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1. Stochastic Modeling and Analysis of Manufacturing Systems

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ABSTRACT

The complexity of manufacturing systems has increased recently. This volume offers a selection of chapters that showcase the latest advancements in probabilistic models and approaches that have been inspired by manufacturing systems research or proven to have substantial potential in this field. One or more flexible machines, a loading and unloading robot, and a part transfer pallet make up a manufacturing module. Because of their high utilization rates, flexible machines are prone to frequent malfunctions.

Therefore, models are required to ascertain the optimal maintenance and repair procedures that maximize the performance of industrial systems, as well as the effects of numerous factors on system performance. Engineers and operation managers can examine a specific machining system with the help of the model this paper presents. An analytical method for evaluating the reliability of complex manufacturing systems is described in this work. According to this method, a manufacturing system can only function if its production capacity needs are met. We shall talk about stochastic manufacturing system modeling and analysis in this study.

KEYWORDS:

Stochastic, Modeling, Analysis, Manufacturing, Systems, Flexible Machines, Raw Materials, Deterministic, Financial Model.

Introduction:

Stochastic Modeling:

A mathematical model of a natural phenomenon provides a quantitative explanation of that phenomenon. There are many examples, ranging from the straightforward formula S = Zgt2, which describes the distance S traveled in time t by a falling object that is initially at rest, to intricate computer programs that mimic vast industrial systems or biological populations.

Ultimately, a model is evaluated based on a single, practical factor: its usefulness. Certain models, like an inventory model that helps identify the ideal amount of items to stock, are helpful as comprehensive quantitative prescriptions of behavior. A different model in a different setting might only offer broad qualitative details regarding the connections between and relative significance of various factors influencing an occurrence. Such a model is helpful in a different, though no less significant, way. [1]

A stochastic model is a group of random variables arranged in a certain mathematical set, each of which is connected to an element of the set. By enabling the random variable to appear in one or more inputs throughout time, a stochastic model serves as a tool for estimating the probability distribution of the potential outcomes. Using typical time series approaches, the random variables are based on the variability and uncertainty discovered in the historical data for the chosen time. The number of stochastic projections reflecting the random variable in the inputs yields the distribution of likely outcomes.

Manufacturing System:

It is considered that manufacturing processes are stochastic. This presumption holds true for batch or continuous manufacturing processes alike. A process control chart, which shows a specific process control parameter across time, is used to document process testing and monitoring. Usually, twelve or more metrics will be monitored at the same time. Limit lines, which specify when corrective measures must be performed to return the process to its planned operating window, are defined using statistical models. [2]

The service sector uses a similar strategy, substituting processes linked to service level agreements for criteria. Manufacturing systems are divided into what are known as manufacturing modules. These modules are made up of one or more machines, pallets or conveyor systems for batch material handling operations, and robots for part loading and unloading. These modules' machines are adaptable and capable of handling a wide range of components. They are known as Flexible Machining Modules (FMM) as a result. Larger systems known as Flexible Manufacturing Systems (FMS) can be created by combining many FMM. In order to achieve high efficiency in production environments with rapidly changing product architectures and consumer demand, these systems are widely employed in industry to process a range of parts. For the purpose of discrete part machining, there are several kinds of flexible production modules. Different varieties of Computer Numerical Control (CNC) punching press systems exist, which are also set up as modular units, in addition to discrete component machining. A CNC press module is made up of a CNC press, a unique loading and unloading mechanism for handling sheet metal, and pallet handling tools for moving the batch of sheet metal into and out of the system. [3]

Flexible Manufacturing Systems:

Due to their great productivity, FMSs have attracted a lot of interest lately in the field of manufacturing automation. Industries with medium volume sales, such the automotive, aerospace, steel, and electronics sectors, find this technology particularly appealing. The principle of an FMS is perfectly adapted to the current unstable market climate, which calls for affordable solutions that offer

(a) quick product start-up,

(b) adaptability,

(c) responsiveness to changes in demand, and

(d) the capacity to easily resurrect out-of-production designs.

A material handling system (MHS) and numerically controlled machine tools configured by a computer to produce low to medium volumes of inexpensive, high-quality items at the same time is known as an FMS. Typically, an FMS's architecture consists of

(a) adaptable numerically controlled (NC) equipment that is capable of performing numerous machining tasks,

(b) an automated material handling system (MHS) that uses robots, carousels, conveyors, carts, automated guided vehicles (AGVs), or other devices to transport tools and parts between machines,

(c) a hierarchical control system that synchronizes the MHS, the workpieces, and the machine movements. [4]

The layout, or system configuration, of the majority of production systems belongs to one of two major categories. Systems that produce goods in vast quantities with little variability typically use the following product layout: Because of the largely linear architecture, each type of product is processed by a distinct subsystem, in which parts go through several steps in sequence, known as a flow line. (The word "flow" also implies that because of the great volume, the discrete aspect of part movement within the system becomes less significant.)

In this instance, the economy of scale resulting from the high volume and the uniformity of processing requirements resulting from the low variation both justify the establishment of distinct lines for each product type. Systems that produce a wide variety of products in small to medium-sized batches, on the other hand, usually adhere to a process layout. The most common example is a job shop, which is made up of several departments that each handle a specific task, such as drilling, milling, lathing, and so on.

High levels of unpredictability and variability in actual manufacturing systems can have a significant impact on the product's cost. In order to attain the necessary standards of economy, quality, and consistency, it is critical to take uncertainty into account when controlling and monitoring the manufacturing process. The uncertainty introduced by the unmolded unknown factors may have an impact on the outcomes. In industrial processes, variables like demand, cycle time, resources, etc., can cause uncertainty. Probability distributions must be used in the stochastic technique due to its unpredictable scenarios. On the basis of neutral, pessimistic, and optimistic forecast values and their probability, such scenarios can be constructed for uncertainty. The stochastic model can be developed using the mean values of the unknown parameters. [5]

The analysis of occurrences where at least one process component is random is known as stochastic analysis. It is typically used in circumstances when a number of random variables are present across time. Numerous methods are available in the literature to address stochastic behavior; Markov models and simulations are among the most widely used.

When a variable's future value is predicted solely using its current value, it is referred to as a Markov process. Process simulations are related to the random generation of values, provided that the values fall within a specified range or follow certain criteria, like the variable's mean and corresponding standard deviation. Values are often produced with a mean x and standard deviation s that follow a normal distribution. Manufacturing processes can be evaluated for productivity and efficiency using the stochastic frontier analysis. To bridge the gap between the existing productivity and the desired outcome, a model can be created for every plant, process, or production line. These models can then be integrated to achieve the overall performance. [6]

Review of Literature:

Throughout their lives, many manufacturing systems endure aging and shame. These systems can be repaired for the most part. Every region of production where things are stocked or have to remain because of technical issues, irregularities, or disruptions / stochastic influences in the production process is greatly impacted by degradation. When a system is failing, it makes sense to assume that its subsequent functioning times following repairs will be stochastically shorter than its subsequent failure-related repair times, and vice versa.

Over time, degradation is indecisive; a stochastic process is the most appropriate way to describe it. Before failing, the majority of engineering assets deteriorate in some way. Based on these deterioration processes—which are revealed by a variety of deterioration indicators—asset failures might be anticipated. (Yusuf 2012) created a parallel system with two different kinds of failures in two units. The impact of degradation, failure, and repair rates on system performance was examined by the authors. [7]

A manufacturing system consists of humans and manufacturing machinery connected by a single material and information flow. A manufacturing system uses energy and raw materials as inputs. Input to a production system might also take the shape of client demand for the items produced by the system. Similarly, materials (completed goods and scrap) and information (system performance metrics) can be separated out of a production system's outputs (Chryssolouris 2006). [8]

Stochastic model application in global business and industry is a dynamic process that deals with stock prices, corporate investments, and aids in the decision-making process for investments in the highly competitive worldwide business market to build particular enterprises (Moheb et al. 2018).

Major corporations frequently employ the stochastic model application to generate market profit and succeed in the marketplace. Organizational data is assumed in this approach. That section also aids in comprehending the company's standing in the commercial sector. [9]

Objectives:

- A brief classification of manufacturing systems
- Stochastic Models of Manufacturing Systems
- Throughput Analysis of Manufacturing Systems
- Benefits to use a stochastic model for investment variety in the business industry.
- Process of business or industry growth through stochastic modeling.

Research Methodology:

This study's overall design was exploratory. Many relevant reading materials are recommended to have a complete understanding of modeling, simulation, and analysis of the manufacturing processes.

These materials include books, journals, earlier research works on related topics, and Internet sites. significant stochastic models and challenges in the stochastic analysis of manufacturing system processes. Integrated optimization models of these systems as well as essential stochastic performance analysis are necessary when using analytical models to develop and manage manufacturing systems and their operations.

The following topics are covered: integrated productivity and quality models; logistics and supply chain management; transportation and material handling systems; and facilities planning. - Manufacturing systems modeling and analysis using stochastic processes - The planning, evaluation, and enhancement of production processes - Analysis of material handling, transportation, and facilities planning systems - Production scheduling, management, control, and scheduling systems Logistical and supply chain management techniques based on analysis; Integrated productivity and quality models. [10]

Result and Discussion:

Case Examples and Analysis of Results:

In this part, numerical findings for a case problem with varied parameters are presented. The results are compared with different systems operating at varying repair rates and conditions.

Table 1 displays the parameter values for the faulty FMM system with a single repair staff. With the exception of the repair rate, which is different for each repair team as will be seen in the figures below, the same factors apply to the situation of two repair crews as well.

The values listed in the table are the averages of the different parameters used in the case studies. Note that in every situation, the mean is the inverse of the rate.

To derive multiple performance metrics, the system of equations from the previous section is solved for the specified parameters. [11]

Table 1: Parameter Values for the unreliable FMM System (Single repair crew)

Operation time per part	$1/v_m$ = 1 time unit, m=1, 2 (for machines 1,2)
Robot loading time for the first part	$1/l_m$ = 0.05 time units, for machines m=1, 2
Robot load/unload time for subsequent parts	$1/z_m$ = 0.1 time units, m=1, 2
Robot unloading time for the last part	$1/u_m$ = 0.05 time units, m=1, 2
Mean time to failure for machine m	$1/\lambda_m$ = 100 time units (Failure Rate=0.01)
Mean time to repair the machine m	$1/\mu_m$ = 10 time units (Repair Rate =0.1)
Pallet transfer rate	w = 5 and w=20 pallets/time unit
Pallet capacity	n=2,….20 units

Stochastic cost models are available to address the impact of wind generating uncertainty on the best possible operation of power networks. Since there are numerous situations that could occur in this specific wind generation case, a scenario reduction approach was used. Taking into account every scenario, the stochastic model provides an almost optimal answer. Although this particular solution is robust against all potential realizations of the uncertainty, it cannot be optimal for any given case.

To solve the stochastic cost model, an adaptive particle swarm optimization technique was presented, which gets beyond conventional problems like parameter adjustment and penalty coefficients. a fresh piece of software that supports decision-making by evaluating life cycle implications and cost analyses. With the use of this tool, investment projects' long-term trade-off between economic and environmental performance may be assessed while taking input parameter uncertainties into consideration. A number of tools are also available in the software to carry out sensitivity analysis.

Thus, the range of costs indicating the possible upside and downside can be derived by applying a stochastic technique (refer to Figure 1). [12]

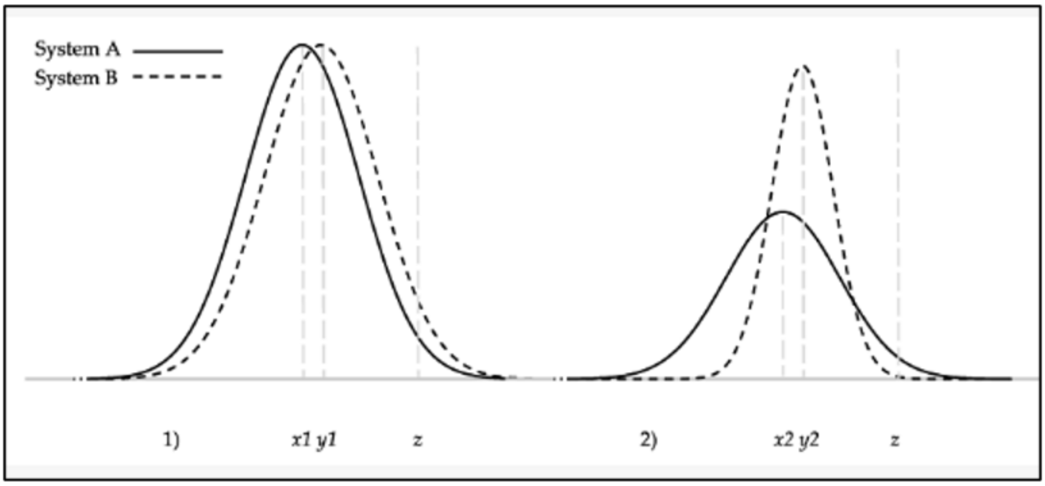

Figure 1: Comparison between deterministic and stochastic values in different situations.

As seen in the above picture, Systems A and B are well below risk z when viewed solely from a deterministic perspective, which considers x1, y1, and x2, y2, but the analysis is inadequate, and a probabilistic approach should be taken into account. The range of potential values for each system under various circumstances is displayed in Situations 1 and 2. In scenario 2, System A is more likely to hit z even though its average (x2) is smaller. However, in scenario 1, System B is more vulnerable. Thus, it is important that we comprehend the behavior of the phenomenon being studied rather than limiting ourselves to a deterministic interpretation. This logic can be used for activities, processes, and goods. Such variability can be measured and its effect on the cost of the relevant cost items can be examined using a stochastic cost model. It is necessary to present the range of expenses as well as the measurement of projections. These forecasts ought to be supported by the computed risk for the pertinent variables. [13]

Type of Stochastic Model:

Financial decision-making models, often known as stochastic models, play a crucial and prosperous role in international commerce and industry. Many stochastic model types, including the Poisson process, Time series process, Markov process, and others, are used in the global investing industry. Different stochastic models are linked to different roles in the business investment market.

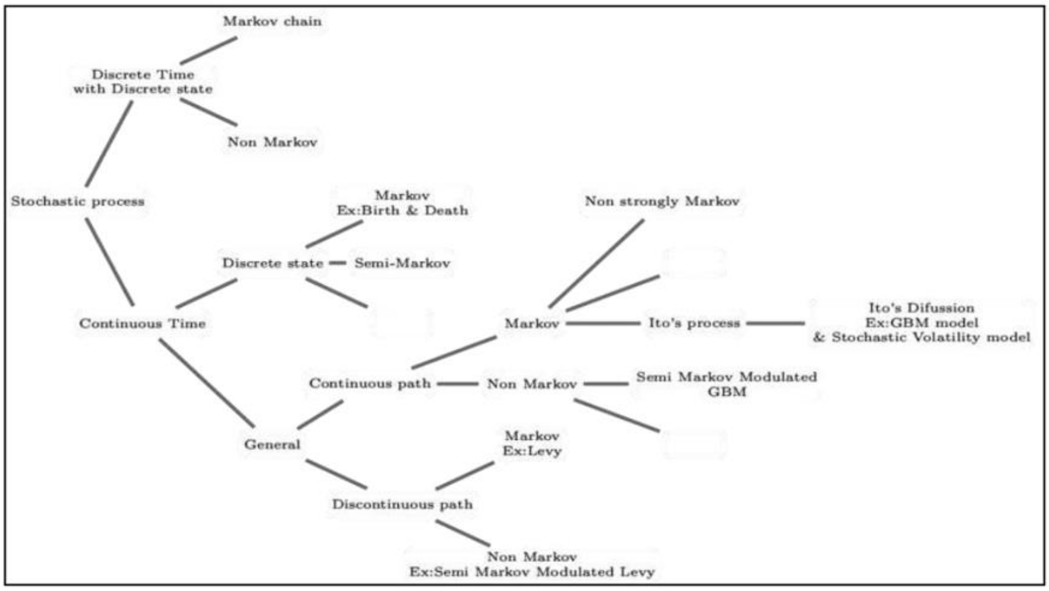

Figure 2: Classification of Stochastic Models

The stochastic models operating in the global business market were categorized in the model given above. One of the stochastic application model's random processes in the investment business market that links influence or incentive for subsequent actions is the Markov process. This financial model system allocates future actions according to the current state of the company. The Bernoulli process in continuous time is employed by the Poisson process of stochastic model application. One popular program that represents the times at which arrivals enter a system is the Poisson process application approach. Time is being analyzed through the time series process under the stochastic models program. The value of a variable is provided by a time series process with evenly spaced time gaps. This program makes assumptions about data and comprehends forces. [14]

Modeling Software in Flexible Manufacturing System:

For the purposes of design, modeling, and continuous performance, manufacturing systems can be analysed and optimised with great effect using simulation. When a complete production system is simulated, several processes inside the system are involved along with the identification of organization machines, robotics, and system layout. Such a model can help with routing and scheduling in a system of flexible production. To determine the system's initial data, model a flexible manufacturing system. To build a flexible manufacturing model, you'll need a number of workstations, a variety of tools, a number and type of conveyors, a conveyor speed, a type of industrial robot, an automated system for storing and retrieving raw materials and finished parts, a number and type of parts, system routing, the technological operations of the parts, the length of time that parts and machines in the system take to process, and priority rules for the parts and machines. The necessary model may be built and the system performance can be analyzed using the simulation software. Software is utilized to model and simulate the system in order to produce the intended results utilizing various criteria for discrete event systems or flexible manufacturing systems. Since the 1960s, a lot of software has been used in industrial systems to find solutions without requiring large financial investments or time-consuming delays before being implemented in a real system. The figures below depict the software's physical view. [15]

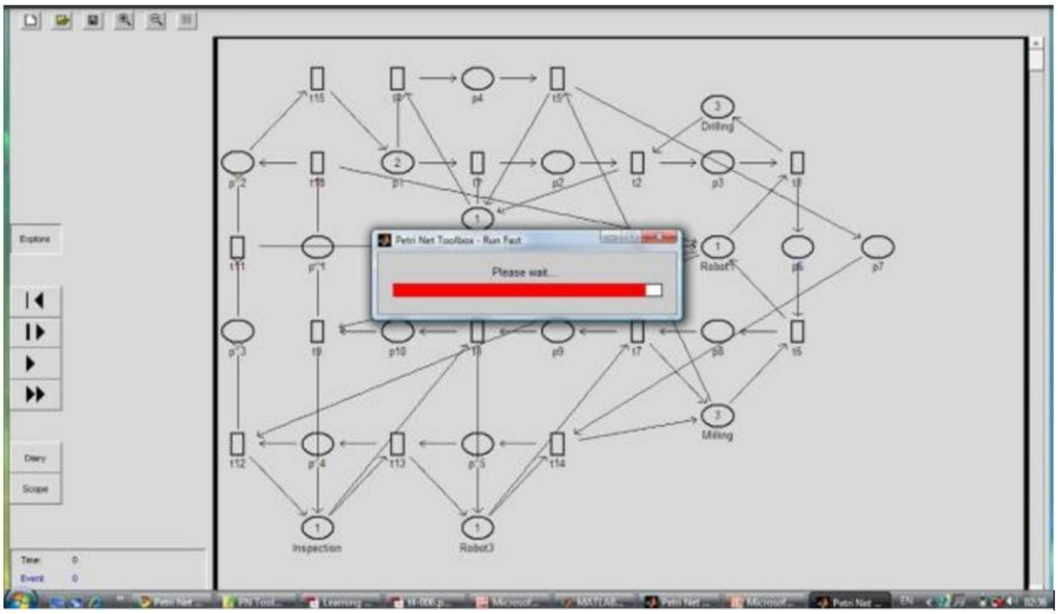

Figure 3: Petri net model of FMS using MATLAB Petri net toolbox (Source: pdfs.semanticscholar.org)

There is software list mentioned below in the table:

Table 2: List of Software

Name of software	Descriptions	Advantages
ARENA	Arena Simulation Software is the Discrete Event Simulation Software.	System modeling. Builds an experiment model by placing modules (boxes of different shapes) that represent processes or logic.
Auto Mod	Simulation of production and logistics systems.	Graphical simulation for complex manufacturing system and material handling systems analysis. It also designed for detailed analysis of operations and flows.
Visual SLAM AweSim	Network or flow diagram.	Simulation project, build a network, sub-network, discrete event, and continuous models.
Matlab Petri net tool box	Simulation, analysis and design of discrete event systems based on Petri Net models.	Graphical editor, behavioral analysis, place and transition computation, time-dependent properties, simulation and analysis of max-plus algebra, design depend on parameterized models.
CPN tools	Graphical modeling of colored Petri nets.	Editing, simulating, and analyzing Colored Petri nets.
TINA	Toolbox for timed Petri Nets.	Extensions as an inhibitor and read arcs, priorities or Time Petri Nets.

CPN-AMI	Tools suitable for Petri net modeling and verification.	Modeling, simulation, model checking and computation of structural properties.
GreatSPN	Qualitative and quantitative analysis of Petri nets.	Design and analysis to evaluate the performance of stochastic Petri net.
Romeo	Toolbox for T-Time Petri nets.	Able to analysis performance for T-Time Petri nets and scheduling.
Snoopy	Design and animate hierarchical graphs among others Petri nets.	The tools used to the simulation of stochastic/continuous Petri nets/timed Petri nets/hybrid

Conclusion:

In order to fulfill shifting demand and cut costs, manufacturing companies are under pressure today to produce a range of products using the same production equipment or manufacturing setup. Flexible manufacturing equipment has been invented in order to accomplish this goal, and it is now a necessary component of manufacturing systems. The current study demonstrates that the inclusion of the coverage factor has improved system dependability, which is a crucial component of any system's reliability analysis. The process, advantages, classification, benefits, and drawbacks of this model in an organization, the risk factors of a company through the stochastic model, the field of research methods, the discussion of genuine data and information, trustworthy examples, recommendations for the risk factor, the next step in this specific process, and general information about the stochastic model in the competitive model in the business industry are all covered in this analysis paper.

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