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Performance Evaluation of a Production Control Architectures for Flexible Manufacturing System

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ABSTRACT

The study offers an analytical approach for assessing production control system performance in terms of volume and variety features of the product being manufactured for the flexible manufacturing system. Throughput, resource utilization, cycle time, and maximum completion time are the four performance indicators taken into account. The objective was to quantify the performance of the production system and define the reactive capability of production control architectures in a market that is becoming increasingly competitive. The examination of the production performances of control systems motivates the evaluation of these architectures through the introduction of scheduling approaches that deal with uncertainty. Results revealed the semi-heterarchical control architecture outperforms the hierarchical control architecture through multiple performance criteria. A case study with regard to a manufacturing control system was presented in order to highlight the significance of the adopted methodology and the contribution of the research.

Keywords: production control system, hierarchical architecture, semi-heterarchical architecture, performance indicator, flexible manufacturing system.

INTRODUCTION

Over the past few decades, production control has gained significance for companies. Being a discipline that provides compact information from numerous company fields to support the management of the organization. From being a first-class auxiliary activity to a strategic task supporting the planning, directing, and controlling of production processes, the role of controlling tasks evolved. Production control systems give management information in the form of logically formed indicators, most frequently key performance indicators (KPI). Purchase, sales, and production control are a few examples of the aggregated or distinct control that may assist these domains [1]. Because customer needs are diverse, unique, and differentiated, manufacturing organizations must have flexible production control abilities. Additionally, their production plans must be able to react quickly to changes in demand [2].

Production control architectures are offered in four types: centralized, hierarchical, heterarchical, and semi-heterarchical. They impact the flow of control and monitoring information throughout the system and specify how process components communicate with one another [3]. Numerous researchers have examined control architectures in various manufacturing environments. In this context, [4] implemented the potential field concept in a heterarchical control system. The potential field model allows the control system to optimize resource allocation and routing in real-time and dynamically respond to unexpected events, such as breakdowns, that affect the performance of a control system in manufacturing systems (e.g., in terms of makespan). A semi-heterarchical control system with a holonic framework was proposed by [5]. Simulations created to solve the allocation problem in flexible manufacturing systems (FMS) were used to validate their concept. They enhanced the performance of the control system by introducing a planning horizon and balancing local and global goals. Unexpected events, like rush orders, can occur in manufacturing control systems, and the time horizon parameter can be adjusted to accommodate these new requirements based on desired performance. In order to govern changes at both the structural and behavioral levels, [6] created a dynamic hybrid control architecture that incorporates a switching mechanism. In order to determine the best operating mode for the control architecture, the switching mechanism is based on the genetic algorithm (GA). A paradigm for switching mechanisms in dynamic hybrid control architectures was also presented by [7] and [8]. It exploits the benefits of both hierarchical manufacturing scheduling systems and heterarchical manufacturing execution systems while minimizing their respective reactivity and optimality limitations. In [8], a dynamic architecture known as ORCA (Optimized and Reactive Control) was implemented in the FMS. This hybrid design can dynamically and partially switch between a reactive heterarchical architecture and a hierarchical predictive architecture in the case that an event that prevents the planned behavior from being carried out happens. The dynamic hybrid control architecture framework suggested by [9] incorporates sustainability measures into control system of FMS. Their strategy tries to steer the efficiency and effectiveness targets during production execution in order to reach sustainable goals. Priority rules for enhancing the responsiveness properties of a semi-heterarchical control system were suggested by [10]. A high-level component suggests a set of priority rules that lower-level components must abide by in their proposed bi-level architecture. Semi-heterarchical architecture for autonomous control of AGVs was suggested by [11] as a way to lower FMS disturbances and boost overall performance. The mixed-model production planning and control assembly problem has been evaluated comparing anarchic manufacturing control to centralized control systems. The traditional systems used in assembly processes often rely on centralized control and planning, which can be limiting in terms of flexibility. The anarchic approach allows for greater autonomy and decision-making capabilities at the individual component level, enabling the system to handle a variety of assembly scenarios efficiently [12]. In order to improve flexibility and adaptability through the integration of automated and distributed learning capabilities, [13] suggests developing an automated learning control architecture for manufacturing systems. For the purpose of enhancing the performance of the manufacturing system. It makes use of both distributed and centralized control techniques and permits the application of artificial intelligence in addition to allowing for exploration outside predetermined operating boundaries.

The production system controlled by a semi-heterarchical architecture for industry 4.0 uses the throughput control model created by [14]. It was created with mass customization (MC). Two new dispatching rules, each evaluated with varying variability, were proposed by [15] for a semi-heterarchical control system in order to efficiently distribute production resources in the FMS manufacturing environment, which is becoming more dynamic. [16] put forth a broad, multi-level predictive maintenance decision making system powered by digital twins. Despite applying their framework to smart manufacturing systems, they neglected to study control system structures. In turn, [17] reviewed literature from the last two decades that focuses on the application of operations research methods in manufacturing system design related by flexible manufacturing system without emphasizing control structures. Without examining their control system, [18] has shown interest in the concept of matrix-structured manufacturing systems.

Most manufacturing companies manage their production in accordance with customer demands because of the impact of issues like machine failure or order fluctuation that affect order periods. In FMS, hierarchical control approaches may encounter difficulties such poor to interact, heightened intricacy, and trouble adapting to unexpected changes. Various levels of the hierarchy might face coordination problems, which would affect the responsiveness and overall efficiency of the system. Furthermore, flexibility may be limited by the rigid structure of the inability of hierarchical control to handle unexpected disruptions or changes in production demands. As a result, when customer demand for quantities or verities increases, manufacturing processes becomes affected, which throws off production schedules. It is essential to incorporate real-time data into production systems at different hierarchical levels in order to tackle these issues and improve their resilience. This is by using an efficient control system architecture that can handle these disruptions in the manufacturing systems. Therefore, the aim of the research was to assess the effectiveness of the FMS control structures and identify the optimal control architectures based on production variety and volume. In turn, NEH algorithm has been proposed as scheduling strategy to minimize makespan (max. completion time) in semi-heterarchical control structure. To achieve the manufacturing objectives, the control system represents interacting the changing demands of customers and manufacturing environment as shown in Figure 1.

The rest of the study is structured as follows: Section 2 illustrates the research contribution. In contrast, Section 3 outlines the theoretical approach in terms of FMS production system, control architectures, and performance measurements. The case study is shown in Section 4, and the experimental tests and findings are clarified in Section 5. Lastly, Section 6 wraps up with discussion and conclusions. In contrast, Section 3 outlines the theoretical approach in terms of performance measurments, control architecture, and production systems.

Research contribution

The literature review presented above indicates that substantial advancements have been achieved in the research domains pertaining to control manufacturing systems. Hence, the contribution of this study may be summarized as follows:

- in the context of the dynamic hybrid control system, the central workshop proposes a rule or algorithm to the local level when there is a need for scheduling behavior. This is done with the aim of decreasing the workload on the central server, which in turn facilitates the resolution of disturbances. This study proposes the use of the NEH heuristic algorithm as a scheduling strategy in the production system, with the objective of minimizing the makespan. This algorithm is being used for the first time inside a hybrid control system;
- in prior studies conducted in the same domain of products and the manufacturing environment, researchers often used a method whereby they combined one product on individual plate in order to optimize a single target, such as minimizing makespan. In this research, the application was conducted within a manufacturing environment that was influenced by previous research studies [4–11]. However, in this study, the approach included the assembly of more than one product on a single plate, hence accomplishing various production goals. The achievement of optimum resource utilization, namely in terms of materials and machinery, leads to a reduction in manufacturing costs. Another goal is to increase the range of variety of manufacturing products, enabling competition in the markets and attracting consumers.

THEORETICAL APPROACH

FMS production system

The evolution towards FMS has been driven by global economies, advancements in technology, and changing customer demands [10]. Every production system has distinct characteristics,

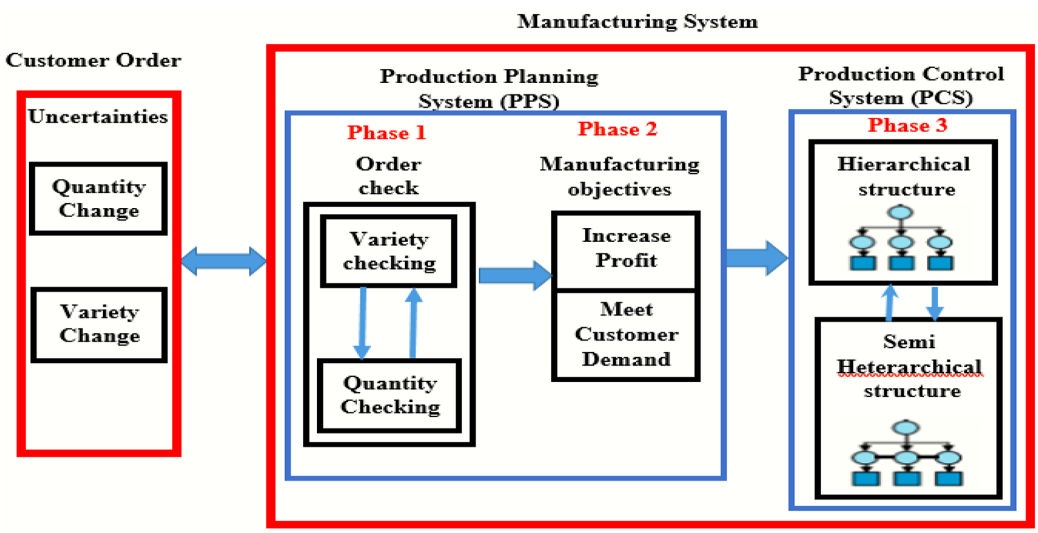

Figure 1. Methodology of production control system

with its categorization mostly based on such parameters as volume and variety. FMS is characterized by its significant level of adaptability, which is described as an automated manufacturing system that operates at a moderate production volume and variety and is centrally managed by a computer [19, 20]. The control system in FMS is responsible for making real-time decisions in three areas: sequencing, machine routing, and material handling. Sequencing involves determining the order in which products are launched in the FMS. Machine routing involves selecting the most suitable machine from a set of alternatives for a particular manufacturing operation. Material handling involves choosing the optimal route from a set of alternative transfer paths provided by the transportation system.

Architecture for production control system

The design of the production control system is a crucial element in achieving success in FMS. A control architecture refers to the comprehensive specification of the constituent elements, organizational framework, operational characteristics, and temporal evolution of a system designed to regulate and oversee the operations of a manufacturing shop floor. Nevertheless, the control architecture for a FMS exhibits a significant level of complexity owing to the substantial demands in terms of volume, the diverse range of products, and the inherent uncertainties encountered during execution. Hence, it is essential for control architecture in FMS to effectively address the complexity arising from the adaptability of the system [10]. The production control systems exhibit a range of architectures, ranging from centralized to decentralized. Figure 2 provides a visual representation of these distinct control system architectures [21, 22].

The centralized control architecture is characterized by the use of a mainframe computer to carry out all tasks related to planning and information processing. In this specific case, all control decisions are made at one location [20]. Hierarchical systems exhibit the presence of several control levels, whereby decision-making responsibilities are divided across these layers. This distribution of decision-making authority enhances the resilience of the system and its ability to withstand disruptions [12]. The complexity and variability of the workshop environment, caused by abnormal occurrences such as emergency orders and machine malfunctions, provide challenges to the production control. The centralized and hierarchical control methods are inadequate in addressing these challenges [23].

There is a growing interest in hybrid control system that do not adhere to either centralized or decentralized structures [24]. Hybrid control systems (semi-heterarchical) strive to integrate the advantages of heterarchical systems into a centralized or hierarchical framework. These systems facilitate or restrict dispersed decision-making, but ultimately possess a power hierarchy [20]. In contrast, heterarchical control architectures offer several advantages. They reduce complexity by localizing information and control.

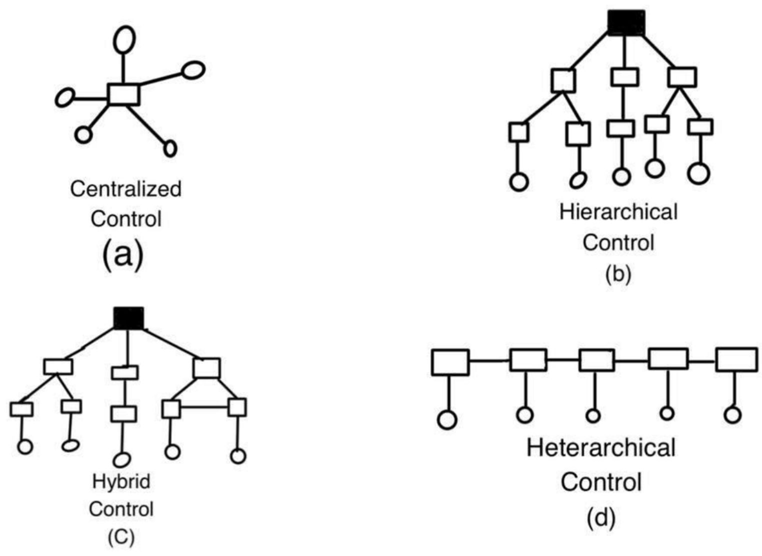

Figure 2. Evolution four basic form of control architectures [21]

This localization leads to lower software development costs as supervisory levels are eliminated. Also, these architectures improve reliability by adopting a fault-tolerant approach rather than relying solely on a fault-free approach. [21]. The switch from a centralized or hierarchical control system to a heterarchical or decentralized control system has the potential to provide a more efficient production environment, particularly when faced with deviations from normal working circumstances [20]. Heterarchical control systems provide the implementation of decentralized decision-making capabilities and autonomy at lower levels, hence facilitating coordination and interaction among system components [12].

Production performance measurements

Evaluation of the performance of a production system mostly revolves around its capacity to effectively accomplish its predetermined goals in the face of disruptions and unforeseen alterations resulting from outside influences [24]. Performance measures play a crucial role in production control as they enable the controller to obtain insights into the present condition of the manufacturing system and implement the required actions to achieve the desired objectives [25]. The primary objective of production control is to ensure efficient production operations by adhering to both technical and economic performance metrics [1]. Evaluation of the production performances of control architectures prompts the consideration of new scheduling approaches. This has great significance as it enables assessing the performance of the production system [15]. The impact of variability on performance necessitates the implementation of a production control mechanism that can effectively address the consequences of variability and demonstrate resilience in its control capabilities [14]. When examining system performance, the range [15, 24] relates to key indicators. Throughput (TH) is defined as the mean output of a production process, such as a machine, workstation, line, or plant, within a specified time period, typically measured in units such as parts per hour. The cycle time (CT) refers to the average duration starting from the release of a job at the initial stage of the routing until it arrives at an inventory point at the conclusion of the routing, while makespan refers to the maximum completion time. The evaluation of the efficiency and effectiveness of a production schedule is often measured using an essential metric.

CASE STUDY

The case study described in this work is based on a real-world FMS situated at the AIP-PRIMECA laboratory at the Université Polytechnique Hauts-de-France. The comprehensive explanation of the system can be found in [26]. The FMS has three assembly machines (robots), namely M2, M3, and M4, along with a load and unload machine (M1) and an inspection machine (M5). These machines are interconnected by a conveyor system. The FMS has the capability to manufacture eight distinct product types, denoted as (T, E, L, I, TI, TE, bE and LI). Each product must be built in accordance with a set mounting sequence. The manufacturing operations include; plate loading, product unloading, axis, r-comp, i-comp, L-comp, screw –comp, and inspection. The products and components required for each product type are shown in Figure 3.

Experimental and results

The main objective of this experimental research is to assess the effectiveness of production control architecture in both normal and disturbed circumstances, with the goal of addressing the scheduling issue for various workloads. This relates to the identification of an optimal sequence for the release of a predetermined set of products within the FMS. To evaluate the potential impact of heightened fluctuations in demand volume and variety within the FMS environment, it is necessary to analyze how the design of the production control system may be affected. According to manufacturing concepts based on volume and variety mix, the demand volume for FMS ranges (400–2000) unit, while the demand variety ranges (3–100). The evaluation of production control will be conducted in two distinct scenarios. The first scenario involves a hierarchical control system with the objective of evaluating the performance of the architecture and its production system under static conditions. The second scenario relates to a semi-hierarchical control system, which aims to evaluate the effectiveness of the control architecture for a production system in a dynamic state. This scenario specifically focuses on the impact of growing job numbers and quantities. The performance indicators that will be examined

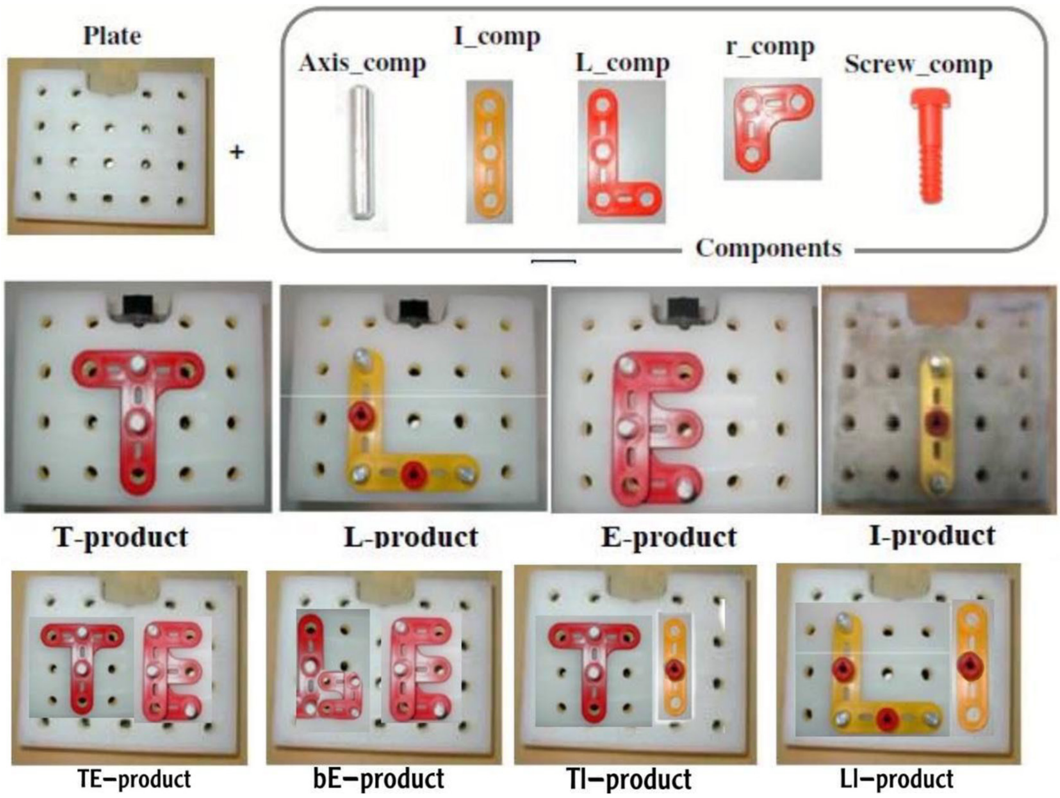

Figure 3. Components and finish products

for each scenario include the maximum completion time (also known as makespan), cycle time, throughput, and resource utilization (specifically machine and material). The control architecture includes two levels of control; the global level and the local level. Additionally, there is a plant level, which encompasses the physical components, such as the product and machinery, responsible for carrying out the production processes. This control system is specifically designed to establish the scheduling of a FMS and determine the optimal release sequence of products. The data obtained from each scenario is analyzed via Microsoft Excel.

Hierarchical control system scenario

At the global level, the hierarchical control system is made up of a single global decisional entity (GDE). This entity is in charge of making sure that lower parts follow the rules for priority. The first come first served (FCFS) scheduling algorithm has been used for this particular circumstance. At the local level, the local decisional entities (LDE) serve as products and resources at the plant level. Their primary responsibility is to oversee the management of production tasks in accordance with the prescribed priority rule. To enhance the analysis of the performance of production system under static environmental circumstances, it is necessary to consider the range of the variety "var" ($3 \leq var \leq 4$) and the production volume "vol" ($400 \leq vol \leq 700$). In this particular scenario, the assumption was made that the demand consists of four distinct jobs, namely (E, L, T, and I), the arrival of these jobs follow predetermined, constant schedule at fixed intervals, specific quantities per batch. It has been predicting of the volume of each part that would be requested from the system assuming there are no disturbances to the system. Table 1 presents the quantity and processing time associated with each job.

Makespan

After the arrival of manufacturing jobs consisting of many tasks, such jobs are then released into the FMS. The calculation of the makespan should include the duration of processing for each job on every machine. The entrance and departure times of every job for processing on the machines were determined and recorded in Table 2.

Table 1. Processing time, quantities of jobs in hierarchical control system

Jobs	Processing time (sec)			Quantity
	M1	M2	M3	
E product	40	60	20	800
L product	40	40	60	400
T product	60	-	20	500
I product	40	40	-	700

Table 2. Max completion time according to FCFS sequencing rule

Jobs	M1		M2		M3	
	Time in	Time out	Time in	Time out	Time in	Time out
E product	0	40	40	100	100	120
L product	40	80	100	140	140	200
T product	80	140	140	140	200	220
I product	140	180	180	220	220	220

Throughput analysis

In this scenario, when the volume of jobs falls between the range of 400–700 units, an analysis of the throughput performance is carried out and shown in Table 3. The volume of demand is 600 units for all four jobs, resulting in a total job quantity of 2400 units.

Cycle time analysis (CT)

The cycle time was selected as another indicator to assess the efficacy of the control architecture in conjunction with the previously analyzed data for production throughput. Table 4 presents the outcomes of the cycle time analysis obtained via the use of a specific formula:

$$CT = operation\ time + idle\ time \tag{1}$$

where: operation time – processing time; idle time – load/unload time, inspection time, transportation time, and changeover time.

Resources utilization

The study of resource utilization performance includes the examination of both material and machine utilization. Table 5 presents the percentages of material utilization for the plates used in the assembly of each respective product inside

Table 3. Throughput performance of jobs in hierarchical control system

Jobs	Job quantity	Production time/hrs	Throughput
E product	800	53	15
L product	400	29	14
T product	500	24	21
I product	700	36	19
Average throughput			17

Table 4. Cycle time results of jobs in hierarchical control system

Jobs	Processing time	Load/unload time	Inspection time	Transportation time	Changeover time	Cycle time
E product	120	20	5	50	45	240
L product	140	20	5	50	31	246
T product	80	20	5	50	17	172
I product	80	20	5	50	30	185

the manufacturing system. The formula used to determine material utilization was employed in order to generate the aforementioned metric:

$$\text{Material utilization} = \left(\frac{\text{Area occupied by products}}{\text{Total plate area}}\right) * 100\% \quad (2)$$

Machine utilization (MU) indicates the percentage of time the machines are used in production. It can by calculated by the formula below:

$$MU = \frac{N\ 01}{\sum_{k=1}^{nc} Mk * Ck} \quad (3)$$

where: *N*01 – total number of operations within the block diagram form, *Mk* – number of machine in the kth cell, *Ck* – number of jobs in the kth cell, *Nc* – number of cells.

Thus, in this case through Table 6, *MU* in the hierarchical production control system = 83%

Table 5. Material utilization in hierarchical control system

Jobs	Area unit	Material utilization
E product	6	40%
L product	5	33%
T product	5	33%
I product	3	20%
Average material utilization	32%	

Table 6. Machine utilization in hierarchical control system

Jobs	M1	M2	M3
E product	1	1	1
L product	1	1	1
T product	1	0	1
I product	1	1	0

Semi-heterarchical control system scenario

At the global level, there exists a singular global decisional entity (GDE) that is tasked with offering many priority rules or algorithms to be suggested to lower components. The primary objective of this entity is to improve the overall performance of the system. Using the shortest processing time (SPT) rule along with the NEH (Nawaz, Enscore, and Ham) heuristic method is suggested as a way to improve scheduling performance. This method is referred to as Algorithm 1. The NEH method is used at the local level to release a series of products into the production system since it has been seen to result in a shorter makespan compared to other algorithms and scheduling dispatching rules. At the local level, the local decisional entities (LDE) serve as products and resources at the plant level. Their primary responsibility is to oversee the handling of production tasks in accordance with specified scheduling methods. In order to better analyze the performance of the production system under dynamic environmental conditions that variety (var) is to be (5 ≤ var ≤ 28) and production volume (vol) is to be (701 ≤ vol ≤ 1800). In this case, external perturbations affect the current production order, where the changing in the number of products to be manufactured. It was assumed that the demand contains eight jobs (E, L, T, I, TI, TE, bE, LI), the arrival of these jobs is less predictable and follows a stochastic pattern influenced by demand fluctuations, so the demand for the product is uncertain. The quantities and processing time for each job are depicted in Table 7 below:

Makespan

The first analysis of this scenario is provided in Table 8, which depicts the total time required to complete a set of jobs from start to finish, including

Table 7. Processing time, quantities of jobs in semi-heterarchical control system

Jobs	Processing time (sec)			Quantity
	M1	M2	M3	
E product	40	60	20	1000
L product	40	40	60	900
T product	60	-	20	850
I product	40	40	-	950
TI product	100	40	20	800
TE product	100	60	40	1000
bE product	80	120	60	700
LI product	80	80	60	1000

Table 8. Max completion time according to SPT of jobs sequencing rule

Jobs	M1		M2		M3	
	Time in	Time out	Time in	Time out	Time in	Time out
T product	0	60	60	60	60	80
I product	60	100	100	140	140	140
E product	100	140	140	200	200	220
L product	140	180	200	240	240	300
TI product	180	260	260	320	320	340
TE product	260	360	360	420	420	460
LI product	360	440	440	520	520	580
bE product	440	520	520	640	640	700

processing times and any delays through three assembled machine. The sequence of the jobs became {(J3 (T)→J4 (I)→ J1 (E) → J2 (L) → J5 (TI) → J6 (TE) → J8 (LI) →J7 (bE)} through applying SPT rule, after it was in the sequence {J1 (E)→ J2 (L)→ J3 (T)→ J4 (I)→ J5 (TI) → J6 (TE) → J7 (bE) →J8 (LI)} which represents the primary arrival of orders to the workshop floor. While the sequence of the jobs became {((J1) E→ J2 (L)→ J7 (bE) → J8 (LI) → J6 (TE) → J5 (TI) → J3 (T) → J4 (I))} through applying NEH heuristic algorithm as shown below in the Figure 4.

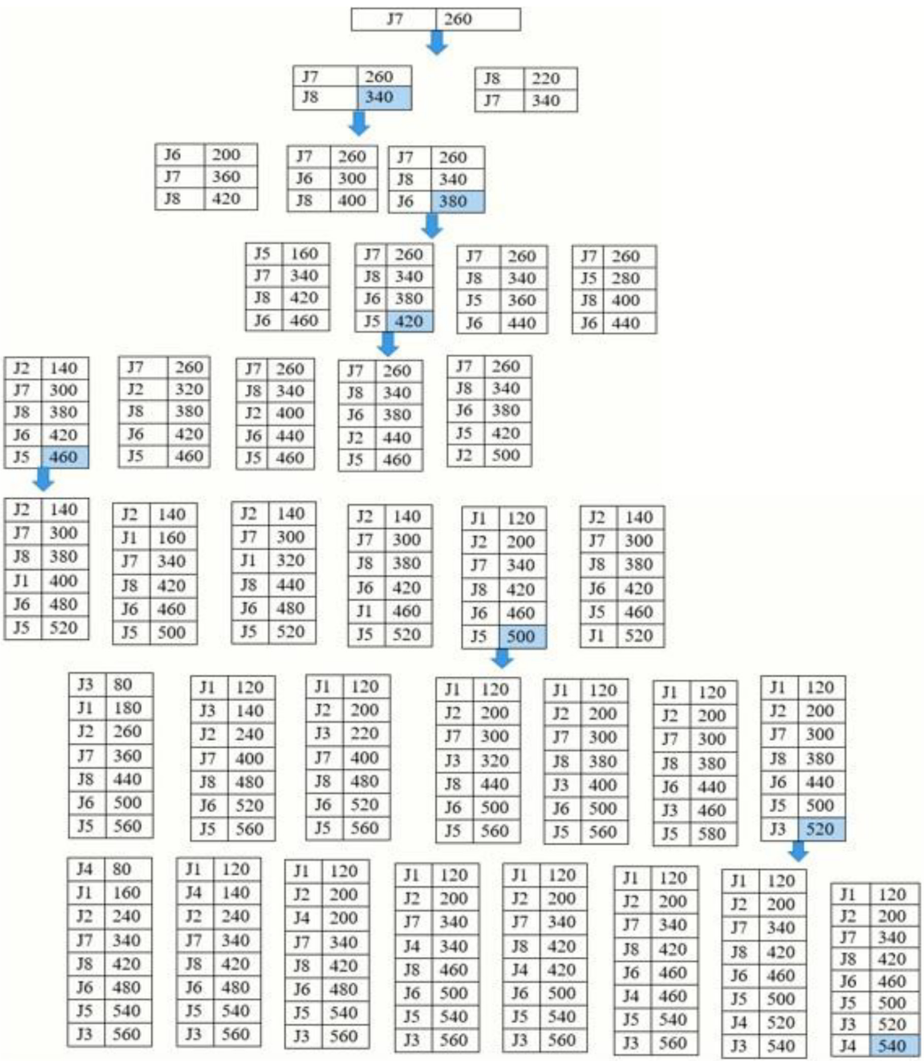

Figure 4. Results of the NEH algorithm depending on the sequence of jobs

Table 9. Throughput performance of jobs in hierarchical control system

Jobs	Job quantity	Production time/hrs	Throughput
T product	850	40	21
I product	950	45	21
E product	1000	61	16
L product	900	61	15
TI product	800	60	13
TE product	1000	89	11
LI product	1000	94	11
bE product	700	75	9
Average throughput			14

Table 10. Cycle time results of jobs in semi-heterarchical control system

Jobs	Processing time	Load/unload time	Inspection time	Transportation time	Changeover time	Cycle time
T product	80	20	5	50	13	168
I product	80	20	5	50	14	169
E product	120	20	5	50	26	221
L product	140	20	5	50	27	242
TI product	160	20	5	50	35	270
TE product	200	20	5	50	44	319
LI product	220	20	5	50	43	338
bE product	260	20	5	50	49	384

Table 11. Material utilization in semi-heterarchical control system

Jobs	Area unit	Material utilization
T product	5	33%
I product	3	20%
E product	6	40%
L product	5	33%
TI product	8	53%
TE product	11	73%
LI product	8	53%
bE product	11	73%
Average material utilization		48%

Table 12. Machine utilization in semi-heterarchical control system

Jobs	M1	M2	M3
T product	1	0	1
I product	1	1	0
E product	1	1	1
L product	1	1	1
TI product	1	1	1
TE product	1	1	1
LI product	1	1	1
bE product	1	1	1

Throughput analysis

The second analysis of this scenario is provided in Table 9, which depicts the throughput performances results of a three assembled machines. It demonstrates increasing demand volume within limits 701–1700. Therefore, demand volume is assumed equal to 900 produced units for eight different jobs, and the total job quantity equal to 7200 units.

Cycle time analysis

Table 10 where the cycle time represents the total time it takes a job to move from the beginning to the end of process as (load, unload, processing, transportation, inspection, and changeover time) as shown below:

Resources utilization

To achieve efficient utilization of resources with the minimum cost incurred and with no wastage of resources, semi-heterarchical production control achieve this objective, as shown in Table 11 below.nIn turn machine utilization (MU)

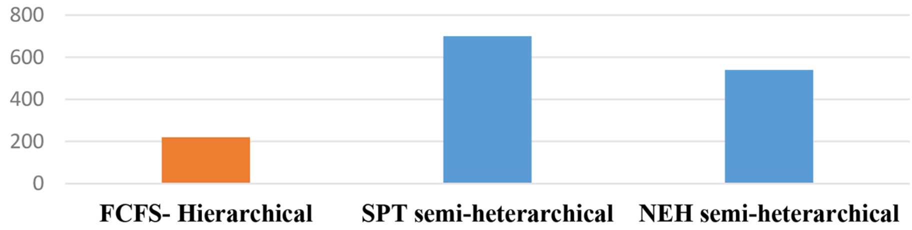

Figure 5. Makespan for the two control systems

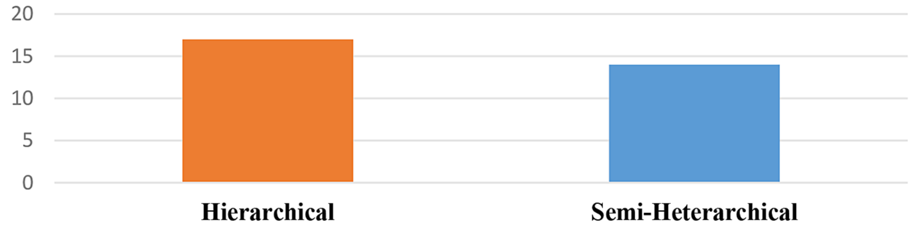

Figure 6. Throughput results for the two control systems

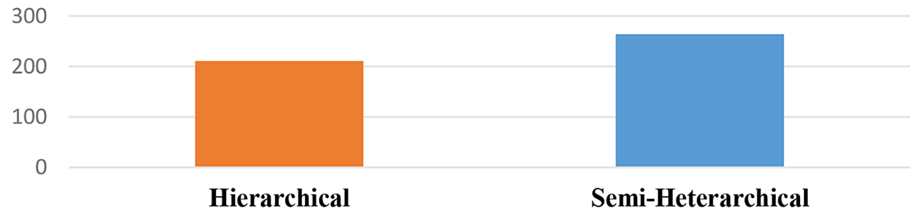

Figure 7. Cycle time results for the two control systems

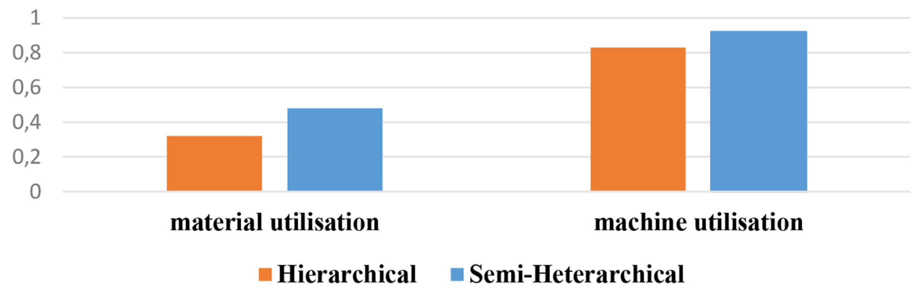

Figure 8. Resources utilization results for the two control systems

in the semi-heterarchical production control system = 92%, it was calculated through Table 12. Figures 5–8 show the results of numerical experiments conducted of the demand orders for each scenarios of the control approaches.

CONCLUSIONS

The goal of this study was to determine how well hierarchical and semi-heterarchical architectures work in production control systems so that they can be compared. In order to meet market demand, FMS was adopted in the research as a production environment where it was utilized to manufacture a wide range of products with little setup time. This is accomplished using an effective control system in addition to some automation to boost output. In general, focusing on FMS in the context of production control systems is strategic due to their high flexibility, and potential future integration of advanced concepts. While newer technologies, such as intelligent manufacturing systems and smart systems may present inside the concept of FMS as an advanced technology. FMS research provides insights into how control systems may evolve in response to emerging technologies, ensuring a well-rounded perspective and laying the groundwork for future advancements in manufacturing control systems. This study employed four performance metrics, including makespan, throughput, cycle time, and resource utilization, to fulfil its objectives. The volume of production when applying the hierarchical control structure was 2400 units, while the volume of production increased when applying the semi-hierarchical control structure to approximately 7200 units.

Due to the increased diversity in the number of products when applying the semi-heterarchical control system from four to eight different products, this requires more production time to perform the manufacturing operations, and thus the makespan value increases from 220–700 seconds. The selection of the NEH algorithm as a proposal, rather than the SPT scheduling rule in semi-heterarchical control structure, is mostly based on its ability to achieve a lower makespan value. The value of makespan by using SPT was equal to 700 time unit in the semi-heterarchical control structure, while the value of makespan by using NEH was equal to 540 time unit, so the time for scheduling production operations was reduced by 160 time units. The observed disparity in makespan values between the two control systems may be attributed to the expected outcome, resulting from the increase in product diversity, and the higher level of difficulty associated with assembling these products on a single plate. In the semi-heterarchical control system, an important characteristic was the generation of several employment opportunities via the assembly of two products on a single plate. This specific characteristic was not present in the first hierarchical control system. In contrast, while examining the throughput metric for production control systems, it was seen that in the context of a hierarchical control system, the throughput was determined to be 17. This measurement was obtained during a manufacturing duration estimated to be 142 time units, resulting in the manufacture of 2400 units. Despite the considerable duration of the manufacturing process, which spanned 525 time units and resulted in the production of around 7200 units, the semi-heterarchical control system achieved a throughput indication of approximately 14. The findings of this study illustrate the potential of using a semi-heterarchical control approach to achieve improved throughput performance in comparison to a hierarchical control approach. Additionally, the findings indicate that the cycle time required to construct a single product on the plate is less than the cycle time needed to assemble two products on the same plate in a semi-heterarchical control approach. This discrepancy may be attributed to variations in the processing time and the rate of change over time. The semi-heterarchical control system demonstrated superior performance compared to the hierarchical control system in terms of achieving effective resource utilization at minimal cost and without any waste. This was shown by an 18% improvement in material utilization for plates used in component assembly. The implementation of a semi-heterarchical control system resulted in a 9% improvement in machine utilization. Therefore, in the context of manufacturing enterprises operating in a competitive market, it is no longer enough to rely only on conventional production control systems (hierarchical) in order to attain operational excellence. These studies should be expanded to managing other uncertainties involving quality change and time delivery of the demands.

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