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ESTABLISHING AN OPTIMAL QUALITY PLANNING DECISION THROUGH DISCRETE EVENT SIMULATION: ANALYSIS CASE STUDY

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Abstract

Random in-process quality control (IPQC) is conducted in one of the departments in a circuit board manufacturing company, Company A, which produces high-mixed products, and results in complete failure of ensuring the quality of parts produced. Consequently, defects occur on the parts produced, leading to high rejection rate. This high rejection rate eventually results in high cost of non-value-added activities, which include rework of rejected parts. This paper introduces quality planning to ensure the quality of work-in-progress (WIP) parts in the production with discrete event simulation (DES) software. A series of experiments is conducted by using varying parameters, including flow patterns of parts in the shop floor and number of IPQC inspector, to assess the significance of these parameters on the performance measures relevant to quality perspective. Statistical analysis is conducted on the simulation results via ANOVA. Findings from this research prove that varying the parameters has a significant effect on the performance measures.

Keywords: Quality planning, IPQC, Discrete Event Simulation (DES), Analysis of Variance (ANOVA)

Abstrak

Rawak dalam proses kawalan kualiti (IPQC) telah dijalankan di Syarikat A, iaitu salah satu jabatan dalam sebuah syarikat pembuatan papan litar yang menghasilkan produk campuran tinggi dan menghasilkan kegagalan dalam memastikan kualiti produk yang dikeluarkan. Oleh sebab itu, kecacatan yang berlaku pada produk yang dihasilkan menyebabkan kadar penolakan yang tinggi. Penolakan yang tinggi ini menyebabkan kos yang tinggi untuk aktiviti bukan tambahan termasuk kerja pembaikian semula produk yang ditolak. Kertas kerja ini memperkenalkan perancangan kualiti untuk memastikan kerja dalam pelaksanaan (WIP) produk di dalam pengeluaran dengan menggunakan perisian penyelakuan peristiwa diskrit (DES). Satu siri eksperimen telah dijalankan dengan menggunakan parameter yang berubah, termasuk corak aliran produk di dalam lantai bengkel dan beberapa pemeriksa IPQC, untuk mentaksir kepentingan parameter tersebut di atas ukuran prestasi yang berkaitan dengan sudut kualiti. Analisis statistik telah dijalankan ke atas keputusan penyelakuan melalui analisis varians (ANOVA). Penemuan daripada kajian ini membuktikan bahawa parameter yang berubah mempunyai kesan yang ketara ke atas ukuran prestasi.

Kata kunci: Perancangan kualiti, IPQC, penyelakuan peristiwa diskrit (DES), analisis varian (ANOVA)

1.0 INTRODUCTION

"Quality" is define as the sum of all attributes that lead to the production of products acceptable to the customer when they are combined [1]. The quality of a product is determined by a series of activities and interdependent processes inside a company. Products are built step by step starting from the identification of quality requirements and going as far as maintenance in exploitation [2]. Product quality and reliability is the main competitive factor for manufacturers, whereas design and manufacturing capability as well as on-time delivery are the second most important factor for manufacturers [3]. The entire organization, i.e., from supplier to customer and from product design to maintenance, is affected by quality. Therefore, quality is a critical factor that enables an organization to deliver a reliable product or service on time, in addition to ensuring that customer requirements are fulfilled. Quality can be attained through managerial processes, which consist of sequences of activities that produce the intended results. Quality control (QC) is one of the processes used extensively in managing quality.

QC has an important function in the manufacturing industry because this process ensures that products conform to specifications before delivery to the customers. To date, QC is a system of routine technical activities that is used to measure and control the quality of the product during the development process. Quality assurance is a set of activities that ensures that the quality levels of products and services are properly maintained and that supplier and customer quality issues are properly resolved [4]. Quality inspection is a method conducted in QC processes to ensure the quality of product in manufacturing process. Inspection is the most common method of attaining standardization, uniformity, and quality of workmanship. "Inspection" is define as the measurement and quality assessment of items produced [5]. Generally, the QC process can be separated into three main processes as depicted Figure 1.

The three main processes in QC are incoming quality control, in-process quality control (IPQC), and outgoing quality assurance. The present research focuses on IPQC. IPQC is define as checks that are conducted before completion of the manufacturing process.[6] IPQC functions is to monitor and, if necessary, adapt the manufacturing process to comply with the specifications, which may include control of equipment and environment. In IPQC, inspection is carried out before completion of the production process. Inspection work is performed while the production process is simultaneously conducted. During IPQC, inspection is carried out at various workstations and critical production points. Inspection prevents wasting time and money on defective units as well as delays in assembly. Consequently, the products are delivered to the customer on time, and customer requirements on product quality are fulfilled.

Several previous studies have investigated on improving quality implementation in organizations. For instance, the use of expert system approach combined with in-process metrology in integrating the quality judgment process into the production process and brought the factory one step further toward total computer-integrated manufacturing is presented [6].[7] The cross-mapping of strategic and quality processes is explore to improve business strategy and quality implementation in organizations [7]. A new integration model is develop to facilitate a smooth transition from a quality assured company to a world-class company [8]. A process metric to measure quality and reliability assurance efforts is proposed in two dimensions, namely, efficiency and effectiveness [9]. A systematic top–down approach for the design of requirement-driven quality systems is presented to select the best-fit software platform by developing a comprehensive list of quality system requirements [10].

Several studies have also developed various methods to improve quality inspection process in the manufacturing industry. An ergonomics study on the visual inspection process at a printed circuit assembly factory was carried out by conducting ergonomics interventions [11]. These interventions rectified the identified problems to achieve improvements in quality, productivity, and OHS as well as reduction in rejection cost. The significant elements of a computer vision system and emphasized the important aspects of the image processing technique coupled is presented.[2] They also reviewed the most recent developments throughout the food industry in terms of accomplishing high-quality food products. A cost-effective solution to ensure product quality by introducing a follow-up stage in the inspection process was proposed [12].

An inspection model of multistage sampling that emphasizes dependency between defects and a more realistic cost structure is formulated [13]. The existing algorithms in computer vision in the field of agriculture and food to meet the present challenges by exploring different possible areas of research with a wider scope was enhanced [14]. The practical application of a quality system process that can be used to improve consistency in visual inspections by removing or substantially reducing fears relative to visual inspection was demonstrated [15]. "QUINTE" is a simulator used to investigate and evaluate inspection strategies with regard to quality, cost, and time in the manufacturing process was developed [16]. This research also introduced the application of "QUINTE" simulator in the industry and its integration to commercial simulation software.

Quality inspection is extremely critical in ensuring the quality of work-in-progress (WIP) parts or finished goods in the manufacturing industry. Random IPQC implemented in most companies today completely fails to ensure the quality of WIP parts produced, which causes some non-value-added activities, such as rework of a large batch of rejected products. The company profit will be reduced because of the additional cost required in rework. Rework activities also result in failure to deliver goods to customer on time and thus may affect the company reputation. Therefore, introducing IPQC planning to overcome this problem is necessary. IPQC aims to detect defects immediately once they occur during the production process, and thus corrective actions can be performed. In the present study, IPQC planning is introduced by considering a number of shop floor parameters to ensure that the quality of WIP parts is at the highest level. A series of experiments is conducted in simulation to test the effect of the different numbers of IPQC inspectors, which are assigned to the shop floor with different flow patterns of parts, on the performance measures. An optimal model is selected based on the analysis of the results obtained from the simulation runs. This paper is arranged as follows. Section 2 describes the approaches performed in constructing discrete event simulation model. Section 3 demonstrates the case study conducted in each experiment and the results obtained from the simulation. Section 4 presents the comparison of results obtained from Section 3 and the selected optimal model. Finally, Section 5 ends with the conclusion of this research.

Figure 1 Three main processes in quality control

2.0 APPROACHES IN CONSTRUCTING THE DES MODEL

The approaches in constructing the discrete event simulation (DES) model consist of three main phases, as illustrated in Figure 2. The stages of Phase 1 commence with the project definition. The problem statement and research objective are defined in this stage. The problem statement focuses on the arising issue related to the project. For example, the initiative of this study is focused on the IPQC planning issue; thus, the project definition from the quality perspective must be identified manifestly at the beginning of the project. This phase is decisive because once the problem and objective of the project are defined, the precise agreement upon project definition will be the focus and determination for setting up the objectives of the project initiative.

The development and verification of simulation models are carried out in Phase 2. In this phase, simulation models are constructed based on the data collected. Theoretical calculation is conducted to verify the simulation by comparing the simulation output to the theoretical output. Subsequently, the relevant performance measures are defined, and experiments are conducted in the simulation by using the identified parameter set. This phase consists of six stages, which are briefly elaborated subsequently. Data collection is the process in which all the pertinent data are collected. For example, from a company perspective, data can be collected by referring to production historical data. These data include the process flow of each part, machine cycle time, machine setup time, and output per shift. All the data collected are analyzed and scrutinized under the theoretical hand simulation stage before they are adopted in the simulation model.

Theoretical hand simulation is conducted to verify the data collected and the simulation model. This step is applied to evaluate whether the developed model will be operating in a constant mode in the long run. Moreover, this step will interconnect all the inter-arrivals and service times to be exact at their mean, which will represent the real outlook of the scenario being modeled. To perform the theoretical hand simulation model, some assumptions should be made for used in the simulation modeling in the next stage. Once the theoretical hand simulation is completed, the hand simulation model is translated to the WITNESS 2008 Manufacturing Performance Edition simulation software. Before any simulation run can be conducted, a verification run is carried out. The process compares the simulation output and the theoretical output. Verifying the simulation ensures that the simulation is running accurately and represents the real environment.

The parameters are established and input into the simulation models. These parameters are varied in the simulation models to test their effects on the results of simulation runs. Further deliberation on the parameters is presented in the case study section. In the simulation, the criterion used to measure the performance of the simulation model is identified as the performance measure. The criteria used depend on the focus of the measurement [18]. Conducting a warm-up period and replicating a certain output stream (e.g., waiting times) are significant to complete the simulation modeling; throughput can be conducted before the actual experimental run. Simulation runs are proposed to utilize standard experimental approaches, where the variables are determined and compared according to the objectives defined under the project definition stage. This approach ensures the effectiveness of the measurement adopted and provides better feedback regarding the relationship between the number of iterations executed and the confidence measures associated with the result from the simulation runs.

The results obtained from the simulation runs in Phase 3, which is the final phase in this study, are collected and analyzed by using ANOVA to test the significance of the different parameters on the defined performance measures. Subsequently, the alternative models are compared to identify the optimal parameters that are implemented on the shop floor to achieve the overall project goals. One-way ANOVA (also known as single-factor ANOVA) is a technique used to statistically analyze the data obtained from the simulation. One-way ANOVA compares the means of two or more experiments performed. One-way ANOVA is performed on the performance measures defined in Phase 2. Significance levels 1% and 5% are selected to determine the critical F value in this study. The alternative models are then compared with regard to the relevant performance measures to obtain the effect of the performance measures on the quality perspective, and final conclusion can be derived at this stage.

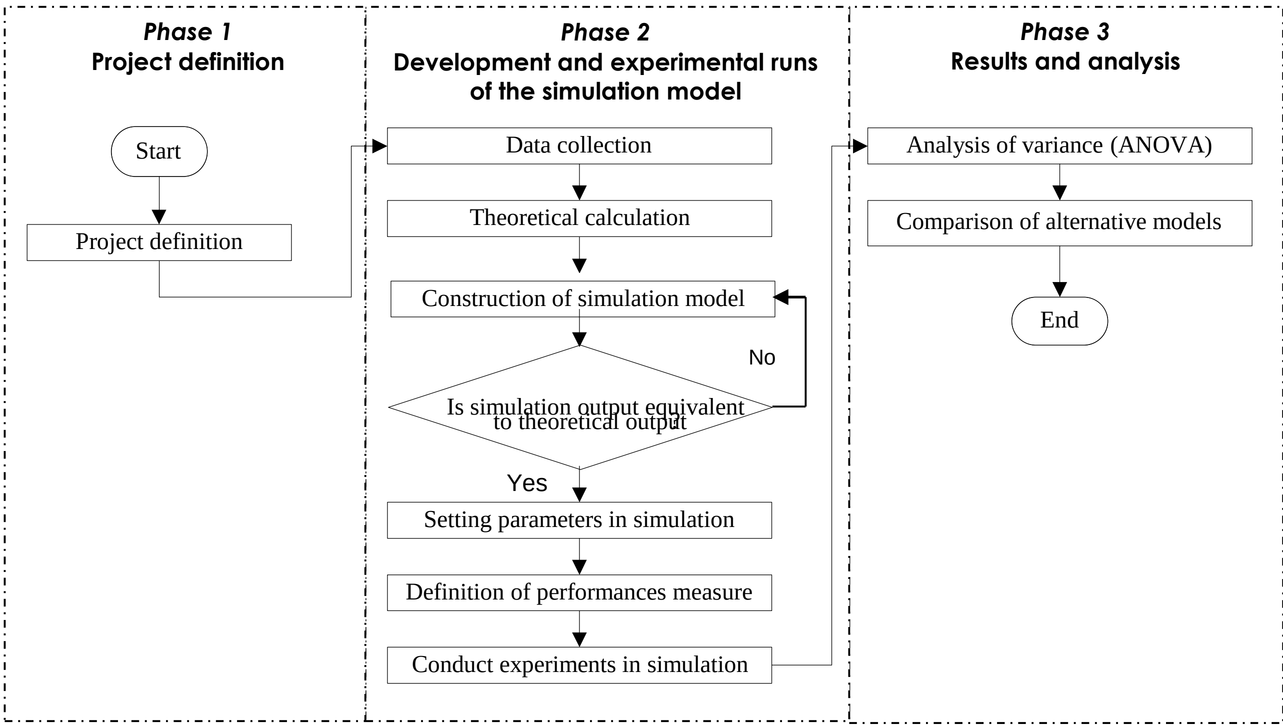

Figure 2 Approaches performed in constructing the DES model

3.0 CASE STUDY

A case study is carried out in the punching department of Company A, which is a circuit board manufacturing company. In this department, punching processes are performed on the circuit boards by various machines according to the requirements of the customer. Quality issues are becoming a setback to the performance of the company and have become appalling because of the lost confidence of the customer. Therefore, the top management of Company A agrees to introduce an improvement project by focusing on the IPQC planning practice. The approaches elaborated in the Section 2 are adopted and explained in the succeeding sections to provide better comprehension of the approaches and problem solved.

3.1 Phase 1: Project Definition

In Company A, the punching department is the backend of the circuit board production line. The production section is divided into incoming and looping groups according to process grouping of punching work required by various customers. The incoming and looping groups comprised five incoming lines and three looping lines, respectively. The incoming group consists of parts that enter the punching process from previous processes for the first time. In a certain scenario, the parts will require processes from other departments (e.g., electrical test) before the overall punching process can be completed. Therefore, the parts will enter the punching department for a second time to complete the remaining punching processes. This group is assigned as looping group. The part is separated into two groups to ensure smooth production and ease of tracking the movement of parts in the punching department. A total of 17 machines are operating in this department, where 12 and 5 are in the incoming and looping groups, respectively. A total of 3 types of machines, known as Machines X, Y, and Z, exist. The tools used on these machines are categorized into soft and hard tools. The setup time of each machine depends on the type of tool used in the machine. The punching processes include subpanel, tie bar, piercing, panel trim, and outline. The cycle time of each machine is set by multiplying the lot size of the part with the time obtained for processing one lot of the part. The lot size of a part is determined by the part type, which is either single or double sided. The lot size of a single-sided board is 300 panels per lot, whereas the lot size of a double-sided board is 80 panels per lot.

In the current condition, one operator is responsible to conduct the production process for each machine, and only one IPQC inspector is responsible for the inspection operation in one shift. The IPQC ensures the quality of the WIP parts by taking immediate actions once a defect is detected. At present, the IPQC inspector is not adopting any standard procedure to conduct the inspection, which is performed randomly. Consequently, because of the lack of planning and randomness in the IPQC procedure adopted by Company A, several issues arise and are perceived by customers. Given these phenomena, the top management of Company A concurs to solve these issues by ascertaining that the primary problem is the failure of the randomness of the adopted IPQC. Therefore, a new practice needs to be proposed, and the performance of the IPQC inspector needs to be measured. Before a decision is made, a simulation model needs to be developed, and simulations runs need to be conducted, which are the focus of Phase 2.

3.2 Phase 2: Development and Experimental Runs of the Simulation Model

All relevant data are collected and analyzed to realize the objective of the project. The current production layout is then modeled. As indicated in the methodology section, theoretical hand simulation is accomplished. The assumptions used in completing the hand simulation are as follows:

1. All part arrivals have the same ratio.
2. All parts are ready for processing at any time.
3. All parts have the same cycle time for Machines X, Y, and Z.
4. The flow of parts is continuous.
5. All machines are operating in ideal condition without breakdown.
6. The production is running in two working shifts per day with 12 h per working shift.
7. No scrapped or rejected parts are produced.
8. The setup time for part change is constant for the machines with the same type of tool, which is either soft or hard tool. For example, for Machine Y with hard tool, the setup time is 30 min. IPQC checking is set by using breakdown function in the machine's detail dialog, where IPQC is conducted by the IPQC inspector for 5 min after every five operations completed by one machine.

Figure 3 shows the hand simulation model. This model translated to the WITNESS simulation software. The constructed simulation model is then verified to ensure that the simulation model is running correctly and able to produce accurate results. The model is checked and compared with the elements and rules by the developed hand simulation. The verification of the simulation is performed by comparing the simulation total output with the theoretical total output.

As previously mentioned, the top management agrees to identify a new practice and measure the performance of the IPQC inspector. By considering the distinctive parameters that will affect the performance and needs of the IPQC on the shop floor, the company applies two criteria to measure the performance of the simulation runs. These criteria are waiting time for IPQC and IPQC inspector utilization, which are elaborated further as follows.

- Waiting time for IPQC

Waiting time for IPQC is the time for the IPQC inspector to reach the machine and to obtain the completed parts for IPQC. Waiting time can be calculated from the percentage of waiting for IPQC, which can be obtained directly from the statistical report generated by WITNESS simulation software. Waiting time for IPQC is expressed as

$$\text{Waiting time for IPQC} = \frac{\%\, waiting\ for\ IPQC\ x\ 0.01\ x\ 720}{total\ number\ of\ shifts} \qquad (1)$$

- IPQC inspector utilization

Inspector utilization is defined as the percentage of busy inspectors who complete the job during the entire run of the model. This information can be obtained directly from the statistical report generated by WITNESS simulation software. The average inspector utilization is calculated using Equation 2.

$$\text{IPQC Inspector utilization} = \frac{\sum busy\ percentage\ of\ inspector}{number\ of\ inspector} \qquad (2)$$

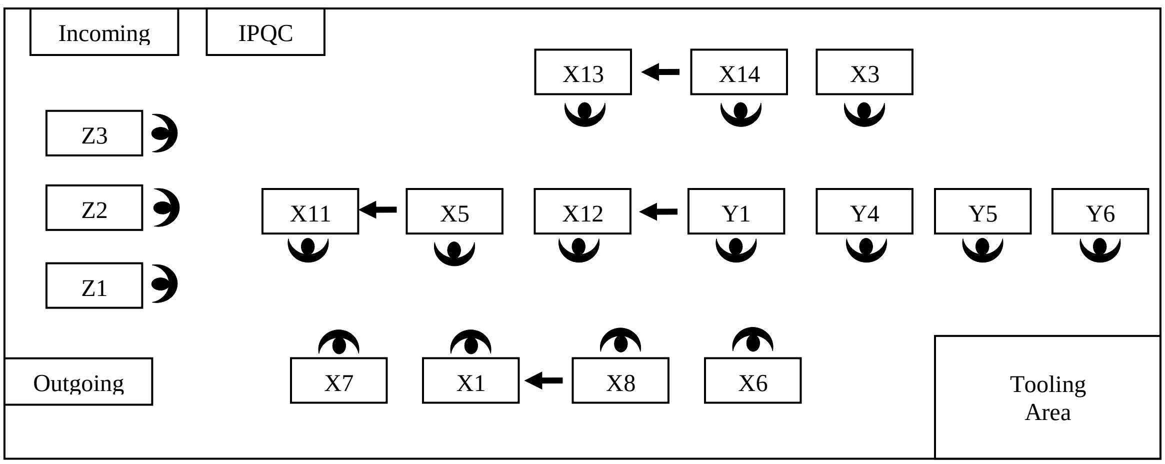

Figure 3 Hand simulation model

After the simulation model is constructed and verification process is completed by considering all the required parameters. In addition, the performance measures were identified and clarified, and the experiments and the data generated through WITNESS simulation software are collected and analyzed. Subsequently, comparisons are carried out to assist the top management in making an informed decision on the best IPQC planning approach to solve the immanent problem of the company. Thus, focusing on this context, we determined that one of the issues that need to be investigated is the effect of different arrangements of machines (production layout) on the shop floor. The various production layouts will accede to a different flow path of the parts, operators, as well as the IPQC inspector. Consequently, varying the number flow will have an effect on the overall planning and performance of the IPQC. In this study, three different production layouts are designed and developed, resulting into three flow patterns of parts. Only one IPQC is assigned to carry out the inspection on the current situation, thus creating chaos and leading to production of low-quality parts. Accordingly, understanding the effect of the overall IPQC performance by varying the number of IPQC inspectors on the shop floor is needed. Table 1 shows the varying parameters used in the simulation runs. The production layouts with flow patterns 1, 2, and 3 are shown in Figure 4, 5 and 6, respectively.

Table 2 Variation of parameters in the simulation models

Flow pattern	Flow pattern 1	Flow pattern 2	Flow pattern 3
Number of IPQC inspector	1	2	3

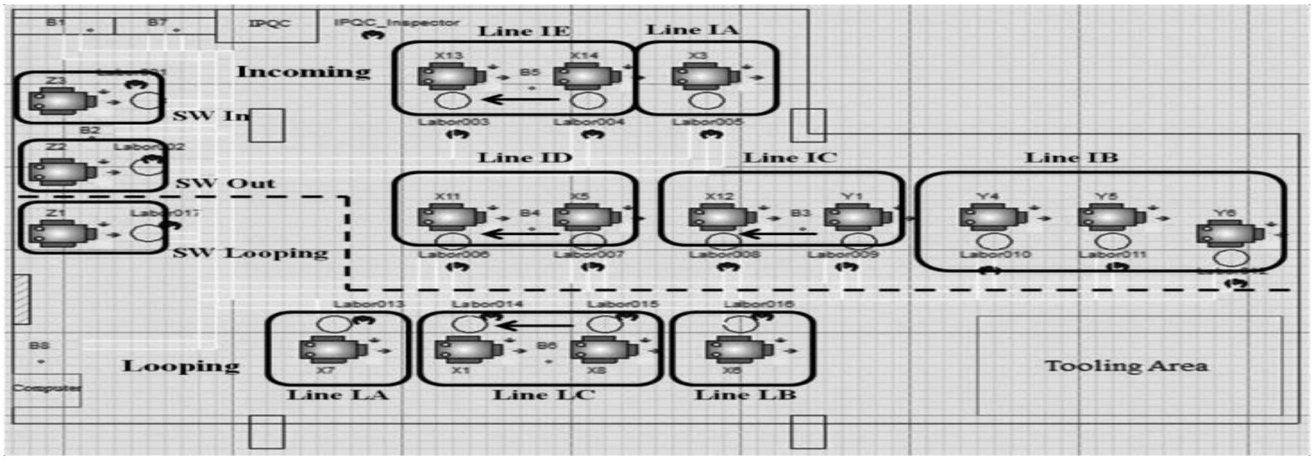

Figure 4 Production layout with flow pattern 1

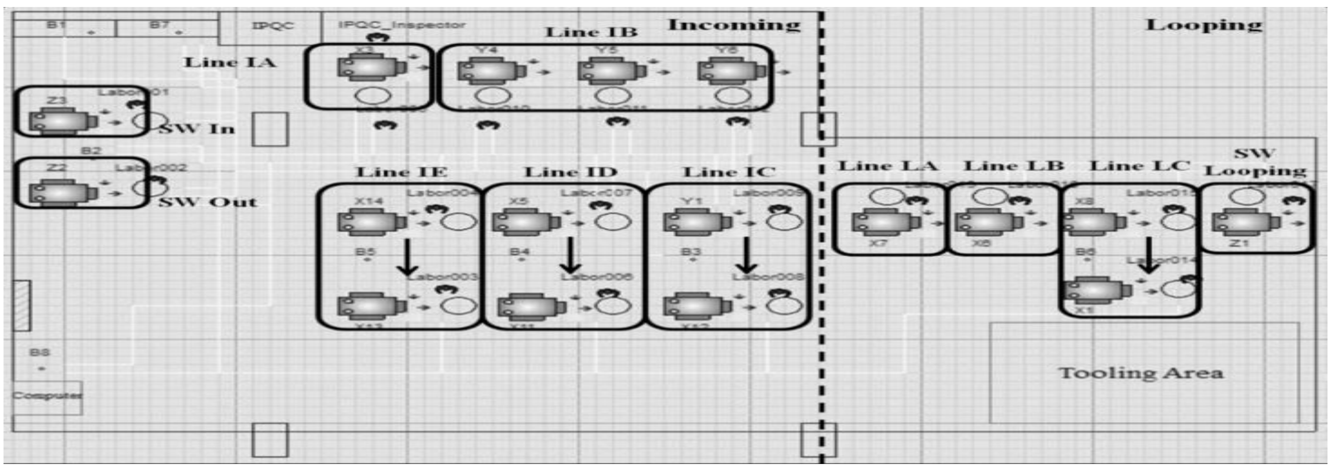

Figure 5 Production layout with flow pattern 2

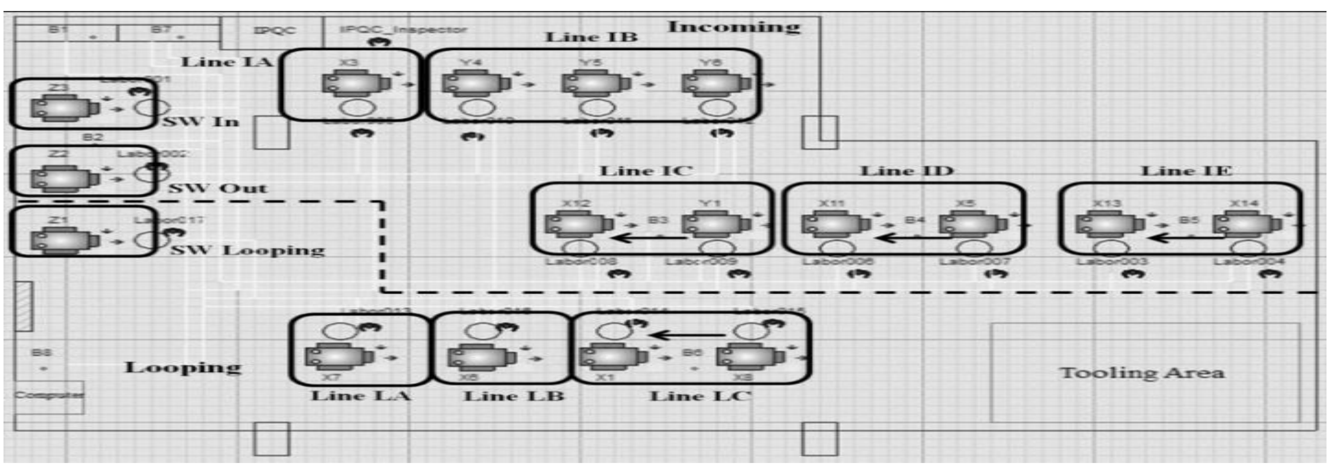

Figure 6 Production layout with flow pattern 3

Three simulation experiments are designed to ensure an accurate representation and replication of the real shop floor environment and to achieve an informed decision from the simulation runs. A total of nine simulation models are constructed by varying two parameters, i.e., flow pattern of parts and number of IPQC inspector. Information of the models in each experiment is shown in Table 2 and detailed in the following sections.

Table 2 Information of models in each experiment

Experiment	Model	Flow pattern	Number of IPQC inspector
1	Model 1	1	1
	Model 2	2	1
	Model 3	3	1
2	Model 4	1	2
	Model 5	2	2
	Model 6	3	2
3	Model 7	1	3
	Model 8	2	3
	Model 9	3	3

3.2.1 Experiment 1: One IPQC Inspector to Three Flow Patterns

This experiment is designed to test the significance of one IPQC inspector assigned to three flow patterns of parts. Three models are tested by assigning one IPQC inspector to the shop floor with flow patterns 1, 2, and 3.

3.2.2 Experiment 2: Two IPQC Inspectors to Three Flow Patterns

This experiment is designed to test the significance of two IPQC inspectors assigned to three flow patterns of parts. Three models are tested by assigning two IPQC inspectors to the shop floor with flow patterns 1, 2, and 3.

3.2.3 Experiment 3: Three IPQC Inspectors to Three Flow Patterns

In this experiment, the significance of three IPQC inspectors assigned to three flow patterns of parts is tested. Three models are tested by assigning three IPQC inspectors to the shop floor with flow patterns 1, 2, and 3.

3.3 Phase 3: Results and Analysis

The results obtained from the simulation runs are collected and analyzed. To obtain a good perceptive of the results generated, the discourse of outcomes is divided into three subdivisions. Each subdivision is further elaborated and detailed.

3.3.1 Results of Simulation

The results are obtained from the statistical report of each of the simulation model from the WITNESS simulation software. The results are segregated accordingly as follows.

Experiment 1: One IPQC Inspector to Three Flow Patterns

In this experiment, three models, namely, Models 1, 2, and 3, are used to investigate the significance of one IPQC inspector assigned for carrying out interval inspection on the shop floor. The number of IPQC inspector in each run is constantly input as 1 in the three production layouts constructed. The average results of all the simulation runs in this experiment are tabulated in Table 3.

Table 3 Results of Experiment 1

Model	Flow pattern	Waiting time for IPQC (min/shift)	IPQC inspector utilization (%)
Model 1	1	1.5431	6.63
Model 2	2	1.6416	6.63
Model 3	3	1.1627	6.71

Table 3 shows that Model 3 has the lowest average waiting time for IPQC and the highest average IPQC inspector utilization. Model 3 adopts flow pattern 3 with the shop floor layout, which deviates from that of Models 1 and 2. The machines in Model 3 are arranged in parallel configuration, whereas in Models 1 and 2, the machines are arranged in serial configuration. This parallel configuration reduces the walking path of the IPQC inspector to each machine to conduct IPQC, thus also reducing the walking time. Consequently, the waiting time for IPQC is reduced. The productivity of the parallel system is higher than that of the serial system [19]. Therefore, the productivity of Model 3 with parallel configuration is higher than that of the other models. This productivity increases the IPQC inspector utilization from 6.63% in Models 1 and 2 with serial configuration to 6.71% in Model 3 with parallel configuration. The results show that the performance of Model 3 is better than that of Models 1 and 2 in terms of waiting time for IPQC and IPQC inspector utilization. Therefore, Model 3 is further analyzed using ANOVA.

Experiment 2: Two IPQC Inspectors to Three Flow Patterns

In this experiment, Models 4, 5, and 6 are designed to test the significance of two IPQC inspectors assigned to three flow patterns. In each model with different flow patterns, two IPQC inspectors are assigned to the shop floor. The average results of all the simulation runs in this experiment are shown in Table 4.

Table 4 Results of Experiment 2

Model	Flow pattern	Waiting time for IPQC (min/shift)	IPQC inspector utilization (%)
Model 4	1	0.1463	3.31
Model 5	2	0.0169	3.31
Model 6	3	0.0126	3.35

The data obtained (Table 4) show that Model 6 has the lowest average waiting time for IPQC and the highest average IPQC inspector utilization. Model 6 adopts flow pattern 3 with the shop floor layout, which deviates from that of Models 1 and 2. The machines in Model 6 are arranged in parallel configuration, whereas in Model 4 and 5, the machines are arranged in serial configuration. As stated in the previous section, the parallel configuration reduces the walking path of the IPQC inspector to each machine when conducting IPQC and thus also reduces the walking time. Consequently, the waiting time for IPQC is reduced. In addition, the productivity of Model 6 with parallel configuration is higher than that of other models. This high productivity increases the IPQC inspector utilization from 3.31% in Models 4 and Model 5 with serial configuration to 3.35% in Model 6 with parallel configuration. The results show that the performance of Model 6 is better than that of Models 4 and 5 in terms of waiting time for IPQC and IPQC inspector utilization. Therefore, Model 6 is used in the ANOVA analysis.

Experiment 3: Three IPQC Inspectors to Three Flow Patterns

In this experiment, as elaborated in the previous section, a similar production layout is used with the increase of quality inspector to three. The average results of all the simulations runs are shown in Table 5

Table 5 Results of Experiment 3

Model	Flow pattern	Waiting time for IPQC (min/shift)	IPQC inspector utilization (%)
Model 7	1	0	2.21
Model 8	2	0	2.21
Model 9	3	0	2.25

Table 5 shows that all the three models in Experiment 3 have zero waiting time for IPQC. However, the IPQC inspector utilization is highest in Model 9. Similar to the previous outcome, the productivity of Model 9 with parallel configuration is higher than that of other models. Consequently, the IPQC inspector utilization of Model 9 is 2.25%, which is higher than that of Models 7 and 8 (2.21%). The results show that the performance of Model 9 is better than that of Models 7 and 8 in terms of IPQC inspector utilization. Therefore, Model 9 is selected for further ANOVA analysis.

3.3.2 Analysis of Variance (ANOVA)

The results obtained from the simulation models are analyzed through ANOVA. In this study, one-way ANOVA is adopted to test the effect of different numbers of IPQC inspector assigned to the shop floor with different flow patterns. One-way ANOVA is used as a hypothesis test to decide whether to reject the null hypothesis (H_0) and accept the alternative hypothesis (H_1), or vice versa. In ANOVA, if the calculated F value is greater than the critical F value, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_1) is accepted. As indicated in previous sections, Models 3, 6, and 9 are selected for ANOVA analysis because the performance of these models is better than that of other models. The performance measures of these three models are summarized in Table 6.

Table 6 Results of Model 3, 6 and 9

Model	Flow pattern	Number of IPQC inspector	Waiting time for IPQC (min/shift)	IPQC inspector utilization (%)
Model 3	3	1	1.1627	6.71
Model 6	3	2	0.0126	3.35
Model 9	3	3	0	2.25

ANOVA is used to determine the hypothesis for waiting time for IPQC and IPQC inspector utilization. The following is the hypothesis for each of the analysis carried out.

ANOVA for waiting time for IPQC is conducted to test the following hypotheses:

H_0 No significant effect of the different numbers of IPQC inspector exists on waiting time for IPQC.

H_1 A significant effect of the different numbers of IPQC inspector exists on waiting time for IPQC.

Table 7 shows the summary of ANOVA with sum of square (SS), degree of freedom (df), mean square (MS), and *F* value (F) on the waiting time for IPQC of the three models of different numbers of IPQC inspector.

Table 7 ANOVA summary for waiting time for IPQC

Source of variation	*SS*	*df*	*MS*	*F*
Between groups	56.16882847	2	28.08441423	26.89411773
Within groups	194.2321031	186	1.044258619	
Total	250.4009315	188		

Notes: $F_{0.05,\,2,\,186} = 3.04$, $F_{0.01,\,2,\,186} = 4.72$

Table 7 shows that the calculated *F* value is 26.89411773. The significance level for the statistical *F* test is set at 5% and 1%. The calculated *F* value in the table is greater than the critical *F* values obtained from the standard *F* distribution table, which are 3.04 ($\alpha = 0.05$) and 4.72 ($\alpha = 0.01$). Therefore, H_0 is rejected, and H_1 is accepted. This result shows that a significant effect of the number of IPQC inspector assigned to the shop floor exists on waiting time for IPQC.

ANOVA for IPQC inspector utilization is conducted to test the following hypotheses:

H0 No significant effect of the different numbers of IPQC inspector exists on IPQC inspector utilization.

H1 A significant effect of the different numbers of IPQC inspector exists on IPQC inspector utilization.

Table 8 ANOVA summary for IPQC inspector utilization

Source of variation	*SS*	*Df*	*MS*	*F*
Between groups	679.3411841	2	339.6705921	42.64938775
Within groups	1481.351397	186	7.964254822	
Total	2160.692581	188		

Notes: $F_{0.05,\,2,\,186} = 3.04$, $F_{0.01,\,2,\,186} = 4.72$

Table 8 shows that the calculated *F* value is 42.64938775. The significance level for the statistical *F* test is set at 5% and 1%. The calculated *F* value in the table is greater than the critical *F* values obtained from the standard *F* distribution table, which are 3.04 ($\alpha = 0.05$) and 4.72 ($\alpha = 0.01$). Therefore, H_0 is rejected, and H_1 is accepted. This result shows that a significant effect of the number of IPQC inspector assigned to the shop floor exists on IPQC inspector utilization.

4.0 COMPARISON OF THE ALTERNATIVE MODELS

In this section, the three alternative models, namely, Models 3, 6, and 9, are compared with regard to the performance measures calculated in the Section 3.3.1 to obtain a better stance in making an informed decision related to the quality planning perspective, i.e., the IPQC waiting time and inspector utilization.

4.1 Waiting Time for IPQC

As illustrated in Figure 7, Model 9 consists of three IPQC inspectors, and the lowest waiting time for IPQC is 0. This result is due to the number of IPQC inspector assigned to the shop floor, which is ought to be adequate to cope with the parts produced. An adequate number of parts ensure a smooth IPQC inspection according to the schedule without causing waiting time on the shop floor. Higher waiting time for IPQC inspection can cause accumulation of WIP parts, which results in blocking of the WIP area, starving, and bottleneck at the machine as the WIP parts can only proceed once approved by the IPQC inspector.

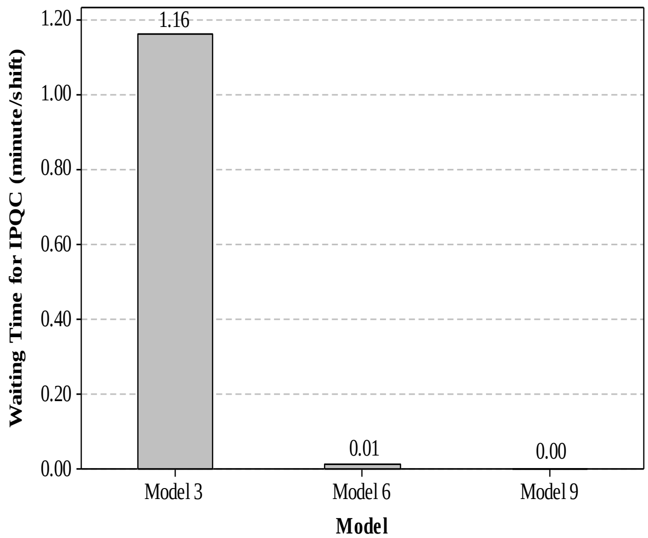

Figure 7 Waiting time for IPQC of three alternative models

4.2 IPQC Inspector Utilization

Inspector utilization is calculated by summing up all the operators' busy time divided by the number of inspectors. A total of one, two, and three numbers of IPQC inspectors are assigned in Models 3, 6, and 9, respectively. Figure. 8 shows that Model 3 exhibits the highest IPQC inspector utilization, followed by Model 6, and Model 9 has the lowest waiting time for IPQC with only 2.25%.

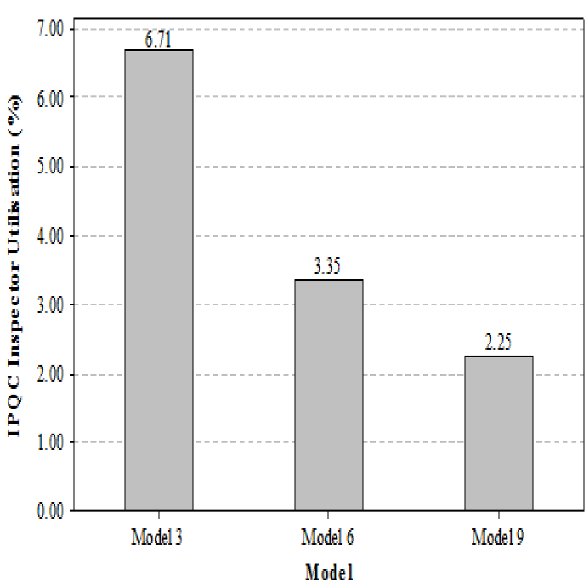

Figure 8 IPQC utilization of three alternative models

4.3 Summary of the Results

Table 9 shows the summary of the result from all experiments that has been conducted. Subsequent to the comparison performed, i.e., waiting time for IPQC and IPQC inspector utilization, Model 6 with flow pattern 3 and two IPQC inspectors is considered the optimal model among the three alternative models. This result is due to the good performance measures (i.e., waiting time for IPQC and IPQC inspector utilization) of Model 6. The waiting time for IPQC in Model 6 is 0.01 min per shift which is acceptable compared with the 1.16 min per shift of waiting time for IPQC in Model 3. Hence the percentage of waiting time for IPQC is highest compare to Model 6 which is 99%. However, Model 6 performs better than Model 9 in IPQC inspector utilization. The IPQC inspector utilization of Model 6 is 3.35%, which is higher than that of Model 9 is 2.25%. This results indirectly can save cost if less waiting time for IPQC is achieved with less operator required and thus increase the utilization for the inspection process.

Table 9 Summary of the results

Model	Flow pattern	Number of IPQC inspector	Waiting time for IPQC (%)	IPQC inspector utilization (%)
Model 3	3	1	99	6.71
Model 6	3	2	0.85	3.35
Model 9	3	3	0	2.25

By implementing this simulation model in real situation, the IPQC inspectors assigned to conduct IPQC in the shop floor can be fully utilized without causing idling among the inspectors. This technique also minimizes waiting time for IPQC during the production process. These approaches can be applied to every department in the company by varying the parameters in simulation. The performance of IPQC in the specific department can be obtained by developing the simulation models. Parameters, such as the number of IPQC inspector assigned to the shop floor, time taken for each IPQC conducted, and number of operations completed by a machine required for each IPQC to be conducted, can be varied in the simulation to obtain the most optimum performance of IPQC. Simulation aims to investigate the performance of IPQC in the shop floor with the parameters set before implementing it in real situations. Consequently, the labor cost of the company is saved, and the productivity of the company is improved. Furthermore, the results obtained in this research prove that adopting quality planning in IPQC is important to reduce defects that occur especially during the production process. Removal of defects during the production process eliminates several non-value-added activities, such as rework, which will help the company to save costs and thus increase profit. Wastage of time and money on defective units and delays in assembly can also be prevented by adopting quality planning in the company. Therefore, the products can be delivered to the customer on time, customer requirements on the quality of the products can be fulfilled, and the company's reputation can be improved.

5.0 CONCLUSION

This paper investigates the effect of different numbers of IPQC inspector assigned to the shop floor, with different flow patterns of parts, on the waiting time for IPQC and IPQC inspector utilization. The results prove that the performance of IPQC in the shop floor is significantly affected by the number of IPQC inspector and flow pattern of parts in the shop floor. The performance of IPQC in the shop floor can be improved by assigning the optimum number of IPQC inspector to the shop floor as well as developing a production layout with suitable flow pattern of part to minimize the walking path of inspectors. Implementation of the simulation model ensures the quality of WIP parts, thus reducing the rework rate in the company. Future investigation should focus on developing different parameters for IPQC conducted in the shop floor to attain optimal performance of IPQC and to ensure the quality of WIP parts. The simulation developed can be applied to the different departments in the company by varying the parameters in the shop floor.

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