Internet of Things (IoT) Utilization to Improve Performance and Productivity of Internal Supply Chain

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Abstract

The inevitable transformations brought about by the rapidly changing Internet of Things (IoT) impact all aspects of life today, including management and businesses. Specifically, areas of businesses depending mainly on internal supply chain capacity are experiencing a paradigm shift to ensure effective company performance regarding purchases, production, company sales, and product distribution. This shift means that challenges faced by the internal chain supply unit can be solved by adopting and adapting IoT as a new way to minimize work delays and save time. Moreover, IoT automatically leads to performance and productivity increases. Therefore, the present paper aims to justify adopting and adapting IoT applications in Indonesian companies, including retail businesses. Most companies' internal supply chain units face several difficulties during and after the devastating peak of COVID-19, which has led to a total global lockdown. These problems' complexity is exponential and requires innovative ways to solve their prevailing challenges. This study used observation, interview, and documentary research methods through a large-scale survey. The survey obtained the necessary information regarding how companies utilize IoT to improve their performance and productivity without hindering their internal supply chain and production units. The study concluded that the adoption of IoT, if well implemented, leads to a sustainable company and uninterrupted supply chain performance, indicating the proper performance of the organization.

1- Introduction

For many years, industrial production has been the primary foundation for most countries' economic growth and development worldwide [1]. However, in many manufacturing and assembling industries, each task must go through a specific course of operations, which mostly have similar multi-complex processes required for production [2]. The processes need innovation, requiring the adoption of and adaptation to the production collaboration process, a vital dimension of doing things related to sustainable supply chain management and production in an organization [3].

In addition, a well-simplified adoption process for employing the Internet of Things (IoT) is essential in today's production chain management structure. Cui et al. [3] proposed merging information systems management with improving data processing capabilities to ensure this adoption. The reason was that data processing capabilities are an integral element required to operate a production process based on IoT smoothly. Though IoT has come to stay in the manufacturing, internal supply chain, assembling industries, and management, its use in most developing countries is

still sparsely implemented [4]. IoT use is primarily limited due to inadequate consolidation and clear-cut unestablished guidelines. The issues in consolidations and guidelines are because most countries have not adopted a broader use of smart technology [5], especially in production companies. Furthermore, studies revealed several reasons why innovation, adoption of, and adaptation to new technologies and ways of doing things take time in the developing world. The reasons include disruption in the supply chain, limited collaboration, and limited resources. In other words, production tasks may go through the same process for years without change. This sameness is due to disruption in, for instance, IT and computer technologies, which are the foundation for the adoption of IoT [6].

Like in other developing countries, IoT technology has been newly introduced to Indonesia because of its strength and opportunities. However, its utilization has been slow due to three actors with varying fears. First, the government, in most cases, considers the technicality of introducing new technology and how it impacts the existing infrastructure [7]. Second, the business community looks at how beneficial novel technology can be for their businesses. Third, community members want to know if the nascent technology can accommodate and fulfill their needs and demands [7].

The present study examined the IoT concept to justify its importance to the government, business actors, and the public. This paper examined how IoT technology has been adopted and implemented in Indonesian companies. In addition, it discussed the inevitable changes and transformations brought about by the rapidly changing IoT) impacting people's lives and company production. Digitalization has become a common development for Indonesia, turning Internet utilization into an everyday activity, with over 171.17 million users across the country [7, 8]. Moreover, Suryanegara et al. [7] revealed that Internet access as a basis for the more straightforward implementation of IoT is evenly distributed across the major Indonesian Islands. Furthermore, Joewono [9] estimated that by 2021, Indonesia's spending on IoT technology was the most in the Asia Pacific region. In addition, the IoT sectors are mostly the banking sector, education sector, and the government as the leading actor [10]. Besides, it was said that these sectors are enjoying the benefits of the 5G technologies.

1-1- IoT and Company Categorization in Indonesia

The desire to innovate and the need to improve the performance of companies using improved production processes resulted in the IoT application in Indonesia [11]. Companies in Indonesia are categorized into five types: 1. service, 2. agriculture, 3. trading, 4. extractive, and 5. manufacturing [12]. Service companies offer services or skills, and agriculture companies are specialized in agriculture and agricultural processing. Additionally, manufacturing companies are comprised of production industries that transform raw materials into final products that the final users can use. On the other hand, trading companies specialize in selling products of manufacturing companies. Furthermore, extractive companies do the mining and extraction of natural resources, which are then sold to other companies. In addition, Figure 1 illustrates the types of companies together with their respective descriptions.

FIVE MAIN FORMS OF COMPANIES EXISTING IN INDONESIA

Figure 1. Shows the Commonly Existing Categories of Companies in Indonesia

The above illustration clearly shows that there are five types of companies, which, if critically examined, are said to be the primary types. This paper mainly focused on category five, which required production. Moreover, there are four major categories of production based on the type of the produced commodity. This study looked at the continuous production analyzed concerning IoT technology utilization. This examination moved away from the delayed form of flow-shop scheduling production, which has numerous challenges due to the uninterrupted manual flow of production work on several machines.

Besides, IoT is a critical component introduced in manufacturing because the process comprises product, supply chain, and product marketing, all of which require a smart way of doing business. Additionally, the complexity of constant production using the traditional ways is exponential and needs innovation or adoption of smart Internet utilization to solve the production challenges. The current study used the IoT collaboration production concept to describe the process under which smart production operates. In Figure 2, a modified working structure is presented, which can be used as an example in simple production.
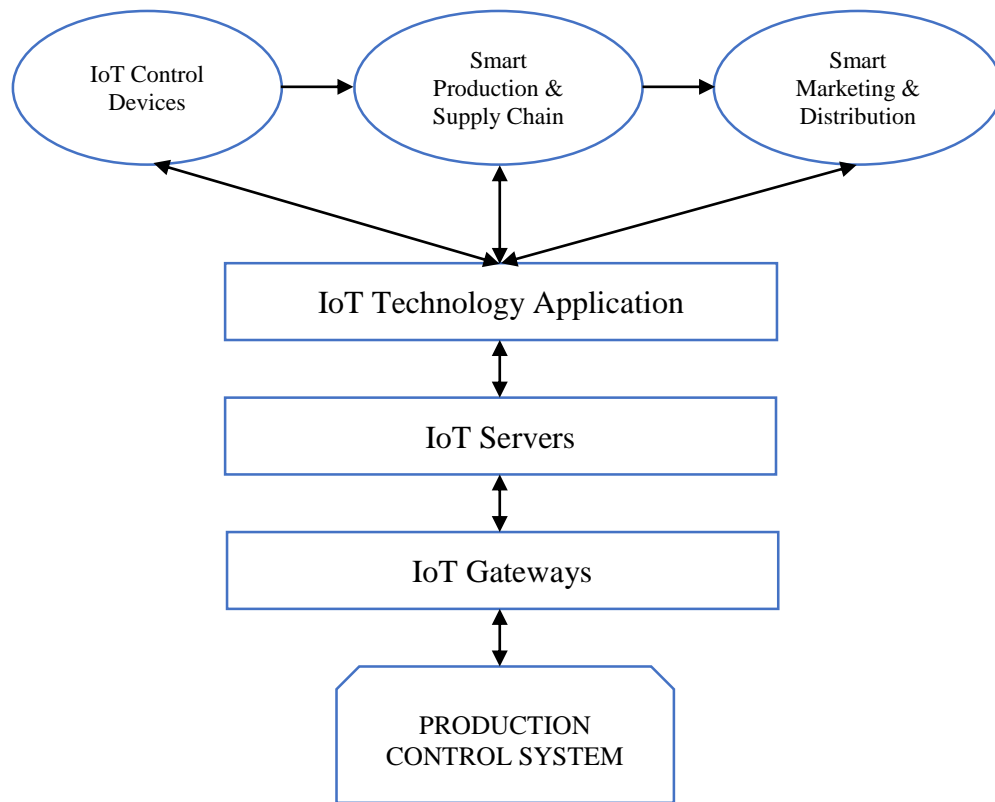
Figure 2. **Proposed Conceptual IoT Production Structure (Adopted from Kumar et al. [13])**

In uninterrupted production, production flow is combined with several smart technologies, which follow a flow system like the one seen in Figure 2 above. Innovative technologies solve the challenges faced in production are solved with the objective function of minimizing work time. First, the types of obstructions are reduced. Then, human interactions with IoT technology ensure smooth production operations [13]. The steps of the proposed production process are described simply in Figure 2. Moreover, the proposed IoT production structure was implemented on the sample problems found in previous studies. A comparison of the obtained results with the optimal solutions and the number of errors indicated the proper performance of the proposed operating system.

The integration of smart production technology starts from an innovative mind, which embraces new technologies for the company's satisfactory and efficient operation amidst the changing business climate [14-16]. Based on Figure 2, for adapting to using IoT or intelligent technologies, the system must be well-established from the beginning of introducing the technology devices required in soft and hard copies. Then, establishing an operating system comes into play, which ensures smooth production and also lays the structure for supply chain flow.

The supply chain structure comprises people, raw materials, and other resources. It is then intermingled with the technology essential for operating the system. However, though selling is still part of the supply chain, this study looked at it as a unit that completes the process. This consideration was since marketing has become more versatile today. Additionally, during and after the COVID-19 outbreak, online innovations in marketing have grown and almost become the leading marketing tool for most countries, including Indonesia.

2- Literature Review

2-1- Business in Indonesia and the Use of IoT

According to the Indonesian Government, the Ministry of Industry predicted that the country's market share and application of IoT would increase and grow faster [14]. Moreover, adopting smart technology aims to minimize the total production operation time [15]. The current study discussed the modern smart technologies used in manufacturing. The study also compared this use with the concept of the production scheduling model first introduced in the 1954s. Ignall and Scharge first applied the concept as a flow workshop [17]. On the other hand, Johnson [18] proved that a flow

workshop with the objective function of the longest makespan of 2 is an m>2 problem, precisely an NP-hard problem. Some studies suggested that it's appropriate to use crucial tools, like an IoT-based system that uses meta-heuristic algorithms [19] to solve problems in a high-quality manner and reasonable time.

According to Sharma and Tripathi [19], meta-heuristic algorithms are organized and independently operated algorithms required to perform challenging tasks using team intelligence in mass production. Furthermore, meta-heuristic algorithms can be used in different activities. Kiani et al. [20] proposed an integrated model which used an algorithm for planting crops. This model also monitored and controlled crop growth using IoT. In addition, for harvesting, the model employed Reverse Ant Colony Optimization, which also has roots in algorithms, operating as an automated robot.

It was assumed that a prepared job could automatically be handled in a classic situation. It was believed that since algorithms were integrated with IoT, the task could be self-automated, and work could go on immediately, depending on how the system was set [21]. In other words, no interruption could be shown with WB (without blocking). However, practically in conventional production, the mentioned process was impossible due to space, operator, and tool constraints. Obstruction occurred when a prepared job could not initiate working on a machine for many reasons. Different types of obstructions were:

- Release when Starting Blocking (RSb): A machine remains blocked by a job until this job starts on the next machine in routing;

- Release when Completing Blocking* (RCb*): A machine will be available to treat its next operation after its job is finished on the following machine functioning in the process [22];

- Release when Completing Blocking (RCb): A machine will be able to treat its next operation after its job is finished and left to be worked on by the next machine [23].

As mentioned before, the production is mainly of varying types, which include flow production concerning different obstruction types. Moreover, there is a hybrid flow shop problem which is a generalized form of two specific scheduling problems: flow-shop scheduling and parallel machine problem. Therefore, it includes a set of production stages, each encompassing several operational parallel machines.

In addition, the product flow in the manufacturing system is identical and one-dimensional. Each job is processed by one machine in each stage, and machines can have different processing speeds at each stage. However, due to the complexity faced in shop floor scheduling, IoT can be employed to enhance controlling the process with the help of sensors, industrial wireless communication, and automated identification of tasks established within the process of shop floor scheduling [24]. Additionally, Reddi & Ramamoorthy [25] discussed that a two-machine problem with RSb could turn into a particular mode of the traveling salesman problem. Moreover, Hall and Sriskandarajah [26] showed that three-machine problems with RSb were of NP-complete type. In addition, Martinez et al. [27] proved that the problems faced by more than four machines and RCb are of NP-hard type. Besides, Trabelsi et al. [22] introduced RCB* obstruction in solving the problem.

In another study in 2012, Trabelsi et al. [28] used new, improved heuristics and a genetic algorithm (GA) to minimize the total processing time of the sequence when a combination of obstructions existed between machines. They compared their methods with the NEH algorithm and with each other. Their results showed that an exact solution of the heuristic algorithm had an average error of 1.61% and an average solution time of one second [28]. In GA, the average error was 0.34%, and the maximum solution time was 11.5 seconds. Furthermore, Shao et al. [29] presented a multistage model using a greedy algorithm to solve a flow-shop scheduling problem. Several heuristic algorithms were used in the greedy algorithm responsible for improving the solution until reaching a local optimal point. It is worth noting that the heuristic method has an extremely high performance in small and moderate size manufacturing companies compared to the large size ones.

Recently, automated machine production has been widely focused on, and IoT has been adopted in the industrial production process [30]. The fully-automated manufacturing structure based on IoT is set with a parallel machine scheduling connected to several servers [30]. Besides, Goli and Keshavarz [31] proposed a mathematical model for parallel machine scheduling problems considering sequence-dependent preparation. They simultaneously minimized earliness and tardiness and used biogeography-based optimization and neighborhood search algorithm. On the other hand, Huang et al. [32] presented a heuristic method to solve a flow-shop scheduling problem. They considered the scheduling time dependent on the sequence. This heuristic method was compared with several algorithms existing in the literature, and the results were indicative of the efficiency of the heuristic algorithm.

Furthermore, Li et al. [33] developed an Artificial Bee Colony (ABC) algorithm for a flow-shop scheduling problem. They redefined the ABC algorithm under discrete terms. Then, they focused on solving the flow-shop scheduling problem with sequence-dependent scheduling time [33]. Implementation results on 780 benchmarks showed that the designed algorithm could perform about 10% superior to other algorithms [33].

2-2- *Flow Shop Problem and IoT System*

The need to perform varying tasks within a shorter period leads to downtime, which is considered a key measure for service delivery in organizations. The innovation of IoT resulted in the shift and change in task performance in the manufacturing sector [34]. In a flow workshop scheduling problem, a set of n jobs ($J = J_1, J_2, …, J_n$) must be performed on a set of m machines ($M = \{M_1, M_2, …, M_m\}$). All J_i jobs need a series of identical operations ($O_i = \{O_{i1}, O_{i2}, …, O_{im}\}$) that must be performed based on the production process. O_{ij} operations need P_{ij} execution time on $M_j \in M$ machine.

The objective function used in the present article was the longest makespan or C_{max}. In this mode, the following assumptions, which were introduced by Baker (1976), were established:

- Each machine treats only one job at a time;

- The operations of one job cannot be simultaneously performed on several machines;

- Production is not discontinued during the process;

- All jobs are independent and are accessible for operations at zero time;

- Preparation time on machines is partial and negligible, and

- Machines are constantly available.

It was concluded, considering the abovementioned, that manufacturing based on a combined IoT system led to better performance. The previously faced challenges were solved through an improved way of doing things. Moreover, the heuristic algorithm presented in the current study was based on the Ant Colony Optimization (ACO) algorithm, inspired by the behavior of ants in nature. The algorithm was used to solve hybrid optimization problems and compare the results with other algorithms, which showed the high efficiency of the algorithm.

The main idea used in the present study was derived from the algorithm presented by Ahmadizar [35]. This idea resulted from the Max-Min algorithm, first introduced by Stults and Hoos (1997). The algorithm is an optimization of the initial ant system. In this algorithm, only the best ants update the pheromones. Moreover, the number of pheromones is limited between the minimum and maximum values.

$$A_i = -\sum_{j=1}^{m} \left((m - (2j - 1))p_{ij} \right) \tag{1}$$

In addition, the slope algorithm (Palmer, 1965) was used to determine the primary pheromone level. The idea of this algorithm was to do jobs as soon as possible with a low processing time for the first machines and a high processing time for the last machines. This algorithm minimized the wasted time before starting the job on the machines. The slope coefficient was first calculated for the i-th job using the equation below to use the algorithm:

In Equation 1, i is the job number, j is the machine number, m is the number of machines, and p_{ij} is the total job execution time on the j-th machine. After the calculation, the job with the highest coefficient was selected as the first job for scheduling. Besides, the second selected job had the highest coefficient among other jobs. The process continued until scheduling the job with the lowest coefficient. The ACO algorithm included steps of mode change, local updating, final updating, and local search, which are explained as follows.

2-3- *Mini-Max Algorithm*

In ACO, all ants start creating a solution in each iteration. The K-th ant uses the selection rule for choosing the next job, as shown below:

$$s = \begin{cases} \arg max\ (\tau_{ij}) & if\ q \leq q_0 \\ s & otherwise \end{cases} \tag{2}$$

In the mentioned equation, q is a random value belonging to the range of [0,1]. In addition, q_0 is a parameter between zero and one, and S is a random variable chosen by probable distribution, as shown in Equation 3:

$$p_{ij}^k = \frac{\tau_{ij}}{\sum_{j \in N_j^k} \tau_{ij}}, i \in N_j^k \tag{3}$$

In this equation, q_0 is a parameter between zero and one, and N_j^k is a set of jobs not selected yet. Moreover, τ_{ij} is the relative importance (pheromone) of placing the i-th job in the j-th location. This variable shows operations favorability level on the i-th job in the j-th location. When the K-th ant finds the justifiable solution, the pheromones of the ant's solution will change based on the equation below, which is known as local updating:

$$\tau_{ij} = (1 - \rho)\tau_{ij} + \rho/C_{max}^k \tag{4}$$

The C_{max}^k parameter is the objective function (the longest makespan) of the total order of the K-th ant. In addition, p is a parameter between zero and one. The local updating rule leads ants to search for a more prominent space to find justifiable solutions. When ants generate their solutions, the solution with the best objective function is selected, and the pheromones are changed based on the updating rule:

$$\tau_{ij} = (1 - \rho)\tau_{ij} + \rho z/C_{max}^{s-best} \tag{5}$$

In this equation, the C_{max}^{s-best} parameter is the best objective function of the order found in this iteration. Moreover, the z parameter is a positive number that shows the relative importance of this order. The final updating rule leads to the continuation of the search in the neighborhood of the best solution. The values of τ_{max} and τ_{min} are updated at the end of each iteration based on:

$$\tau_{max} = 1/(\rho C_{max}^{s-best}) \tag{6}$$

$$\tau_{min} = U\tau_{max} \tag{7}$$

Now, all τ_{ij} are compared, and if they are larger than τ_{max} or smaller than τ_{min}, they will be equated to the maximum and minimum amount.

2-4- Primary Pheromone Amount

The maximum τ_{max} and minimum τ_{min} are calculated using the equations below:

$$\tau_{max} = 1/(\rho C_{max}^s) \tag{8}$$

$$\tau_{min} = U\tau_{max} \tag{9}$$

The C_{max}^s is the objective function obtained from the slope heuristic algorithm. In the formulas above, p and U are between zero and one. The primary pheromone amount is first equated to τ_{min}. In addition, the obtained pheromone of the solution is updated by using the slope method:

$$\tau_{ij} = (1 - \rho)\tau_{ij} + \rho/C_{max}^s \tag{10}$$

Equation 10 leads to the increase of s-order pheromone relative to the minimum amount, which leads to a search for an immediate solution.

2-5- Local Search Algorithm and IoT

One way to increase the ant algorithm efficiency is using local search methods. Therefore, first, all the input sequence operations are moved in pairs. Then, if the solution is improved, the current sequence is replaced with a new sequence. The general structure of the ant algorithm employed was as follows.

Table 1. The Structure of the Ant Algorithm Used

Step 1: allocating initial parameters of primary solution generation and allocating primary pheromones

Step 2: The following stages will be repeated until the termination condition is met.

    2.1: Repeat the following steps for each ant in the colony.

        A) A solution is generated by frequently repeating the transition rule.

        B) The solution quality is improved by a local search.

        C) The local updating process is performed.

        D) In the case of solution optimization, it will be replaced by the best current solution.

    2.2: Pheromones are corrected based on the final updating rule.

    2.3: The minimum and maximum pheromones are updated and pheromones are limited.

Step 3: The best solution is exhibited.

However, though it is argued that the local search method is not required to increase efficiency, IoT helps integrate multiple entities or tasks to establish seamless collaboration between the virtual and physical components of manufacturing [35]. In other words, IoT can cause a change from the mere use of manual machines and the Internet to a collaborative network of systems [35].

Regarding Table 1 above, there was an allocation of initial parameters of the primary solution used for generating and allocating phenomena related to utilizing IoT in manufacturing in the current paper. There were steps followed for each point: frequently generating solutions, improving quality, updating the process, renewing software or hardware, correcting errors, minimizing losses, and maximizing good performance. It is worth mentioning that IoT encourages collaborating networked systems to help sensing, processing, communication, and data saving [35].

3- Results and Discussion

The problems were implemented in Delphi software in a computer with a CPU of Dual-core 3.16 GHz and a 2GB memory. The ACO algorithm solved the sample problems, and the parameters of U, z, and p were considered at 0.005, 20, and 0.1, respectively. Moreover, the number of ants and a maximum number of iterations for algorithm discontinuation were considered 10 and 50, respectively. Furthermore, the q_0 parameter was calculated by Equation 11, where the n parameter is the number of jobs.

$$q_0 = (n - 2)/n \tag{11}$$

Obstructions were placed between machines as follows and were repeated periodically:

1. RCb
2. RSb
3. RCb*
4. Wb

The results were evaluated by implementing the proposed algorithm on the study's data based on Trabelsi et al. (2010). Table 2 shows the number of solved problems.

Table 2. The number of solved examples

Column	Number of Jobs (n)	Number of Machines (m)	Number of Solved Examples
1	5	{5,6,7,10,15,20,50,100}	100
2	6	{5,6,7,10,15,20,50,100}	100
3	7	{5,6,7,10,15,20,50,100}	100
4	8	{5,6,7,10,15,20,50,100}	100
5	9	{5,6,7,10,15,20,50,100}	100
6	10	{5,6,7,10,15,20,50,100}	100
7	11	{5,6,7,10}	100
8	11	{15,20,50,100}	20
9	12	{5,6,7}	100
10	12	{10,15,20,50,100}	20

In the present study, the results were compared with the optimal solution in another article by the same authors. The following results were obtained from the comparison of the obtained results with the results of the metaheuristic algorithm existing in Trabelsi et al. (2010). In addition, Table 3 shows a comparison of Different Solutions:

Table 3. A comparison of different solution methods in n=10 mode

	a	b	c	ACO
5	2.31%	5.31%	3.93%	1.69%
10	4.64%	6.01%	5.95%	4.50%
15	15.90%	8.69%	9.77%	7.86%
20	9.57%	8.38%	8.20%	7.56%
50	15.72%	25.48%	9.89%	9.88%
80	44.35%	51.02%	62.69%	44.02%
100	28.84%	23.36%	73.33%	23.11%
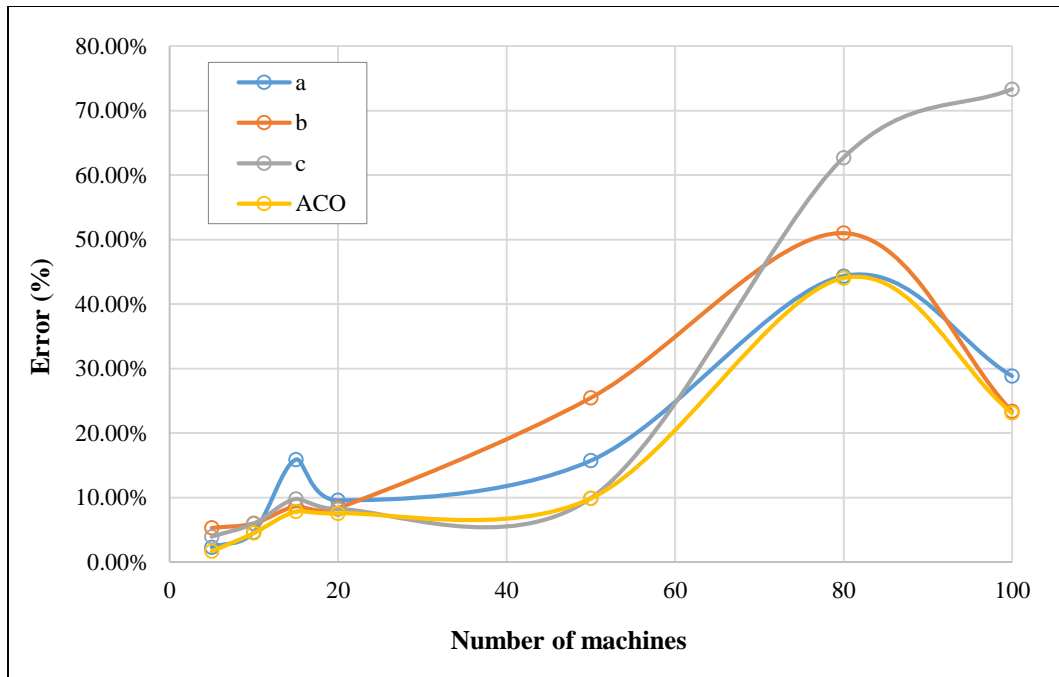
Figure 3. Error rate for mode of n=10

Table 4. A comparison of different solution methods in mode of n=20

	a	b	c	ACO
5	3.12%	1.99%	3.76%	1.82%
10	1.02%	5.21%	4.23%	0.39%
15	5.69%	4.00%	2.39%	1.77%
20	14.36%	2.79%	5.56%	2.57%
50	3.20%	4.61%	41.15%	2.69%
80	9.63%	31.18%	41.27%	9.61%
100	68.69%	83.59%	43.86%	43.72%
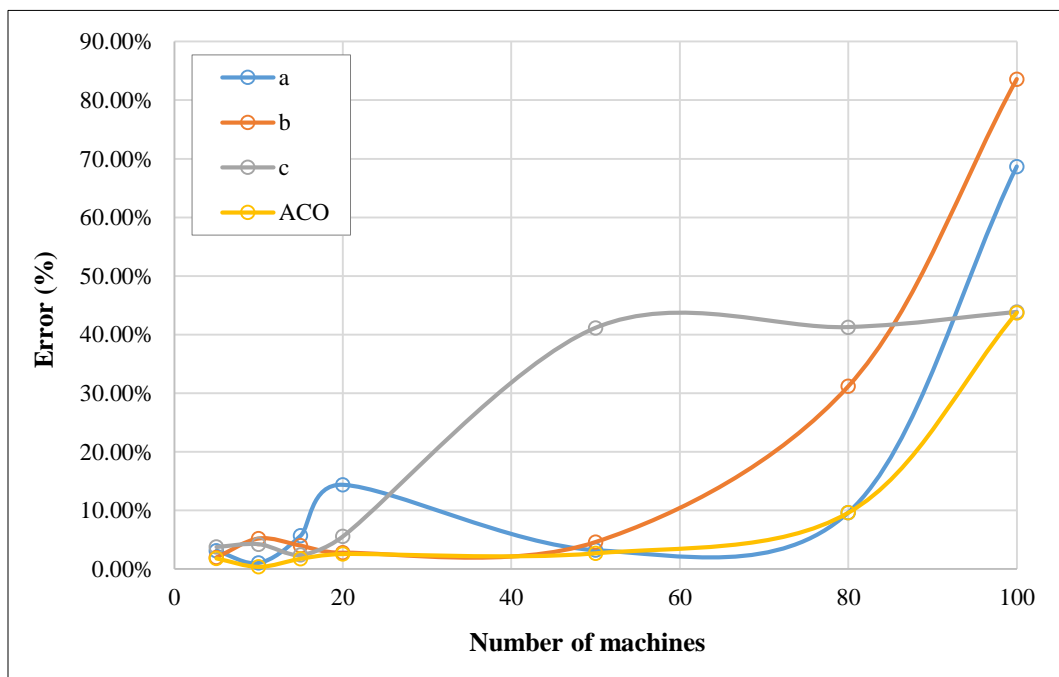
Figure 4. The error rate for the mode of n=20

Comparing Figures 2 and 3 and Tables 3 and 4 showed the maximum error obtained in the n=10 and n=20 modes was approximately 70% and 80%, respectively. This finding demonstrated that problem complexity increased by increasing the number of jobs. Moreover, Figure 1 shows that the error rate in the ACO algorithm is lower than in other algorithms in all modes. The same applies to Figure 2, where the ACO algorithm performs better than other algorithms, confirming its efficiency.

Applying IoT in Indonesia has been caused by the desire to innovate and the need to improve the performance of companies through improved production processes [11]. This application means that challenges faced by the internal supply chain unit can be solved by adopting and adapting to IoT as a required new way to minimize work delays and save time. In addition, the utilization of IoT automatically increases performance and productivity. Thus, the present study sought to justify the importance of adopting and adapting IoT applications in Indonesian retail business companies.

The current study used the ant algorithm to solve the problem of workshop flow with combined obstruction. The problem is solved with the objective function of minimizing work time. Therefore, first the obstruction types were introduced. Then, the current workshop problem was explained. The steps of the proposed algorithm are described below. Besides, the proposed algorithm was implemented on the sample problems in the literature. The results were also compared with the optimal solution. Furthermore, the amount of error indicated the proper performance of the proposed algorithm. In the present study, the results were compared with the optimal solution found in another study by the same authors. The following results were obtained by comparing the results with the metaheuristic algorithm results in the article by Trabelsi et al. [22]. In most cases, an optimal solution was obtained in most cases for problems with 5-8 jobs. In addition, there was no difference between the studies regarding solution time.

Moreover, the algorithm used in the present research yielded better solutions for more extensive problems than algorithms *a* and *b*, as shown in the diagrams below. Compared to algorithm c, the current study's algorithm yielded a better solution or a near-optimal solution while the solution time decreased significantly. Method *a* was the GA with 50 chromosomes (individuals). Besides, in method b, the previous algorithm solution was improved by TSS and NEH algorithms. Moreover, method c was the best solution for algorithms *b* and *a* with a GA of 100 chromosomes (individuals).

In many manufacturing and assembly industries, each job must go through a specific course of operations, which mostly have a similar order for all tasks. In other words, tasks pass the same route. In such systems, the machines are stacked one after another, and the system is known as a flow workshop. Generally, the flow workshop is a branch of operation scheduling and is assessed in several articles annually. Flow workshop problems must determine the time and machine used for producing each product.

4- Conclusion

Many governments, business actors, and the people themselves, as beneficiaries of the public service and consumers, have been anxiously using the varying means of smart living to improve economic performance. Hence, this utilization has been integrating IoT into all human activities, like machine operations within the manufacturing sector. The sequence of machines' operations significantly impacts the job volume during construction. This influence is to the extent customers' demand is met on time and the overall cost of the product decreases, resulting in the need for collaborative job performance of multiple devices, including IoT and the scheduling of the flow operating system. Therefore, it is attempted to schedule operations in a production unit to employ the maximum use of the existing sources, like workforce and machinery. Nonetheless, machine failure is unavoidable, which can increase operational costs and cause a delay in the completion of customer orders. The flow-shop scheduling problem is one of the most complicated issues in combined optimization and a branch of production scheduling. In this problem, the objective is to determine the processing sequence of n jobs on m machines such that a previously determined objective function, like production course, is optimized. In this mode, a job is considered complete when all operations related to that job are finished.

On the other hand, each job in a classic production workshop problem encompasses a set of identical items and cannot be divided into smaller parts. In other words, each batch of items must be completely transferred from one machine to another, even if a part of that batch's items is prepared to be processed on the next machine. Therefore, the first constraints assume that jobs are independent, and the second constraints show that each job cannot be decomposed. However, these two constraints are not always established in the real world.

The present study applied the AOC algorithm to optimize the solution for the flow workshop problem with combined obstruction. The proposed algorithm was implemented on the data presented by Trabelsi et al., where the optimal solution was accessible to evaluate the results. The results of the proposed algorithm improved the solutions in most cases compared to the solutions in this article. There was also a significant difference in the time spent solving more extensive problems. It is recommended that the algorithm be optimized in future studies and be used to solve other flow workshop problems.

5- Declarations

5-1- Author Contributions

Conceptualization, D.H. and IM.D.; methodology, Y.E.; software, D.H.; validation, D.H., IM.D. and Y.E.; formal analysis, Y.E.; investigation, IM.D.; resources, D.H.; data curation, IM.D.; writing—original draft preparation, D.H and Y.E.; writing—review and editing, D.H.; visualization, IM.D.; supervision, D.H.; project administration, IM.D.; funding acquisition, D.H. All authors have read and agreed to the published version of the manuscript.

5-2- Data Availability Statement

The data presented in this study are available in the article.

5-5- Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

7- References

[1] Worrell, E. (2004). Industrial Energy Use, Status and Trends. Encyclopedia of Energy, 395–406, 395–406. doi:10.1016/b0-12-176480-x/00196-0.

[2] Pfeiffer, S. (2022). Productive Power in Concrete Terms. In F. Butollo & S. Nuss (Eds.), Marx and the Robots (pp. 120–137). Pluto Press. doi:10.2307/j.ctv28vb1tp.11.

[3] Cui, L., Gao, M., Dai, J., & Mou, J. (2022). Improving supply chain collaboration through operational excellence approaches: an IoT perspective. Industrial Management and Data Systems, 122(3), 565–591. doi:10.1108/IMDS-01-2020-0016.

[4] Kalsoom, T., Ahmed, S., Rafi-Ul-shan, P. M., Azmat, M., Akhtar, P., Pervez, Z., Imran, M. A., & Ur-Rehman, M. (2021). Impact of IoT on manufacturing industry 4.0: A new triangular systematic review. Sustainability (Switzerland), 13(22), 12506. doi:10.3390/su132212506.

[5] Kassab, M., DeFranco, J., & Laplante, P. (2020). A systematic literature review on Internet of things in education: Benefits and challenges. Journal of Computer Assisted Learning, 36(2), 115–127. doi:10.1111/jcal.12383.

[6] Shuo-Yan, C. (2018). Digital Fusion with Internet of Things. Journal of International Affairs, 72(1), 107–120.

[7] Suryanegara, M., Arifin, A. S., Asvial, M., Ramli, K., Nashiruddin, M. I., & Hayati, N. (2019). What are the Indonesian Concerns about the Internet of Things (IoT)? Portraying the Profile of the Prospective Market. IEEE Access, 7, 2957–2968. doi:10.1109/ACCESS.2018.2885375.

[8] Nurhayati, S., Noor, A. H., Musa, S., Jabar, R., & Abdu, W. J. (2022). A Digital Literacy Workshop Training Model for Child Parenting in a Fourth Industrial Era. HighTech and Innovation Journal, 3(3), 297–305. doi:10.28991/hij-2022-03-03-05.

[9] Telkomsel IoT. (2022). Boosting Productivity in Indonesia's Main IoT Sectors with 5G. Available online: https://telkomseliot.com/id/berita-insight/boosting-productivity-in-indonesias-main-iot-sectors-with-5g (accessed on March 2022).

[10] Evandio, A. (2022). Anggaran Belanja IoT di Indonesia Bisa Tumbuh Dua Digit. Available online: https://teknologi.bisnis.com/read/20210312/84/1366937/anggaran-belanja-iot-di-indonesia-bisa-tumbuh-dua-digit (accessed on February 2022).

[11] Mahendra, E.A., Dachyar, M., & Farizal. (2019). Internet of things-based processes improvement of Indonesian hospital. Proceedings of the International Conference on Industrial Engineering and Operations Management Pilsen, July 23-26, July 2019, Czech Republic.

[12] Karawang New Industry City. (2019). 5 Types of Companies You Can Find in Indonesia. Available online: https://www.knic.co.id/5-types-of-companies-you-can-find-in-indonesia (accessed on March 2022).

[13] Kumar, S., Tiwari, P., & Zymbler, M. (2019). Internet of Things is a revolutionary approach for future technology enhancement: a review. Journal of Big Data, 6(1), 111. doi:10.1186/s40537-019-0268-2.

[14] Umali, T. (2018). The potential of IoT in Indonesia. Available online: https://opengovasia.com/the-potential-of-iot-in-indonesia/ (accessed on January 2022).

[15] Liker, J. K., & Morgan, J. M. (2006). The Toyota way in services: The case of lean product development. Academy of Management Perspectives, 20(2), 5–20. doi:10.5465/AMP.2006.20591002.

[16] Simmie, J. (1998). Reasons for the development of "islands of innovation": evidence from Hertfordshire. Urban Studies, 35(8), 1261–1289. doi:10.1080/0042098984358.

[17] Ignall, E., & Schrage, L. (1965). Application of the Branch and Bound Technique to Some Flow-Shop Scheduling Problems. Operations Research, 13(3), 400–412. doi:10.1287/opre.13.3.400.

[18] Johnson, S. M. (1954). Optimal two- and three-stage production schedules with setup times included. Naval Research Logistics Quarterly, 1(1), 61–68. doi:10.1002/nav.3800010110.

[19] Sharma, V., & Tripathi, A. K. (2022). A systematic review of meta-heuristic algorithms in IoT based application. Array, 14, 100164. doi:10.1016/j.array.2022.100164.

[20] Kiani, F., Randazzo, G., Yelmen, I., Seyyedabbasi, A., Nematzadeh, S., Anka, F. A., Erenel, F., Zontul, M., Lanza, S., & Muzirafuti, A. (2022). A Smart and Mechanized Agricultural Application: From Cultivation to Harvest. Applied Sciences (Switzerland), 12(12), 6021. doi:10.3390/app12126021.

[21] Boorman, S. A. (1975). A Combinatiorial Optimization Model for Transmission of Job Information through Contact Networks. The Bell Journal of Economics, 6(1), 216. doi:10.2307/3003223.

[22] Trabelsi, W, Sauvey C., and Sauer N. (2010). Heuristic methods for problems with blocking constraints solving jobshop scheduling. Proceedings of the 8th international conference on modelling and simulation, Hammamet, MOSIM'2010, Tunisia.

[23] Martinez, S. (2005). Ordonnancement de systemes de production avec contraintes de blocage. PhD thesis, IRCCyN, Nantes, France.

[24] Wu, X., Tian, S., & Zhang, L. (2019). The Internet of Things Enabled Shop Floor Scheduling and Process Control Method Based on Petri Nets. In IEEE Access 7, 27432–27442. doi:10.1109/ACCESS.2019.2900117.

[25] Reddi, S. S., & Ramamoorthy, C. V. (1972). On the Flow-Shop Sequencing Problem with No Wait in Process. Operational Research Quarterly, 23(3), 323–331. doi:10.1057/jors.1972.52.

[26] Hall, N. G., & Sriskandarajah, C. (1996). A survey of machine scheduling problems with blocking and no-wait in process. Operations Research, 44(3), 510–525. doi:10.1287/opre.44.3.510.

[27] Martinez, S., Dauzère-Pérès, S., Guéret, C., Mati, Y., & Sauer, N. (2006). Complexity of flowshop scheduling problems with a new blocking constraint. European Journal of Operational Research, 169(3), 855–864. doi:10.1016/j.ejor.2004.08.046.

[28] Trabelsi, W., Sauvey, C., & Sauer, N. (2012). Heuristics and metaheuristics for mixed blocking constraints flowshop scheduling problems. Computers and Operations Research, 39(11), 2520–2527. doi:10.1016/j.cor.2011.12.022.

[29] Shao, W., Shao, Z., & Pi, D. (2020). Modeling and multi-neighborhood iterated greedy algorithm for distributed hybrid flow shop scheduling problem. Knowledge-Based Systems, 194, 105527. doi:10.1016/j.knosys.2020.105527.

[30] Xu, D., Li, G., & Zhang, F. (2021). Scheduling an automatic IoT manufacturing system with multiple servers. Computers and Industrial Engineering, 157, 107343. doi:10.1016/j.cie.2021.107343.

[31] Goli, A., & Keshavarz, T. (2022). Just-in-time scheduling in identical parallel machine sequence-dependent group scheduling problem. Journal of Industrial and Management Optimization, 18(6), 3807. doi:10.3934/jimo.2021124.

[32] Huang, J. P., Pan, Q. K., & Gao, L. (2020). An effective iterated greedy method for the distributed permutation flowshop scheduling problem with sequence-dependent setup times. Swarm and Evolutionary Computation, 59, 100742. doi:10.1016/j.swevo.2020.100742.

[33] Li, Y., Li, X., Gao, L., Zhang, B., Pan, Q. K., Tasgetiren, M. F., & Meng, L. (2021). A discrete artificial bee colony algorithm for distributed hybrid flowshop scheduling problem with sequence-dependent setup times. International Journal of Production Research, 59(13), 3880-3899. doi:10.1080/00207543.2020.1753897.

[34] Scholtz, B., Kapeso, M., & Van Belle, J. P. (2019). An Internet of Things (IoT) Model for Optimising Downtime Management: A Smart Lighting Case Study. In L. Strous & V. Cerf (Eds.), IFIP Advances in Information and Communication Technology 548, 89–104. doi:10.1007/978-3-030-15651-0_9.

[35] Karthick, S., & Gomathi, N. (2022). Sparrow Search Algorithm-based Resource Management in Internet of Things (IoT). EAI Endorsed Transactions on Energy Web, 9(37), 1–11. doi:10.4108/eai.13-5-2021.169915.