Model Of Quality Control Station Allocation With Considering Work In Process, and Defect Probability of Final Product

by Paduloh Paduloh

Model of Quality Control Station Allocation With Consider Work In Process, and Defect Probability of Final Product

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Abstract. Planning is needed in quality control for the target output produced is good. Quality control in the production line is carried out based on the inspection with acceptance of products that meet the requirements. This quality control method is carried out by allocating the quality control station flexibly to separate the rework products to be reworked and scrap to dispose of. The number of acceptable product proportions will depend on the ability of the production line to produce the product expressed in the probability of the product defect. The probability of a production line defect product will be affected to the probability at each work station, where the proportion of product defects that occur will also determine the allocation of the number of quality control stations. Research that discuss the allocation of quality control stations by considering the probability of the final product on the production line and the proportion of work in process does not yet exist, therefore researchers intend to do so. The development of this model is done by developing an objective function to minimize the total production cost. The total cost consists of processing costs, inspection costs, waiting costs, quality control station assignation costs, rework costs, and scrap costs. The aim is to find the configuration of the quality control station allocation in the production line at a minimum cost. From the results of the study obtained quality control station allocation model that can minimize assembly costs and be flexible to changes in demand parameters, costs, defect probability of final product.

1. Introduction

Quality control in a production process is a very important factor for the industrial world, in addition to maintaining consistency in the quality of the products produced according to market requirements. This can be done because good quality control and is carried out continuously will be able to detect abnormalities of quality products quickly, so that anticipatory action can be taken immediately. If this quality control is not carried out properly, it will cause a lot of wasted material, energy and time, and of course much cost, so that it is thought to create a system that can prevent problems regarding quality [1].

Quality control can be carried out in various ways, one of the ways in quality control based on an inspection by receiving products that meet the requirements and rejection of products that do not meet the requirements [1]. Inspection is an activity to test products, production components, and materials to be processed in order to comply with design specifications. Inspection activities are important in the production process because these inspection activities will conclude the quality value of a product is good or not.

Products classified as nonconforming will be separated into rework and scrap products [2],[3] as follows:
1. Rework is a nonconforming product with a job repeat that guarantees the product will conform to its specifications. The method used for reworked products is reworking nonconforming products using the same resources and facilities.
2. Scrap is a non-conforming product that cannot be repaired or is not economical to repair so it will be discarded.

Rework can be distinguished in 2 ways, namely the resources used and the route of the process traversed by the reworked product [2]. In terms of the resources used it can be done inline. Inline rework product repair will return the nonconforming product to the upstream workstation and rework with the same facilities and resources according to the work operation standard while the production flow is working (Figure 1).

Figure 1. Inline rework

In terms of the process route that the reworked product will take, it refers to the stage or work station that the reworked product will pass through. In Figure 2, the reworked product is job repeat specifically only for the defects that are found and each damage is repaired at a specific stage to repair the damage.
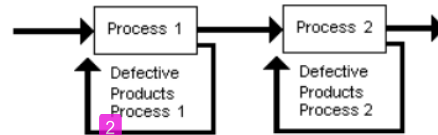

Figure 2. Multiple stages in online rework

Meanwhile, in a single stage rework products will be repaired through regular processes and facilities so that the reworked product will go through the production flow again (Figure 3).
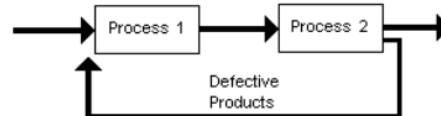

Figure 3. Single stages in online rework

Quality control station configuration shown it effect of work in process inventory, by allocated quality control stations on a se[17] production line with 4 independent work stations than by following Little's law, the expectation of work in process inventory in the system was reduced from 46% to 31.18%. The advantage of eliminating work-in-process inventory is that it saves production costs [4].
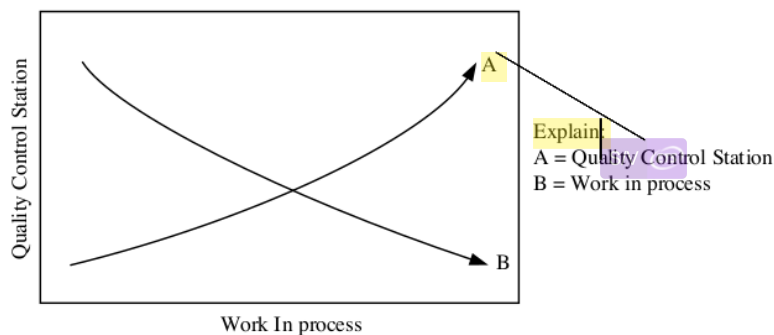

Explaint
A = Quality Control Station
B = Work in process

Figure 4. Comparison of the allocation of quality control stations to work in process.

Figure 4 explains that the more quality control stations allocated will be able to reduce work in process [4], [5]. However, the increasing number of quality control stations assigned will make the assignation

costs even higher. Therefore, with the right number of quality control stations, the total production costs that must be incurred will decrease.

By minimizing work in process inventory, the rework rate can be kept as low as possible, by minimizing the average work in process in the production flow, it will be able to reduce the rework rate [5]. On the other hand, if the average work in the process increases, the rework rate will also be up linearly.
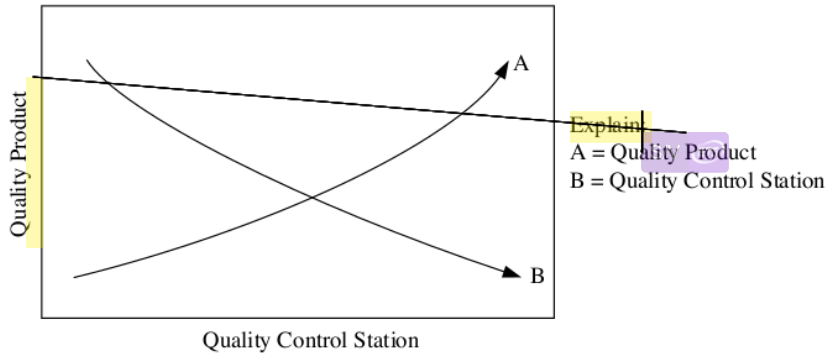

Figure 5. Comparison of the quality products to allocation of quality control stations

Figure 5 explains that changes in the parameters of the quality product express in a proportion of non-conforming products will directly affect the allocating quality control station decision [6], therefore quality products at the production line must be planned coherent. Instead of planning the quality at the workstation, the quality must be planned at the production line based on the output requirement. Trade will establish an optimum number of quality control stations based on quality product probability.

To support the decision to optimize good quality products and reduce work in process inventory, optimization of finished product inventory is also carried out. In optimizing the finished product inventory, one way that can be done is to only produce the amount needed [7].. Another concept that is similar to the Toyota Production System is Lean Manufacturing [8]. These two concepts are used to solve the problem of products being available promptly both in quantity and in place so that the inventory level can be kept to a minimum because it only produces what is needed and only when it is needed in the quantity needed.

If the production flow only produces the amount needed, in this case consumer demand, then the production flow can save both production costs and raw material costs. Furthermore, by using this system, the production system can accommodate changes in demand while maintaining a minimum inventory level.
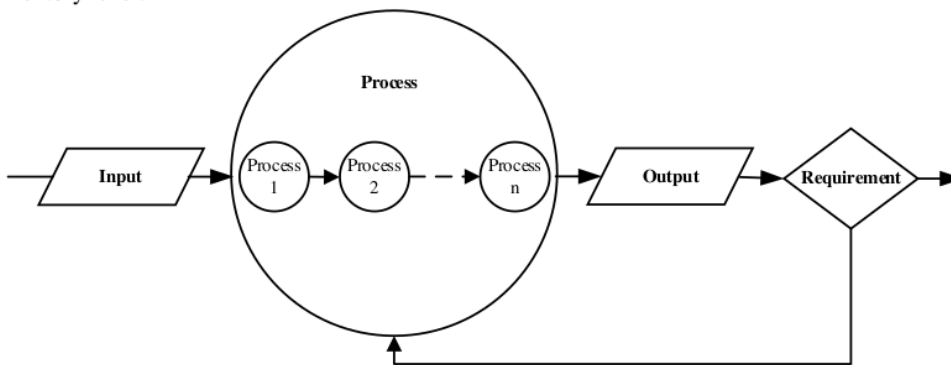

Figure 6. Flow Process Diagram

In Figure 6, to control the amount of final production level, the probability of the production line must be planned. The production line probability has planned referred to output requirement, then the probability of workstation can we know.

2. Model Development

Illustration of the production flow of the proposed model used in this study is as follows:
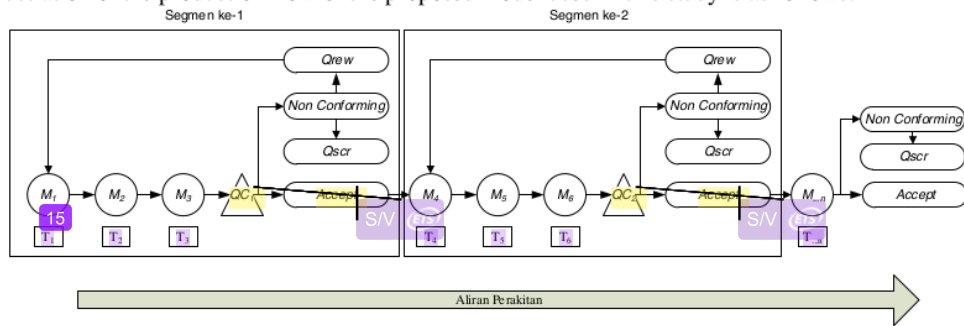

Figure 7. Proposed model production flow

Annotation:
$QC_{1..N}$ = quality control station
Q_{rew} = rework product
Q_{scr} = scrap product
$M_{1..N}$ = workstation
$T_{1..N}$ = task

Figure 7 shows that each work station in the production stream is connected serially. Each work station can only perform one operation in turn and the operations performed are unique operations or cannot be done at other stations. To be able to carry out the 2nd operation at the 2nd work station, the predecessor operation must have been completed first, so that the product flow will flow and pass through the first station to the last station. Each product requires a series of operational processes before the product is finished. There are 2 types of product outputs produced by the work station (Mi) to the quality control station (QCS), namely accept and nonconforming. The output in the form of accepttance will be received by the quality control station and forwarded to the next work station, while the non-conforming product output will be separated by the quality control station into two types, namely scrap and rework. Each nonconforming product has a large proportion.

In this research model, a condition is also developed if at the final work station in the production flow there is no quality control station, then the non-conforming products at the work station will entirely become scrap products because there is no quality control station that functions to return reworked products for reprocessing.

2.1 System Assumptions

The assumptions used in this model are:
1. The ability of the work station to work is greater than the amount of the arrival rate of the product raw material so that the production flow is in a steady state.
2. Raw materials used in the production flow are always available.
3. If there is an accumulation of products waiting to be processed or inspected in front of the workstation, the buffer capacity is not limited.
4. Each workstation begins the next process as soon as it is ready and the product is available in the buffer.
5. Each work station has a processing cost and every quality control station has an inspection cost.

6. Operating and inspection time at each work station follows the Takt time.
7. There is no error for each product inspected.
8. The probability of producing conforming products that arrive at the work station is determined and constant.
9. The probability of a job succeeding and failing at each workstation is independent.
10. Nonconforming products will be separated based on the proportion of rework products and the proportion of scrap products.
11. Product rework will be reworked with the same facilities.
12. Scrap products will be removed from the production stream and subject to penalty costs.

2.2 Model Design Notation

The notations used in this model are as follows:

i	Workstation and quality control station, $i = 1...k$
a	Product arrival rate. (time/product)
c_i	Process costs at workstations M_i. (rupiah/product)
c'_i	Inspection cost at the quality control station QC_i, if assigned. (rupiah/product)
D	Demand. (product/period)
f'_i	Quality Control Station Cost QC_i. (rupiah/period)
h_i	Saving cost per unit of waiting time will be processed at the workstation M_i. (rupiah/time/product)
h'_i	Holding cost per unit of waiting time will be inspected by the quality control station QC_i. (rupiah/time/product)
M_i	Location of the workstation on the production line.
N	Number of the work station in the production line.
p_i	Probability of conforming after completion of the process.
pq_{scr}	The proportion of non-conforming is scrap.
pq_{rew}	The proportion of non-conforming is a rework.
pi	Defect probability at each workstation
pl	Defect probability of final product in production line
q_{ij}	Probability of conforming being completed at the workstation -i still conforming after leaving the work station -j.
Q_{max}	Maximum production lot size. (product/period)
QC_i	Quality Control Station was assigned after the workstation M_i.
r_B	Penalty cost for flowing scrap in the system. (rupiah/product)
WC	Work time capacity. (time/period)
CT	Cycle time. (time/product)
x_i	Process time for workstation M_i. (time/product)
x'_i	Inspection time of the quality control station QC_i. (time/product)
B_i^{pm}	Process costs and waiting for the product at the workstation to-i. (rupiah/product)
B_i^{im}	Inspection cost and waiting for the products at the quality control station to-i. (rupiah/product)
B_i^{inst}	Quality control station assigned costs to-i. (rupiah/period)
B_i^{scr}	Scrap products cost at work stations to-i. (rupiah/periode)
$L_i(Y)$	The final location of the quality control station QC_i was assigned before the work station M_i on configuration Y.
Q	Lot size production. (product/period)
Q_{scr}	Scrap products. (product/period)
Q_{rew}	Rework products. (product/ period)
t	Production line taktime. (time/product)
w_i	Waiting time for the product to be processed/ inspected. (time/product)
Y_i	The quality control station with $Y_i = 1$ indicates that the quality control station QC_i is assigned, otherwise if $Y_i = 0$ indicates that the quality control QC_i is not assigned.
TC	Total cost production (rupiah/period)

3. Model Improvement

3.1 Quality Planning with Just In Time Approach in fulfilling demand.

This concept is used to overcome the problem of products available on time both in quality, quantity, and place so that inventory levels can be minimized as they only produce what is needed and only when needed in the required amount. Also, quality management will produce a conforming product based on final probability planning in the production line. By using this system, the production flow can accommodate changes in demand and probability planning while maintaining a minimum inventory level [9], [10].

In developing this research model, the production line has a defect probability of producing non-conforming products in the form of rework products and scrap products which was passed on each work station, and each workstation has an independent probability. The scrap products identified by the quality control station will be excluded from the production stream, thereby reducing the total output from the production line and disrupting the fulfillment of the demand. To be able to meet the total demand, the output from the production line must match the number of requests. The amount of production flow that must produce to meet the amount of demand is described as follows:

$$Demand\ (D) = Production\ Output \tag{1}$$
$$Lot\ production\ inputs(Q) = Demand(D) + Scrap(Q_{scr}) \tag{2}$$

3.2 Takttime Calculation

To reduce inventory levels, the production flow only makes the required number based on the takt time. Moreover, to determine the rhythm of production, it is necessary to have a takt time which regulates the rate of each work station. This Takt time is a reference for how fast the production line must work to meet demand. The tactical value in the development of this research model is explained as follows:

$$Takttime(t) = \frac{Workhours\ Capacity(WC)}{Production\ Input\ Lot(Q)} \tag{3}$$

However, before applying Takt time, the maximum capability of the production line in producing products must be known first. This can be done by looking at the cycle time of the production flow. The expected number of products that can be produced in 1 day is explained as follows:

$$Maximum\ lot\ production\ input\ (Q_{max}) = \frac{Workhours\ Capacity(WC)}{Cycle\ Time(CT)} \tag{4}$$

3.3 Queue model [M/M/1] at Steady State condition

In a production line consisting of several work stations that are carrying out production activities, there will be a queue of products waiting to be processed. The queue itself arises because of the ability of the work station to work and the rate of arrival of products coming to the work station. If the work station's capacity is greater than the average number of product arrival rates, the condition is called a steady-state condition. This condition must be fulfilled in a production line so that the production flow is not choked up. In this study, the assumption of steady-state conditions is met if a <1 / t, where a is the average number of arrival rates that follow the Poisson distribution, while 1 / t is the takt time which regulates the service time rate of work stations and quality control stations that follow the distribution. Exponential [11], [12]'.

In this model, there is one service facility, namely work stations, work station service capacities, and unlimited sources of product arrival. Based on this information, it can be calculated the performance measure of the expected waiting time in the queue (Wi) [13].

Through the queuing model, in steady-state it can be shown that the estimated waiting time for the product to be processed in the queue is as follows:

$$wi = \frac{\frac{1}{a}}{\frac{1}{t}\left(\frac{1}{t} - \frac{1}{a}\right)} \tag{5}$$

4. Model Component

4.1 Decision Variabel

The decision variable for this research model is $Y_i = 1$ indicates that the quality control station QC_i assigned, otherwise if $Y_i = 0$ indicates that the quality control station QC_i is not assigned.

4.2 Objective Function

The objective function of this model is to minimize the total cost of production (TC). Total production costs (TC) described as follows:

Total production costs = ((Production lot size + rework Product lot size) x (Total processing and waiting costs + Total inspection and waiting costs)) + The total cost of the quality control station assignation + Total product scrap cost.

$$min = TC \tag{6}$$

$$TC = \sum_{i=1}^{k}\left(\left(Q + Q_{rew_i}\right) x \left(B_i^{pm} + B_i^{im}\right)\right) + B_i^{inst} + B_i^{scr} \quad \forall i = 1 \dots k \tag{7}$$

a. Production lot size

In this research model, each work station has an independent probability of producing non-conforming products in the form of scrap. The scrap products identified by the quality control station will be removed from the production stream, thereby reducing the total product output from the production stream. The size of the production lot is the number of product imports that must be prepared by the track to be processed to produce the amount of product output that matches the number of requests. The size of the production lot is determined by the amount of demand added with the number of scrap products that may occur on the production line. The Q_{csr} value is rounded up to an integer so that the input production lot size becomes an integer number of scrap products depends on the probability of scrap products at each work station (model 9).

$$Q = D + @Roundup\left(Q_{scr}, 0\right) \tag{8}$$

$$Q_{scr} = \sum_{i=1}^{k}\left(Y_i \, x \, \left(1 - q_{ij}\right) x \, Q \, x \, pq_{scr}\right) + pq1 \quad \forall i = 1 \dots k \tag{9}$$

$$pq1 = \begin{cases} Y_k = 0 \,; \left(1 - q_{jk}\right) x \, Q \, x \, \left(pq_{scr} + pq_{rew}\right) \\ Y_k = 1 \,; \, 0 \end{cases} \quad \forall j = 1 \dots k \tag{10}$$

Model 10 explains that at the end of the track at the k-th work station there is no quality control station($Y_k = 0$) Then the proportion of reworked products from the j to the k work stations is considered scrap products because there is no quality control station to return the reworked products for rework.

b. Rework product lot size

Lot size of reworked products from work station j if there is a QC quality control station. Product rework occurs because the product that is processed by the work station has not met the specified specifications so it must be reprocessed at the previous work station. The rework product lot size is obtained from the proportion of rework products from the probability of non-conforming products that may occur at work stations n if there is a QCi quality control station and then sent back to the upstream work station for reprocessing using the same facilities (model 11). The rework product lot size is described as follows:

$$Q_{rew_i} = \left(1 - q_{ij}\right) x \, Q \, x \, pq2_i \quad \forall i = 1 \dots k \tag{11}$$

$$pq2_i = \begin{cases} Y_j = 0 \; ; \; 0 \\ Y_j = 1 \; ; \; pq_{rew} \end{cases} \quad \forall i = 1 \dots k \tag{12}$$

In model 12, it explains that if there is no quality control station ($Y_j = 0$) at the j work station, the proportion of nonconforming products at work stations i to j is considered entirely scrap products because there is no quality control station to return the product rework to be reworked so that the value is 0, but if there is a quality control station ($Y_j = 1$) at work station j, then at work station i to j there is a proportion of reworked products to be reworked.

c. Processing costs and waiting costs per product
    Process costs are the costs required to process products at the work station while waiting costs are the costs of waiting for the product to be processed at the work station. This cost is an additional process cost per product with product waiting costs (model 13) where the waiting cost is obtained from the waiting cost per unit of time divided by the waiting time for the product to be processed. The estimated waiting time for the product to be processed in the queue is described in model 14 with the takt time in model 15. The processing costs per product and the waiting costs per product are described as follows:

$$B_i^{pm} = ci + \frac{hi}{wi} \quad \forall i = 1 \dots k \tag{13}$$

$$wi = \frac{\frac{1}{a}}{\frac{1}{t}\left(\frac{1}{t} - \frac{1}{a}\right)} \tag{14}$$

$$t = \frac{WC}{Q} \tag{15}$$

d. Inspection cost and waiting cost per product
    The inspection cost is the cost required to inspect the product at the quality control station in the planned period, while the waiting cost is the cost of waiting for the product to be inspected by the work station. This cost is an additional inspection cost per product with product waiting costs (model 16), where the waiting cost is obtained from the waiting cost per unit time divided by the waiting time for the product to be inspected. The estimated waiting time for the product to be processed in the queue is described in model 17 with the takt time in model 18. This cost is calculated if there is a quality control station ($Y_i = 1$) at the work station. Inspection costs and waiting costs per product are::

$$B_i^{im} = Y_i \, x \left(c'i + \frac{h'i}{wi} \right) \quad \forall i = 1 \dots k \tag{16}$$

$$wi = \frac{\frac{1}{a}}{\frac{1}{t}\left(\frac{1}{t} - \frac{1}{a}\right)} \tag{17}$$

$$t = \frac{WC}{Q} \tag{18}$$

e. Quality control station assignation costs
    The quality control station assignation cost is the cost charged to each quality control station in pairs. This cost is the multiplication of the binary variable (($Y_i = 1$)if there is a quality control station and ($Y_i = 0$) if there is no quality control station} and the cost of assigning the quality control station (model 19). This cost is calculated if there is a quality control station ($Y_i = 1$) at the work station. The total assignation cost of the quality control station is:

$$B_i^{inst} = Y_i \, x \, f'i \quad \forall i = 1 \dots k \tag{19}$$

f. Scrap product costs

The cost of scrap products is a cost caused because the products processed by the work station do not meet the specified specifications and cannot be reprocessed but are still flowing at the work station. This cost is calculated at each work station so that it can be considered a loss in work costs. This cost is a multiplication of the probability of non-conforming products with the the proportion of scrap products which is then multiplied by the penalty cost (model 20). This cost is calculated at each work station where there is no quality control station ($Y_i = 0$). The total scrap cost is:

$$B_i^{scr} = (1 - Y_i)\ x\ (1 - q_{ij})\ x\ Q\ x\ r_B\ x\ pq3_i \qquad \forall\ i = 1\ldots k \tag{20}$$

$$pq3_i = \begin{cases} Y_j = 0\ ;\ pq_{scr} + pq_{rew} \\ Y_j = 1\ ;\ pq_{scr} \end{cases} \forall\ i = 1\ldots k \tag{21}$$

Model 21 explains that if there is no quality control station ($Y_j = 0$) at the j work station, the proportion of reworked products at work stations i to j is considered scrap products because there is no quality control station to return the reworked products to be reworked, but if there is a quality control station ($Y_j = 1$) at work station j, then at work station i to j only scrap products are taken into account.

g. Defect Probability Of Final Product

Defect probability at each work station is determined by square root of defect probability of final product in production line with workstation number (model 22). The number of the workstation will affect the probability of p_i:

$$p_i = \sqrt[N]{pl} \tag{22}$$

Independent probability p_i at q_{ij} express with:

$$q_{ij} = \prod_{i=1}^{j} p_i \qquad \forall\ i = 1\ldots k \tag{23}$$

Model 23 explains that probability of conforming being completed at the workstation -i still conforming after leaving the work station -j, and p_i at q_{ij} is an independent probability,.

4.3 Constraints
Constraints that used in this reaserch is:

a. The takt time must be greater than or equal to the cycle time.
This limiter ensures that the takt time does not exceed the maximum capability of the production line to produce a product

$$t \geq CT \tag{24}$$

b. The takt time must be greater than the average product arrival rate (steady-state assumption).
This limiter guarantees that the workstation capability indicated by the tacttime is greater than the average product arrival rate.

$$\frac{1}{a} < \frac{1}{t} \tag{25}$$

c. The allocation variable Y is a binary integer variable.

$$Y_i \in \{0,1\} \qquad \forall\ i = 1\ldots k \tag{26}$$

5. Model Testing & Analysis of Results
In table 1 it can be seen that the results of the model processing resulted in a decision to allocate the quality control station at station 3 and station 7 with a total cost of Rp. 6.420.122. The resulting takt time is 11.16 minutes with a production input of 41 products. The illustration of the quality control station placement is depicted in Figure 8.

Table 1. Improvement Model Result

Demand	Quality control station	Takt time	Production Input	Total Cost
35	3 and 7	11. 16 minute	41 products	Rp. 6.420.122
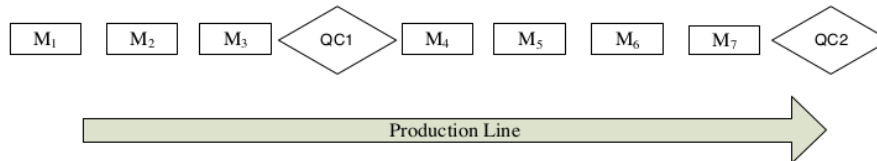
Figure 8. Illustration of proposed model quality control station allocation

The results of the development of the model are expected to assist the production department in determining the location of the quality control station quickly, effectively, and efficiently so that it can control the quality of the finished product on the production line. The results of the application of the proposed model show that the placement of the quality control stations for the proposed model is at the 3rd and 7th work stations with a total cost of Rp. 6.420.122.

6. Conclusions and suggestions
6.1 Conclusion
After conducting research, the following conclusions can be drawn:
1. This research is a model development [6] with work in process products in the JIT environment in providing products on time.
2. Based on the sensitivity analysis, it can be concluded that:
   a. The number of requests that fluctuates with the limit does not predominantly influence decisions to be made regarding the allocation of quality control stations.
   b. Changes in the parameters of the proportion of non-conforming products will directly affect the decision, because the higher the proportion of scrap products, the greater the number of products that must be produced. The enlarging proportion of scrap products will increase the number of quality control stations assigned to anticipate high penalty costs due to scrap products flowing along the production line. The proportion of reworked products of 0.5 and scrap products of 0.5 began to change the alternative decisions made.
   c. Changes in the conforming probability parameter will affect the decision directly, because the lower the conforming probability, the greater the number of products that must be produced. The higher the probability of conforming, the fewer quality control stations will be. By increasing the probability of conforming products, it will change the alternative decisions made.
   d. Changes in cost parameters will influence the decisions to be made regarding the optimal configuration of the quality control station allocation. This parameter affects the number of quality control stations that can be assigned which in turn will affect the decision solutions that can be taken. By increasing costs consisting of process costs, inspection costs and quality control station assignation costs, it will change the alternative decisions made.

6.2 Suggestions
As suggestions for further research, namely:
1. This model is only developed for serial trajectories, so that further research can be carried out by developing a model on a non-serial path.
2. This study did not consider any errors in the inspection, so that the errors in the inspection could be developed in further research. This may be done because inspections carried out manually by humans are possible for errors, where the product should be defective but considered either by the examiner or vice versa.

3. Further research can also be carried out by calculating the cost of reworking different products, because in reality the repair process requires preparation in advance of repairing the product, for example opening stitches, removing defective parts, etc.
4. In this model only produces one product, in subsequent developments it can be developed into multi-products.

7. Acknowledgment

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Wrong Form You may have used the wrong form of this word.

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Confused You have used either an imprecise word or an incorrect word.

Proofread This part of the sentence contains an error or misspelling that makes your meaning unclear.

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Dup. Did you mean to repeat this word?

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