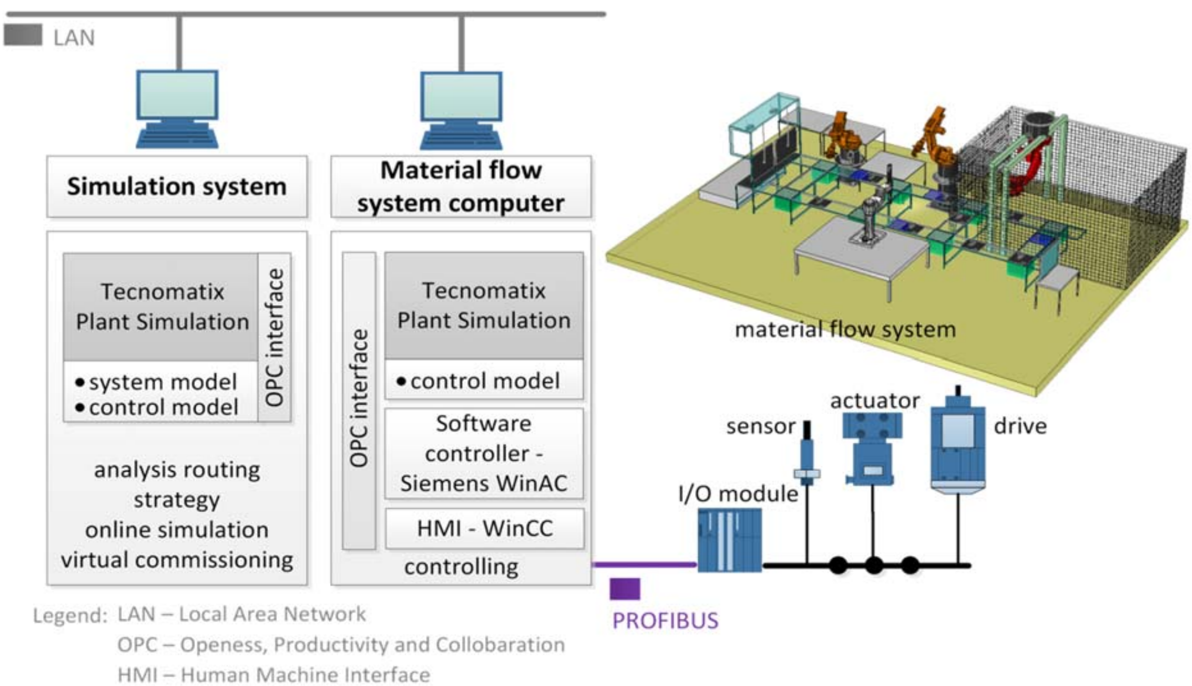

Figure-9. The architecture of application-oriented integration to enable SIL for reconfiguration.

The core of this integration is the material flow simulation software. It will consist of system models and control models. System model has to be constructed as close as possible to the real system with homogeneous level of details. All the relevant I/Os have to be considered and included in the model as Boolean variables. These variables are then mapped with the system I/Os through OPC items. OPC server has to be used for creating the items.

The control model consists of control logics program. Here the rules and routing strategies have to be coded in the form of simulation programming language not the lower level PLC programming language based on IEC 61131. This allows the changes of routing strategy to be performed by changing the simulation codes without converting or translating from one language to another.

Depending on either the system model or the real system is connected to the control model, two operations can be performed within this architecture. By connecting with the system model, analysis of the routing strategy and virtual commissioning can be performed. While controlling of the real system with the selected routing strategy can be done by enabling the OPC connection.

The information flow in controlling of the real system can be described as: The software controller which connected with the system I/O modules will receive the signal from real system. This signal will be sent to the material flow simulation software for evaluation by the

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control logics program. If the condition is satisfied the signal will then be sent back to the software controller

Demonstration

The system model and control model of the assembly system have been developed by using a material flow simulation software. System simulation is then performed by using the internal communication of the software between system model and control model. The behavior of the system model with the movement of its actuator is monitored and recorded. Next, the control model is used to control the real physical system through SIL technique. Communication between them is done using OPC protocol. The outcome from SIL technique is recorded and compared with the system simulation as shown in Figure-10.

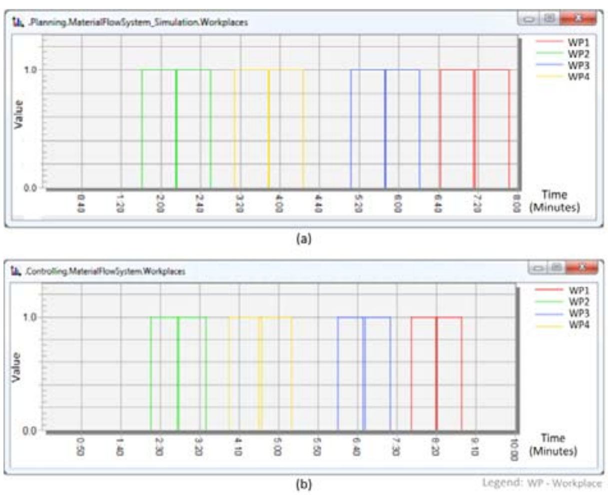

Figure-10. Outcomes from the system simulation (a) and SIL technique (b) for movements of the workplace lifters.

The same graph pattern is achieved from the outcomes of system simulation and SIL technique. However a 3% difference in time has been noticed. The SIL technique required more time to complete the whole operation compared to system simulation due to some reaction times of the actuators have not been considered in the system model.

CONCLUSIONS

In conclusion, the research is regarding the comprehensive review of the simulation techniques to support the reconfiguration of manufacturing system. The software simulation is used for testing and verifying the routing strategy of the system during reconfiguration. Since reconfiguration required modification of the system logic and analysing them before implementation, SIL will shorten the time since the same software is used for logic modification, routing strategy analysing and operation control. The architecture of an approach to achive this has been proposed. Nevertheless, for the first application, the time and effort need to be invested in developing the model. After the model is available, the next reconfiguration process can be done much easier. Based on the demonstration, it is proved that SIL technique has allowed the material flow simulation software that commonly used for system analysing to directly control the operation of manufacturing system. Eventough slightly longer time is required compared to the system simulation due the reaction time between hardware and software. This additional time however is not noticeable. This demonstration has showed that there is a potential for the SIL technique to support the reconfiguration which will help manufacturer to deal with frequent changes in the manufacturing industry.

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