# AN INVESTIGATION OF THE EFFECT OF PRODUCT QUALITY ON REWORK MANPOWER DURING PRODUCTION VIA SIMULATION

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ABSTRACT

This paper describes a simulation study made of a production system to determine the percentages certain types of defects must be reduced during production in order to reduce the manpower needed in reworking defective produced units.

## INTRODUCTION

Decisions involving quality conformance are controlled by many factors, the important ones being production, inspection, and rework costs [1]. Production costs are the costs involved in manufacturing or producing a product given a set of product specifications. Inspection costs are the costs of testing and inspecting the manufactured units to determine if they meet the product specifications. Rework costs refer to all costs, including reinspection costs, in making manufactured units acceptable that failed initial inspection. Other costs that are effected by quality conformance, such as after-sales-service costs, will not be considered in this paper.

As the quality level in production is increased, production costs generally increase, rework costs usually decrease, and inspection costs normally, but not always, remain constant. This means that in most systems there is a direct tradeoff between production and rework costs. Because management generally desires to minimize total costs, it is important to determine the optimal production quality level. This paper discusses a specific investigation made to aid management in determining this quality level.

## PROBLEM DEFINITION

Management was interested in determining in one of their production systems whether or not they could reduce their costs by increasing the production quality level. This production system produced three medium size products. Each of the three products started out on a separate production line and merged into one production line for final production and inspection. Units failing inspection were routed to a rework area while those units passing inspection continued on the production line to be prepared for shipping.

The specific question management wanted answered from the study discussed here is, for given reductions in rework manpower, how much would certain types of product defects found in inspection need to be reduced. Management, using this information, would then be able to determine if the increase in production costs to meet the necessary quality level improvements was less than the rework costs savings due to manpower reduction.

## SYSTEM DESCRIPTION

The portion of the production system of concern in this study is shown in Figure 1. The production lines carrying the units are overhead conveyors and they are labeled with small letters. The main production line "g" moves continuously during production at a rate of three units per minute. When the conveyor stops, production and inspection stops and vice-versa. Conveyor g, as shown in Figure 1, is entering the inspection area carrying a mixture of products A, B, and C from the final production station.

The units on conveyor g are tested and inspected as they move through inspection stations U and V. Defective units are routed to the rework area from station U and V by conveyors h and l. The defective units coming from U can have one or more of five defects and those coming from station V can have one or more of four of these five defects. Rejection proportions at the two stations are given in Table 1. Defective units occur randomly because they are mainly human and not machine caused.

Defective units enter the rework area on conveyors h and l and are merged together on conveyor m. Units on conveyor h enter conveyor m immediately, provided conveyor m is not full. Units on conveyor l enter conveyor m only when conveyor m becomes almost empty or if conveyor l is almost full and conveyor m is not. The maximum capacity sizes of the conveyors in the rework area are given in Figure 1 by $Q_i$'s, e.g., conveyor m has a maximum capacity of 7.

The rework area has three stations T, R, and I. Units on conveyor m enter station T one by one for testing to identify their defects. Mean testing times are given in Table 2. Units having defects $d_4$ or $d_5$ leave the rework area by conveyor j as they cannot be easily repaired. All other units leave station T on conveyor n to enter station R. Units having defect $d_3$ are repaired at station T

FIGURE 1
PRODUCTION FLOW

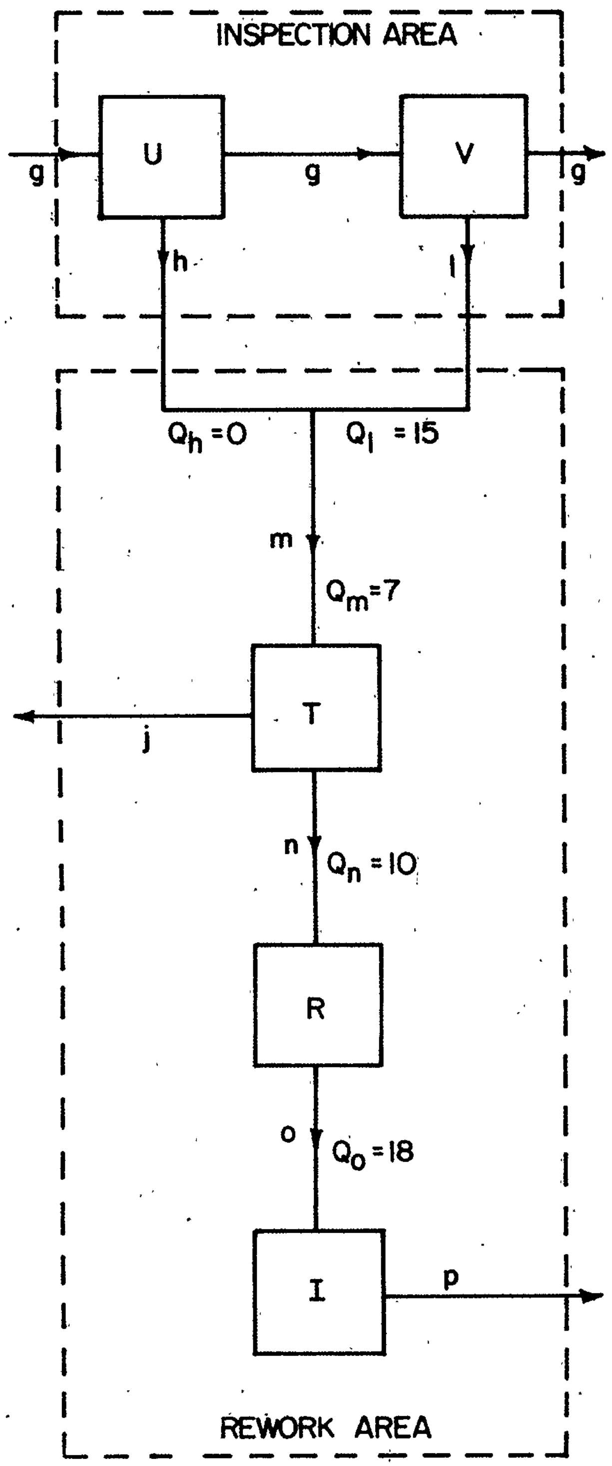



TABLE 1

PROPORTION OF DEFECTIVES

| Defect Type | Product Type A | Product Type B | Product Type C |
|---|---|---|---|
| | Station U | | |
| $d_1$ | .03 | .03 | .051 |
| $d_2$ | .015 | .045 | .075 |
| $d_3$ | .1365 | .1350 | .150 |
| $d_4$ | .0015 | .003 | .006 |
| $d_5$ | .006 | .006 | .006 |
| | Station V | | |
| $d_1$ | .045 | .1065 | .063 |
| $d_2$ | .0405 | .0465 | .081 |
| $d_3$ | 0 | 0 | 0 |
| $d_4$ | .0015 | .0015 | .003 |
| $d_5$ | .0015 | .0015 | .0015 |

prior to leaving. Mean repair time is 12 seconds per unit. Units having defects $d_1$ and $d_2$ are repaired at station R. Their mean repair times per unit are 120 and 108 seconds, respectively. All units leave station R on conveyor o to enter station I for inspection. Mean inspection time is 60 seconds per unit. Units leave station I on conveyor p. Times at the three stations are normally distributed.

Stations in both the inspection and rework areas become "blocked" if the conveyor leaving the station is at capacity and a unit wants to leave that station. This means that the station is forced to become idle as another unit cannot enter it. If either station U or V in the inspection area becomes blocked, then the main production line g must be stopped and production is halted until they become unblocked. The blockages at stations U and V cause the main production line to be stopped about 5% of the total operating time. In addition, production line g is down (stopped) about 5% for other reasons, causing line g to be down about 10% of the total time.

## SYSTEM ANALYSIS

### GENERAL

Management was interested in investigating the economic feasibility of reducing the manpower in

TABLE 2

MEAN TESTING TIMES (IN SECONDS) AT STATION T

| Defect Type | Product Type A | Product Type B | Product Type C |
|---|---|---|---|
| | If Rejected at Station U | | |
| $d_1$ | 72 | 72 | 72 |
| $d_2$ | 54 | 54 | 54 |
| $d_3$ | 72 | 72 | 72 |
| $d_4$ | 150 | 150 | 150 |
| $d_5$ | 120 | 120 | 120 |
| | If Rejected at Station V | | |
| $d_1$ | 60 | 60 | 60 |
| $d_2$ | 54 | 54 | 54 |
| $d_3$ | --- | --- | --- |
| $d_4$ | 150 | 150 | 150 |
| $d_5$ | 120 | 120 | 120 |

the rework area by increasing the product quality level in production. At the present time three operators are assigned to the rework area, one each at stations T and R and one 75% of the time at Station I, the latter operator having two hours of other assigned work that can be done aperiodically. Specifically, management wanted to know what values of rejection rates were required for certain types of defects in order to have only one or two full time operators in the rework area.

Management and its production engineers believed only the rejection rates of defects $d_1$, $d_2$, and $d_3$ could be reduced and, in particular, they believed defects $d_1$ and $d_2$ were their best candidates economically. This meant that the rejection rates of defects $d_1$, $d_2$, and $d_3$ were control or independent variables. Other ways to improve system operation were not considered feasible by management. This included reducing the times at the rework stations and rearranging the work stations to change the maximum capacities of the different conveyors.

The dependent or performance variables of interest were the number of operators needed in the rework area, i.e., the utilization of each of the work stations, and the number of units entering station U, the latter being a measure of the operating time of production line g and thus would be reduced if blockages occurred at stations U and V.

The portion of the total production system that had to be modelled is that shown in Figure 1 and explained above. It was determined because of the complexity of the system, that simulation was the appropriate modelling technique to be used in obtaining the desired information.

SIMULATION MODEL

A simulation model of the system was developed using GPSS [5]. Initial attempts to run the model were unsuccessful because the main production line was getting blocked a significant portion of the time. On investigation, it was found that the times being used for the stations in the rework area were too large. After another time study was made to obtain the appropriate times for the stations in the rework area, the model ran satisfactorily and was ready to be validated. The validation procedure selected was to determine if the values of the performance variables of the system were within the 95% confidence intervals of the performance variables obtained from the simulation model. If the system values were, the model was considered validated [4].

The batch method [2, 3] of output analysis was used to obtain the point estimates and confidence intervals of the steady state performance variables. Five batches of eight hours each were used after the model was run for two hours to eliminate the transient response in all of the experiments performed in this study.

The simulation results of the current system are given as Case I in Table 3. The values of the performance variables from the actual system fall within the 95% confidence intervals and thus the model was considered validated. This included the fact that the operators of stations R and I were not busy 100% of the time.

MODEL EXPERIMENTS

In order to reduce the number of simulation experiments for given levels of rework manpower, reasonable rejection rates were needed for the three types of defects. It was decided to assume an "idealized" system and develop approximate analytical models to obtain upper bounds on combinations of rejection rates. The assumptions made were to allow infinite queues and no blocking, and to use only expected times at the work stations. These models then allowed the rejection rates to be varied as percentages of the current rejection rates to give the utilizations of the different rework stations. For example, Figure 2 gives the utilizations of the three rework stations for different percentages of reduction in defect rate of $d_1$ for two different settings of defect rates of $d_2$ and $d_3$. Because of the allocation of work to the different stations, reductions of defect rates have different effects on different stations as can be seen in Figure 2. For example, the change in the rate of $d_1$ has more of an effect on station R than on station T.

The first set of experiments performed used two operators in the rework area. Since there are three rework stations, a decision rule had to be determined on how to assign the two operators. This then became another independent variable for the set of experiments. It was decided to assign one operator full time to station T to minimize the down time of production line g. In order to have a better utilization of this operator, a portion of one type of repair that could be performed at station T was assigned to this operator. This repair

TABLE 3

RESULTS OF SIMULATION EXPERIMENTS

| Performance Variables | CASE I $P_1=0$; $P_2=0$; $P_3=0$ 3 Operators | | | CASE II $P_1=30$; $P_2=30$; $P_3=30$ 2 Operators | | | CASE III $P_1=40$; $P_2=40$; $P_3=40$ 2 Operators | | | CASE IV $P_1=50$; $P_2=50$; $P_3=0$ 2 Operators | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MEAN | 95% C.I. L.L. | 95% C.I. U.L. | MEAN | 95% C.I. L.L. | 95% C.I. U.L. | MEAN | 95% C.I. L.L. | 95% C.I. U.L. | MEAN | 95% C.I. L.L. | 95% C.I. U.L. |
| $N^*$ | 1291 | 1236 | 1346 | 1287 | 1181 | 1393 | 1366 | 1335 | 1397 | 1364 | 1335 | 1393 |
| $\rho_T$ | 0.980 | 0.947 | 1.000 | 0.934 | 0.828 | 1.000 | 0.841 | 0.754 | 0.928 | 0.929 | 0.864 | 0.989 |
| $\rho_R$ | 0.838 | 0.791 | 0.886 | 0.483 | 0.456 | 0.510 | 0.438 | 0.388 | 0.488 | 0.392 | 0.362 | 0.422 |
| $\rho_I$ | 0.734 | 0.710 | 0.757 | 0.515 | 0.487 | 0.543 | 0.501 | 0.459 | 0.543 | 0.584 | 0.545 | 0.623 |

$P_1$ - Percentage Reduction of Defect $d_1$

$P_2$ - Percentage Reduction of Defect $d_2$

$P_3$ - Percentage Reduction of Defect $d_3$

N - Total Production Per 8 Hour Shift

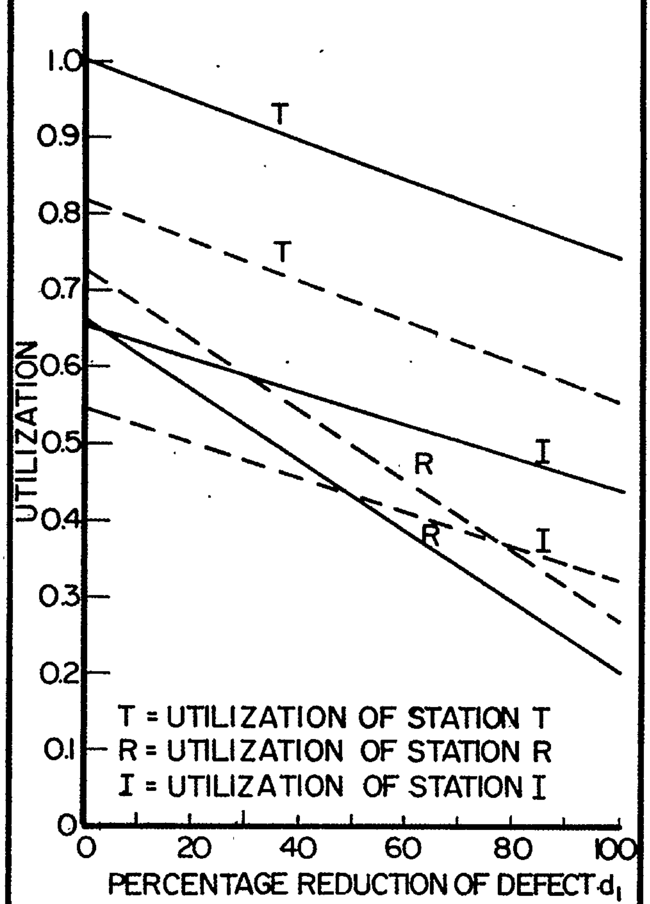
$\rho_T$ - Av. Utilization of Station T

$\rho_R$ - Av. Utilization of Station R

$\rho_I$ - Av. Utilization of Station I

*Total production per 8 hour shift with 5% downtime (excluding downtime due to inspection stations blockage) is 1368 units.

FIGURE 2
EFFECT OF QUALITY IMPROVEMENT ON UTILIZATION




SOLID LINE - PERCENTAGE REDUCTION OF $d_2 = 50$ AND $d_3 = 0$

DOTTED LINE - PERCENTAGE REDUCTION OF $d_2 = 40$ AND $d_3 = 40$

work was assigned depending upon the queue lengths before stations T and R. The other operator was assigned to operate stations R and I, with the decision of which station to operate being made on simple rules involving the sizes of the queues before stations R and I.

Results of three experiments using two operators and the decision rule regarding their assignments stated above are given in Table 3 as Cases II, III, and IV. With 30% reduction in each of the three defects, Case II, the two operators were busy about 93% and 99% of the time and the production line was blocked by stations U and V about 5% of the time. If each of the three defects were reduced 40%, Case III, the production line was never blocked and the two operators were busy 84% and 93% of the time.

If defects $d_1$ and $d_2$ were each reduced 50% and $d_3$ remained the same, Case IV, essentially no blockage of the main production line occurred and the two operators were busy 93% and 97% of the time.

After management was presented the results of several experiments using two operators, they did not desire results using only one operator because they did not believe it would be economical to reduce to one operator in the rework area.

## CONCLUSIONS

A system analysis study using simulation was performed to give management different sets of reductions in defect rates of produced products with two operators in a rework area to allow them to determine if they should increase product quality during production.

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