Performance Analysis of Process Parameters Effecting the Automated Assembly System

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Abstract: The automated assembly systems are designed to perform the assembly operations in a fixed sequence to assemble products. Four types of system/operational planning issues are significant which are: delivery of parts at workstations; single station system; multi-station automated systems; and partial automation. This paper is focused on multi station automated system which is employed for operational performance of the assembly operations. Standard mathematical routines have been modeled and analyzed using real life industrial data engaged in assembling of products in high technology industry. Sensitivity analysis is carried out to observe the impact of process parameters on the performance of system. A comparison of these functions allowed users to identify sensitive process parameters affecting the system. It has been learnt that yield related parameters are the most sensitive in the automated system followed by the cost and process cycle time.

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1. Introduction

The increasing demands for productivity, proper allocation of resources and minimizing cost have motivated continuous research for analysis and modeling of manufacturing systems. Among automated systems, assembly operations play a vital role in manufacturing industry these days. An automated system performs a sequence of automated assembly operations to combine multiple components into a single entity. This single entity consists of a base part to which other components are attached. The components are joined one at a time in each workstation and the assembly is completed progressively. The assembly systems can be classified according to the physical arrangement either in-line assembly machine; dial type assembly machine, carousel assembly system or single station assembly machine. [1].

In automated assembly four types of operational planning issues are significant which are: delivery of parts at workstations; single station system; multi-station automated systems; and partial automation. This research is focused on multi station (either in serial or formed in cells) automated system which is employed for operational performance study of the assembly operations. Generally, automated assembly lines consists of several workstations having deterministic and random (stochastic/probabilistic) operations, defective components causing workstation jammed (parts that causes the workstation or entire production line to stop), failures (upstream or downstream failures), repair times (down time repair time) and reworking (sometimes fast reworking is required on the station or sent to separate workstation for reworking). This demands rapid resource rescheduling, capability and an ability to monitor performance measures [2]. Various techniques have been developed to analyze the system's behavior. Among these techniques, analytical models have been used extensively which employs deductive reasoning of mathematics to solve the typical problem for the model [3]. The same approach is adopted in which the mathematical routines have been modeled to analyze the system in question.

2. Process Description and Mathematical Model

The movements of the parts through various cells are modeled as an entity (parts) flows in the system. The arriving parts enter the system, stay in the queue till the resource is available, and get delayed by the processing time of the respective stage. It is further delayed by the fast reworking time (if required) and is checked for any rework. If the fast reworking is not required on the respective stage, it goes to the next station as dictated by the product model type. After completing all operations on resources, if no rework is required then the parts exit the systems as 'good parts'. There are three events of interest with their associated probabilities i.e. the component which is launched onto the base plate is either defective or made the station jam. In this case; the fraction defect rate of the parts at the station (Dr_i) is multiplied by the probabilities that a defect will cause the station to jam (jm_i). The second case deals with the defective component does not cause a station jam with probability of $(1-jm_i)Dr_i$, and case three deals with components which is not defective having proportion of good parts equal to $(1-Dr_i)$. Therefore, the variables of interest in above stated scenarios are fraction defect rate (Dr_i) and defect that cause the station to jam (jm_i) and down time of the production line. The important responses affected by these variables (but are not limited to) are the production rates, yield related parameters, efficiency and cost per unit. The flow chart below explains the model logic and parts flow information given in figure 1.

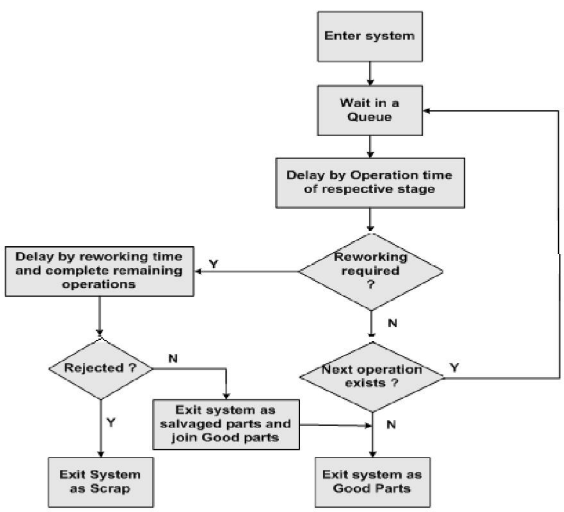


Fig. 1 Parts flow information in the system.

In analyzing the performance of an automated assembly system, the routines that govern the systems have been modeled in some spread sheet software [1] [4]. The lists of abbreviations used are given below:

Abbreviations

Dr_i = Fraction defect rate
jm_i = Defect that cause the station to jam
P_{yp} = Proportion of good assemblies or yield
P_{Dp} = Proportion of assemblies containing at least one defective component
F_d = Frequency of downtime occurrence per cycle
T_{pt} = Average actual production time
T_{cyc} = Ideal cycle time
T_{avd} = Average downtime per occurrence
R_{pt} = Production rate Theoretical
R_{ap}= Production rate of acceptable products (units/min)
E_{up} = Efficiency of the Up time Production line
C_{asy} = Operating cost of the assembly system
C_{mt} = Cost of materials
C_{tl} = Cost of tooling
C_{pg} = Cost per good assembly
L Eff = Line Efficiency
D_{per}= Percentage of time assembly line is down for repair

As described in the preceding paragraph that the probabilities of the three possible events are equal to unity for n workstation assembly machine.

$$\prod_{i=1}^{n}\left[jm_i Dr_i + (1-jm_i)Dr_i + (1-Dr_i)\right] = 1 \quad (1)$$

The proportion of acceptable product coming off the line is P_{yp} and the term represents the probability that a defective component is not added at station i in equation (2).

$$P_{yp} = \prod_{i=1}^{n}\left(1 - Dr_i + jm_i Dr_i\right) \quad (2)$$

For the above situation, as P_{yp} is the proportion of good assemblies, then the proportion of assemblies containing at least one defective component P_{Dp} is given by:

$$P_{Dp} = 1 - P_{yp} = 1 - \prod_{i=1}^{n}\left(1 - Dr_i + jm_i Dr_i\right) \quad (3)$$

The yield P_{yp} is one of the important performance parameter of an assembly machine. The proportion of assemblies with one or more defective components P_{Dp} must be considered a significant disadvantage of the machine's performance. If each station jam results in a machine downtime occurrence, F_d can be determined by taking the expected number of station jam per cycle; that is,

$$F_d = \sum_{i=1}^{n} p_i = \sum_{i=1}^{n} jm_i Dr_i \quad (4)$$

The average actual production time per assembly is given by

$$T_{pt} = T_{cyc} + \sum_{i=1}^{n} jm_i Dr_i T_{avd} \quad (5)$$

The T_{cyc} i.e. ideal cycle time of the assembly machine, which is the longest assembly task time on the machine plus the indexing or transfer time. From the average actual production time, the production rate is the reciprocal of the production time;

$$R_{pt} = \frac{1}{T_{pt}} \quad (6)$$

The production rate should be corrected to give the rate of acceptable product that is those that contain no defects. This is simply the yield P_{yp} multiplied by the production rate R_{pt}:

$$R_{pt} = P_{yp} R_{pt} = \frac{P_{yp}}{T_{pt}} = \frac{\prod_{i=1}^{n}(1 - Dr_i + jm_i Dr_i)}{T_{pt}} \quad (7)$$

The line efficiency is calculated as the ratio of ideal cycle time to average production time.

$$E_{up} = \frac{R_{pt}}{R_c} = \frac{T_{cyc}}{T_{pt}} \quad (8)$$

Where Tpt is calculated from equation 5 and proportion of downtime is:

$$D_{Per} = 1 - E_{up} \quad (9)$$

The cost per assembled product must take account of the output quality.

$$C_{pg} = \frac{C_{mt} + C_{asy} T_{pt} + C_{tl}}{P_{yp}} \quad (10)$$

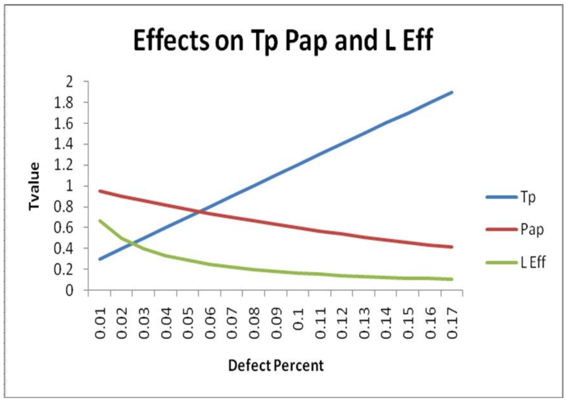
Other than above way of indicating the performance of the production line, several researchers have developed modeling approaches which are focused to queue discipline. As in the literature assembly queuing systems have been studied by [5] in which focus was to study a fork-join queue in an open system. Rao and Suri [6] and Krishnamurti et al. [7] also treat a fork-join queue, but then as a closed system. An exact analysis of an assembly system is presented from upstream job and downstream demand perspective developed by Gold [8] and analysis for using simulation and technology driven strategy was proposed by [9,10]. However, none of the references consider general inter-arrival and assembly times, and some of them only look at assembly systems for two parts. The next section explains the model behavior analysis of the assembly system followed by the results and conclusions.

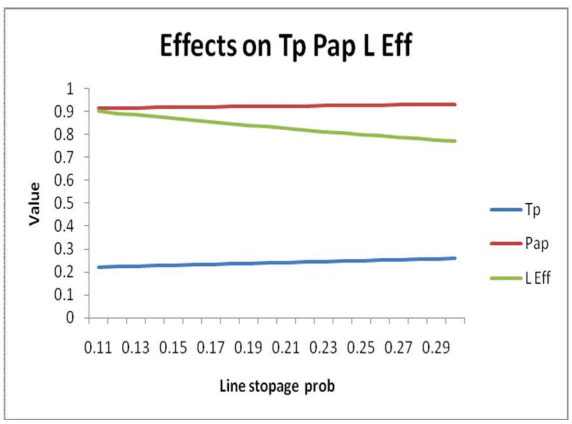
Model Behavior and Analysis

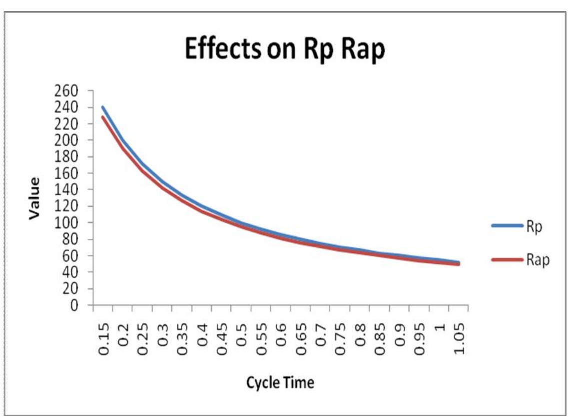
Designing of experiments essentially involves selection of performance measures, factors that would have to be varied, and the levels of each of these factors that we want to investigate. The performance indicators related to the automated assembly lines are cost, quality and throughput as discussed with the company's management. It was decided that by using the routines and modeling the real world system according to the existing scenario (it is for this reason that subscript (i) is used for generic assembly system in the mathematical routines as given above). It is followed by carrying out sensitivity analysis to identify the most important input parameter affecting the system. The parameters of interest are defect rate, station jamming when malfunction occurs, and cycle time and down time percentage. The in-depth study and discussion it comes out that, the company's operations and scheduling was affected by these parameters and a large number of back locks occurred. To cope with this situation, series of experiments with existing base case have been designed. The base value which company currently operating is explained in subsequent paragraph. There were a series of eight stations arranged in series in the form of cell to assembly an electronic part used in automatic product. The station cycle time was 12 seconds and the parts were added in each station with an average defect rate of 0.01 and it was recorded that the station jamming time for all of the stations observed was 0.5. Whenever, there is a jam due to malfunctioning parts, the line stops and causes station to jam and the average downtime is 2.5 min. The cost of operating the assembly machine is approximately Rs. 3500 per hour (this included cost of all of the resources engaged for the assembling of the part i.e. components added to the base part). It is required to analyze the system with the input parameters as mentioned in the previous section and the output responses important for the company. Yield of the parts, percentage of good parts in terms of production rate, the efficiency of the line and cost per part are the responses declared important. The effects of various parameters are shown in figure 2 (as a sample, all graphs cannot be shown because of lack of space). The list of experiments with their base values used is given in following table:

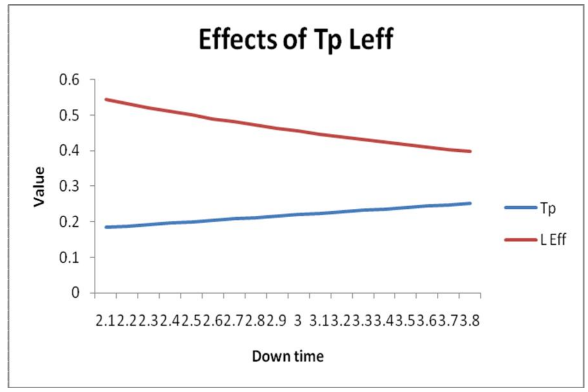
Table 1. Sensitivity Analysis (Base values)

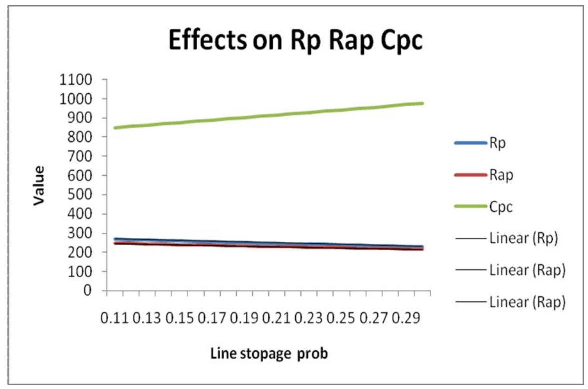
Experiment Type (Sample)	Base Value
Effect of changing the average fraction defect rate	0.2 to 0.5 min with a step size of 0.01
Effect of changing the Prob of jamming of the station	0.1 to 0.35 with a step size of 0.1
Effect of changing the cycle time	0.1 min to 1.05 min with a step size of 0.5
Effect of changing the down time of the station	2.5 to 5 min with a step size of 0.1











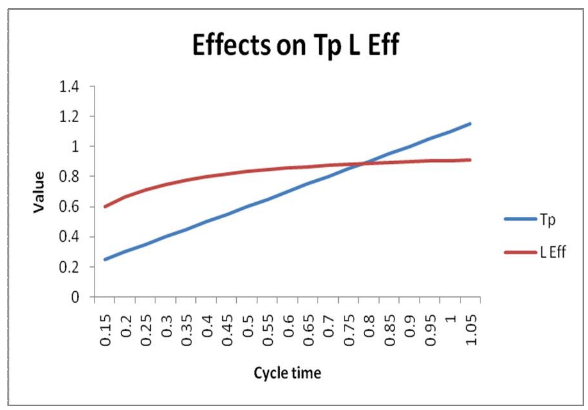


Fig. 2 Effects of various Process parameters (sample graphs)

3. Discussion and Conclusions

It has been observed that certain parameters are important and effecting the system. The fraction defect rate was analyzed using a base value of 0.2 min, as the defect rate increasing that the parts quality level getting worst and all of the performance parameters were affected i.e. there is a drop of production rate, the significant effect on process yield, the production line efficiency decreases and cost per unit increases. With the station jamming, using initial or base value of 0.1, as it is increased from this value, there is very little effect on the component quality, but production rate and line efficiency were the most significant affected parameters. Since, in automated system the object is to balance production line and all station time must not vary. The line was balanced with 0.2 min, and by varying the time to 1.05 minutes, significantly affected the cost per unit, production rate but there is very little effect on the quality level of the part. The effect of down line effect on the performance of the automated system was less obvious as compared with the others parameters.

It is recommended for the case company to focus on the fraction defect rate as it is found to be the most important among others parameters. This can be achieved by properly training of the operators working on the production line, using properly assembling tools etc. There must be pool of operators (semi skilled and highly skilled), so that when a new model arrives on the production line, the skilled operator perform his task and then shift it to semi skilled workers. In this way, the semi skilled workers will not make any mistake which hampers the production as well as yield. Regarding the jamming of the stations, if a sudden jam occurs, storage buffers in the line should be provided so that entire line does not stop. During this time, the upstream stations continue its production. It has been learned that yield rated parameters are the most sensitive parameters affecting the system followed by cost and down time. It therefore, strengthens our belief to make the parts right with good quality, first time every time.

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