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PERFORMANCE ANALYSIS OF MANUFACTURING SYSTEMS BY QUEUEING THEORY

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ABSTRACT

Manufacturing is the application of tools and a processing medium to transform the raw materials into physical article for consumption. This effort includes all intermediate processes required for the production and integration of the products mechanism.

Manufacturing systems consist of extensive interactions between people, information, materials and machines. Typically one of the main problem is to deal with the diversity of the products. A complicated feature arising in manufacturing systems is that of synchronized resource possession. The manufacturing of a part requires a machine and an operator simultaneously. There is a considerable need to develop a methodology based on queueing theory to handle the delay and blocking issues of manufacturing systems. A successful implementation depends on the ability to eliminate all forms of waste, continuous improvement; employee involvement, disciplined implementation, supplier participation, reorganization of production floor, modular designs, cell layout, process control and total quality creation,

KEYWORDS:

Manufacturing Process,
Flexible Manufacturing System,
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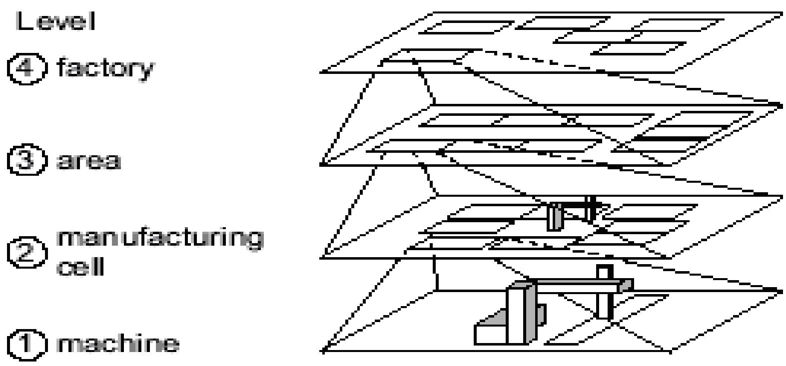
1. INTRODUCTION

Manufacturing can be interpreted as the use of tools and labour to make things for use or sale. The term may refer to a vast range of human activity, from handicraft to high technology, but is most commonly applied to industrial production, in which raw materials are transformed into finished goods on a large scale.

The three basic functions of manufacturing are **procurement**, **production** and **distribution** which can be smoothly performed by using the tools of Operations Research. The raw materials are procured and converted through the production process to semi finished or finished units, finished products are stored in warehouse to meet the customers demand and finished products are distributed at different locations. There are other functions too in a supporting role such as planning, designing, accounting, personal management and marketing and so on. The four traditional types of manufacturing systems are job shop, disconnected flow line, connected flow line and continuous flow process. The job shop consists of a variety of different types of machines, some of which can perform operations on many different types of jobs. In disconnected flow lines there are limited numbers of identifiable routings and job types, but inventories can still build up between work stations. In contrast, the connected flow line requires all jobs to visit machines and work stations in the same sequence. Connected flow lines are often encountered in the automotive industry. In continuous flow processes, continuous products flow automatically down on a fixed route.

We can identify manufacturing system at four different levels (a) at factory level (b) at area level (c) at cell level and (d) at machine level.



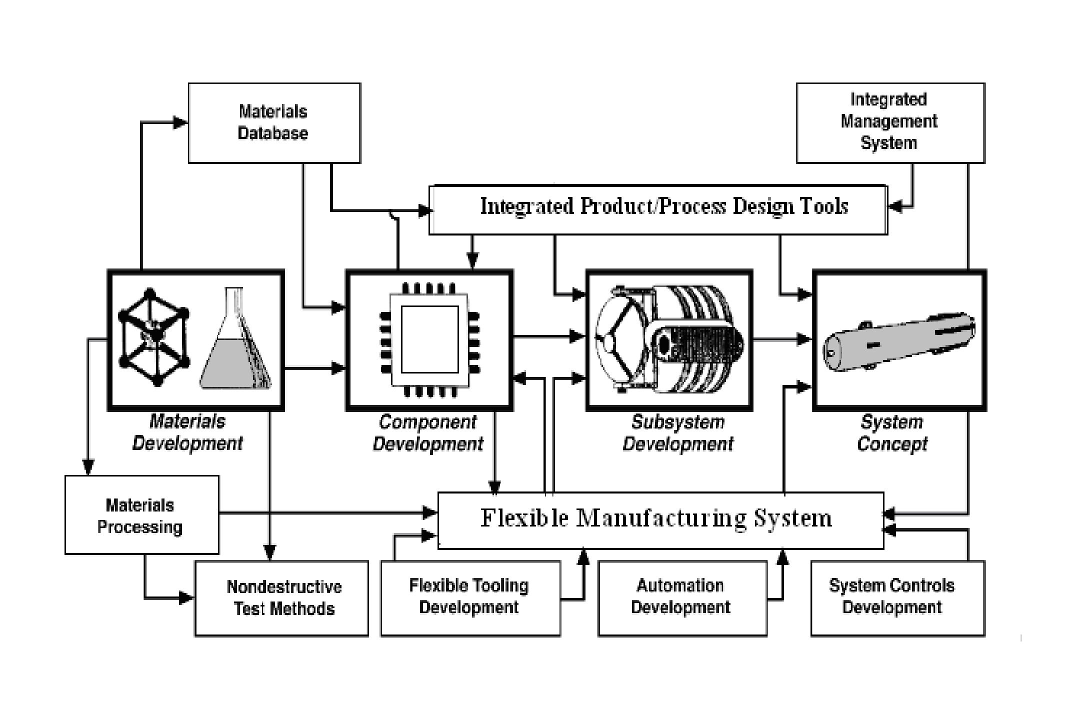
MANUFACTURING SYSTEM AT DIFFERENT LEVELS

Competition in the manufacturing industry over the next decade will be focused on the ability of flexibility and rapidly respond in changing market conditions. Success in manufacturing requires the adoption of the method in customer acquisition and order fulfillment process that can manage anticipated change with precision while providing a fast and flexible response to unanticipated changes and these objectives are achieved by flexible manufacturing systems (FMS).

A flexible manufacturing system (FMS) is a manufacturing system in which there is some amount of flexibility that allows the system to react in the case of changes, whether predicted or unpredicted. Flexible Manufacturing was developed from the need to customize the manufacturing process. This new system became popular in the early 1970s. As cost and quality became bigger concerns, along with the market becoming more complex, the speed of delivery became more important to the customer. Therefore, in order for companies to keep up with the changing industrial trends, they had to be more flexible in their operations and manufacturing systems.

The main advantages of FMS are its high flexibility in managing manufacturing resources like time and effort in order to manufacture a new product. The best application of FMS is found in the production of small sets of products like those from a mass production. Fig. 1.2 depicts the various stages of flexible manufacturing system.

Various types of machining systems such as computers, robots, machine tools and transport devices, etc. have generated interest in the development of techniques and standard that would facilitate the performance prediction of machining systems.



FLEXIBLE MANUFACTURING SYSTEM

Automation plays an important role in the global economy and in daily experience. For manufacturing system, the purpose of automation has shifted from increasing productivity and reducing costs, to broader issues, such as increasing quality and flexibility in the manufacturing process. Automation is now often applied primarily to increase quality in the manufacturing process.

QUEUEING SYSTEM IN MANUFACTURING PROCESS

Queueing problem is identified by the presence of groups of units/customers who arrive randomly to receive the service. The units/customers, upon arrival may be attended immediately or may have to wait until the server is free. This methodology is applicable in the field of business, industries, government, transportations, library etc.. Queueing models are basically relevant to service oriented organizations and suggest ways and means to improve the efficiency of service. Queueing theory is concerned with the mathematical modeling and analysis of systems that provide service to random demands. A queueing model can be developed for an abstract description of a manufacturing system. Typically, a queueing model represents the system's physical configuration, by specifying the number and arrangement of the servers, which provide service to the units/customers and the stochastic (that is, probabilistic or statistical) nature of the demands, by specifying the variability in the arrival process and in the service process.

With a proper interpretation, it is possible to characterize a queueing system that is implicitly built into the single stage or multistage manufacturing system. Consequently, the analysis of manufacturing system can be carried out through the analysis of queueing system which can be described as follows. A typical manufacturing system consists of a number of resources that process a variety of products. The parts arriving at the different resources have to wait in the queue if resources are not available. Thus, there are numerous queues in the system at various resources and there are interactions between the queues. The system is dynamic in the sense that the arrival patterns of products are dependent on the product demand, which is stochastic. The processing rates of the resources are stochastic because resources exhibit a natural variation in their performance. Also, the resources are subject to unforeseen failures. The common characteristic is that a number of physical entities (the arrivals) are attempting to receive service from limited facilities (the server) and as a consequence the arrival must sometimes wait in the line for their turn to be served.

PERFORMANCE EVALUATION OF MANUFACTURING SYSTEM

The complexity of manufacturing systems requires mathematical models to predict the performance and to obtain insight into the system behavior. Generally, two types of issues are associated with manufacturing systems, addressed as performance evaluation and optimization. Performance evaluation is related to the analysis of the manufacturing system often called descriptive or evaluative model whereas optimization is related to design, planning and operation of the system also called generative models. These viewpoints are focusing on the fast response on manufacturing system. Performance measurements of a manufacturing system provide the necessary information for process control, design, development and characterization for the service system and make it possible to establish challenging and feasible goal. The use of performance analysis is strongly related to the necessity of improving process transparency in manufacturing systems. Performance prediction model for manufacturing system uses step by step comparative approach considering the system performance factor such as blocking, delay, throughput, system configuration, system reliability, availability and maintainability, life cycle cost, system optimization, etc.. For the design or improvement of manufacturing systems it is important to be able to predict their performance. For this purpose, queueing and inventory models are being developed and analyzed. In the present study, we analyze manufacturing systems in different frameworks with the objective to evaluate various performance measures by using queueing, reliability and inventory techniques and to evaluate the best alternative using classical optimization tools.

Question is on what criteria do we evaluate and compare manufacturing systems? The effective process time (i.e. the process time including setups, downtimes, operator delays and other disturbances) may prove to be very helpful in reducing the complexity. Some commonly used performance indicators in manufacturing system are described as follows.

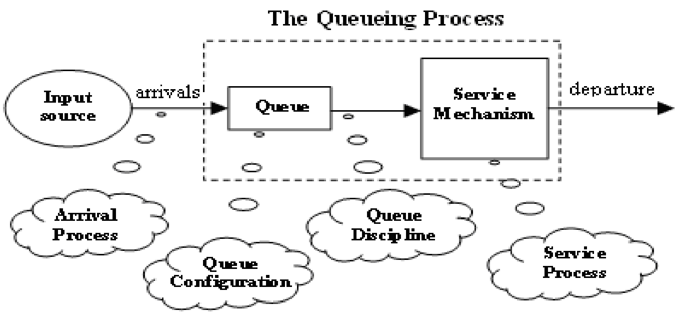
- ❖ **Raw process time** denotes the net time that a lot needs for processing on a machine. This process time excludes additions such as setup time, breakdown or other sources that may increase the time a lot is on the machine.
- ❖ **Throughput** denotes the number of lots per unit-time that leaves the manufacturing system.
- ❖ **Flow time** denotes the time a lot is in the manufacturing system.
- ❖ **Work in process** denotes the total number of lots in the manufacturing system, i.e. in the factory or in the machine.
- ❖ **Utilization** denotes the fraction of time when the machine is not idle. A machine is considered idle if it could start processing a new lot. Thus, processing time as well as downtime, setup time and preventive maintenance time all contribute to the utilization.
- ❖ **Delay** signifies the time when a lot is in manufacturing system before processing starts. This time depends on the number of lots ahead of it in the system and the rate with which they are removed from the system.
- ❖ **Loss probability** is the probability that an arriving unit finds all processor busy or idle.
- ❖ **Mean response time** indicates the mean time a lot spends in the system i.e. waiting in the queue before processing starts and being processed. We can simply apply Little's law to find mean response time.

In order to analyze a manufacturing system, we need a way to model it and to determine its performance. There are many accepted models for manufacturing systems based on queueing theory.

Performance modeling has become a very important part of manufacturing system design and is equally important for maintaining the system at its peak ability. The manufacturing methods used by companies have changed dramatically in recent years with the use of advance robotics and computer control to optimize production, this in turn has lead to reduce prices and higher quality of product. The production lines can only get better with more modeling and investment and this is the best achieved with the use of performance modeling.

Queueing phenomenon occurs in several real-life congestion situations when resources (machines at a factory, elevators, telephone lines, traffic lights) cannot immediately render the amount or the kind of service required by their users. Queueing theory is an extremely active area of research. One of the key reasons for its strong viability is that, time and again, interesting new questions from production and manufacturing give rise to new and challenging queueing problems.

The basic processes assumed by most queueing models are the following. Arrivals requiring service are generated over time by an input source. These customers enter the queueing system and join a queue. At certain times, a member of the queue is selected for service by some rule known as the queue discipline. The required service is then performed for the customer by the service mechanism, after which the customer leaves the queueing system. This process is depicted in many alternative assumptions can be made about various elements of the queueing process.



Components of a basic queueing process

Performance Measures of Manufacturing System

Queueing theory studies congestion situations by formulating mathematical model and then using these models to derive various measures of performance. Queueing analysis provides a vital information for effective designing of queueing systems in different frameworks. There are various generic performance measures using which the performance of a service system can be described. Some performance measures for the analysis of queueing models developed in our present study are described as follows:

❖ QUEUE LENGTH

Queue length can be defined by the number of customers waiting for service to begin and the number of customers being served.

❖ WAITING TIME

The time spent by a customer in waiting before taken into service including service time is identified as waiting time. Let W_q is the waiting time in the queue excluding service time for each individual customer and assume that mean service time is constant $1/\mu$, for all $n \geq 1$, then waiting time can be given by

$$W = W_q + \frac{1}{\mu}$$

❖ AVERAGE QUEUE LENGTH

The number of customers in the queue per unit time signifies the average queue length. Let P_n be the probability that there are exactly n customers in the queueing system then average queue length is given by

$$L = \sum_{n=0}^{\infty} nP_n$$

❖ BUSY AND IDLE PERIOD

Busy period of a server is the time during which he remains busy in servicing. Thus it is the time between the start of service of the customer to the end of service of the last customer in the queue.

When all the customers in the queue are served, the idle period of the server begins and it continues up to the time of arrival of the customer. The idle period of a server is the time during which he remains free because there is no customer present in the system.

❖ RELIABILITY

Reliability is mainly concerned with the determination of the probability that a system will operate adequately for a given period of time in its intended application. Let the random variable T be the life time or time to failure of a component. The probability that the component survives until some time t is called the reliability (or the survival function) R(t) of the component. Thus reliability can be defined as

$$R(t) = P(T > t) = 1 - F(t)$$

where F(t) is the distribution function of the component life time. It is a measure that the device is working during the interval (0,t].

The reliability of the device is also defined by

$$R(t) = \Pr\{X(u) = 1, 0 \le u \le t : X(0) = 1\}.$$

❖ AVAILABILITY

Availability is a combined measure of reliability and maintainability. We define the availability A(t) of a component or a system as the probability that the component is properly functioning at time t. In the absence of a repair or replacement, availability is simply equal to reliability R(t)=1-F(t) of the component. Limiting or stationary availability is defined by $A = \lim_{t \to \infty} A(t)$.

❖ MEAN TIME TO FAILURE

Let X denotes the life time of a component so that its reliability $R(t) = P(X > t)$ and $R'(t) = -f(t)$. Then the expected life or the mean time to failure (MTTF) of the component is given by

$$E[X] = \int_0^\infty tf(t)dt = -\int_0^\infty tR'(t)dt .$$

Since R(t) approaches zero more faster than t approaches ∞, we have

$$E[X] = \int_0^\infty R(t)dt$$

❖ THROUGHPUT

Throughput can be defined as mean number of customers whose service is completed in single unit of time.

The performance measures would facilitate us to compute and investigate various system metrics that would help in improving the efficiency of the manufacturing system.

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