Inventory replenishment in multi-stage production setting under stochastic demand: a review

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Abstract
Inventory management is central to production planning and control particularly in multi-stage production environment where production output is stochastic and customer demand is also stochastic. Surplus inventory ties down money and stock-out situation result in loss of value and goodwill. Therefore, it is necessary to determine optimal inventory policies for different manufacturing scenarios to maintain a balance between safety stock inventory and customer demand satisfaction at all time. Consequently, this review attempts to identify and document the underlying trends and most recent methods of inventory replenishment under stochastic demand with emphasis on multi-stage production setting. Prominent in literature among the models used to treat inventory problem in stochastic demand situation is “Approximation by Probabilistic Distribution”. Other models used include, Genetic Algorithm (GA), Just-in-time with Kanban simulation, Markov Process Decision, Fuzzy Inventory Model, Multi-stage inventory-queue model and Demand forecasting among others. It appears that there exist only approximate solutions than exact solutions in solving stochastic demand inventory problem suggesting that there is need for more work to be done in the area toward achieving exact solutions to the problem than approximation.

Key words: Inventory replenishment, Multi-stage production and stochastic demand.

1. INTRODUCTION
Inventory replenishment is fundamental in production environment particularly in multi-stage production system under stochastic demand situation. Manufacturers desire to satisfy customers’ demands always and at the same time avoid keeping unnecessary inventory that ties down money that may be used for other productive purposes. In addition, manufacturers wish to maintain minimal inventory to avoid out-of-stock situation that will result in loss of value and goodwill. Consequently, it is necessary to maintain a balance between minimal inventory and customer demand satisfaction. The root of Economic Order Quantity (EOQ) was provided by Harris in 1915 to guide basic inventory decisions particularly in production setting [1]. However, the EOQ model assumes inventory situation with constant demand and delivery lead time which does not conform with reality because in most cases demands are uncertain and therefore require development of models that can handle stochastic demand situation. [2] Defined replenishment as the interval of period between successive replacement decisions. Nevertheless, the interval of periods between successive stock replacements in production system is most times stochastic in practice which points deficiency in the classical EOQ model. Different approaches have been used to minimize in-process inventory. For example, Just-in-Time (JIT) is extensively used in production setting to address work-in-process inventory to
nominal level to avoid excess inventories. [19] Emphasized that the reason for keeping safety stock is an attempt to curb arbitrary variations in customer demands and delivery lead time. High level of product branding and reduction in product lifecycle put pressure on manufacturers to frequently release new models of products into the market with the aid of technological growth and innovation [15]. Therefore, attempt to stay ahead of other competitors’, manufacturers must provide features that will keep customers loyal to their product by ensuring their brands are available at all time to satisfy customers’ demands. For instance, Samsung, Apple Inc, Facebook, Amazon among other organizations have practiced this method to remain relevant in the market and in attempt to achieve the goal of making products available at all times, manufacturers must manage their inventory through models that can guarantee safety stock to meet customer demand at minimal inventory costs. The ability to meet the demand of the customers in short notice means that raw materials must be in stock ready to be pulled for production therefore reducing Order to Delivery (OTD) lead time which increases competitive advantage of manufacturing organizations. Increasing Available to Produce (ATP) components further enhances customer satisfaction as the order to delivery is reduced, but this will lead to high inventory cost therefore a balance between the OTD and ATP is required.

Demand for finished product is normally predicted with specific forecast methods in attempt to know the aggregated demand for each component which balances production quantity and capacity requirements for components. A good prediction will reduce the OTD lead time while keeping minimal inventory cost of component. Based on forecast value, there is a long capacity plan for each component of the finished product. Hence, prediction models are desired for exact prediction than approximation. Customer order triggers assembling of a particular product but accurate prediction provides advance information on the order before it is placed by a customers. [15] Stated that forecasts are not 100% precise because the difference between the actual demand and predicted demand is the present output measurement value. The problem of predicting what the customer wants together with high level of inventory and reliability in manufacturing are the major factors that lead to uncertainty in production setting.

Amongst these sources of uncertainties, predicting customers demand is the main cause of uncertainty in production system. This means that manufacturers must maintain high inventory intelligent information to cope with the unpredictable customer demand scenarios.

2. MULTI-STAGE PRODUCTION INVENTORY SYSTEM

Inventory management is fundamental in production planning and control particularly in multi-stage production environment. In multi-stage production system, be it serial, parallel, assembly or hybrid setting, the rate of production determines the number of machine setups, scheduled production orders, tooling and fixtures necessary for carrying batches of in-process inventories [1]. Also, [1] explained that coordination of production among work-stations by selecting reorder intervals ensure production does not occur at a stage except it occur at all the intermediate successor stages to avoid work-in-process inventory buildup (nested policy). In efficient inventory management, the bullwhip consequence as a result of wrong demand information transferred from the downstream to the upstream is reduced such that stock-out incidence and inventory carrying costs are reduced [2] stated. Similarly, demand needed by succeeding stages in multi-stage production system is controlled by demand for the final product. [11] Stated that the architectural design of a multi-stage production setting and facility layout should minimize transportation time of WIP between different stages to ensure overall production efficiency. Variability in output and demand a multi-stage manufacturing system can come from both the manufacturing processes and the demand for the output at each production
stage or from the final product [14]. According to [11], the three major inventories in multi-stage production settings are the raw material, work-in-process (WIP) and finished product inventories.

The architectural design of a multi-stage production setting and facility layout should minimize transportation time of WIP between work stations to ensure overall production efficiency in materials requirement planning (MRP) nervousness in attempt to improve the overall performance of the system. Figures 1-4 depict different architectural designs for multi-stage production settings.

3. INVENTORY REPLENISHMENT UNDER STOCHASTIC DEMAND

Researchers in the area of stochastic demand inventory have proposed different model approaches to treat the problem. For example, [4] Proposed approximate probabilistic distribution model for a medium term inventory with stochastic demand. [5] Ascertained that in inventory system, it is difficult to precisely determine the size of inventory replacement at the
point of placing order, instead one is restricted to selecting between order levels dictated by probability distribution of a random replenishment size. [12] Investigated production system with stochastic output attributable to bottleneck problems and emphasized that it is difficult to meet the exact final demand on account of random output in production setting.

Table 1. Summary of Recent Stochastic Demand Inventory Modeling Effort

| Model Approach                                      | Author |
|-----------------------------------------------------|--------|
| Renewal theoretic model for random process          | [2]    |
| Just-in-Time (JIT) with Kanban simulation           | [3]    |
| Demand forecasting                                  | [3]    |
| Approximation methods by probabilistic distribution, and spreadsheet model | [4], [5], [6], [7], [8], [10], [15], [16], [20] |
| Genetic Algorithm (GA)                              | [7]    |
| Markov Process Decision                             | [7]    |
| Fuzzy Inventory Model                               | [7], [19] |
| Multi-stage inventory-queue model                   | [9]    |

Renewal theoretic model was applied by [2] to determine optimum inventory replenishment for random demands to minimize procurement, transportation, inventory holding and waiting costs while satisfying customer demands. In a pull production inventory system of JIT approach, the succeeding station demands and removes in-process materials from the preceding station base on the rate and time the succeeding station consumes the materials whereas in push production environment, demand by the succeeding station is determined by the final product demand [3] explained. [6] demonstrated that stochastic inventory optimal policy fluctuate prices steadily and thus leads to the use of approximation methods. [7] Developed genetic algorithm for stochastic demand inventory problem and [8] asserted that optimal policies for stochastic inventory demand in production system is judged by assumption that probability of demand is independent of time. [9] Used a multi-stage inventory-queue model and a job-queue decomposition approach to assess the performance of manufacturing and supply systems with inventory control at every work station. Also, [10] presented approximate steady-state distribution model and established that the approach is accurate on the tested problems. [18] Applied approximation method to determine the demand specific and the random distribution of low customer order waiting time. [17] Used Markov model in assembly line to address stochastic demand inventory problem. Also, [19] proposed fuzzy inventory model to address stochastic demand in production system to obtain optimal order quantity. [20] Used spreadsheet inventory model to approximate safety stock required to curtail stochastic fluctuation in demand and delivery lead time in production system. A table of stochastic demand inventory models is developed from literature as a summary of analytical tools used to address random demand inventory problem.

It appears from literature assessment that problems associated with physical distribution in supply chain administration are fragmentally documented. Hence, the gap is bridged by this review as documented and depicted in table 1

4. CONCLUSION

It is obvious from literature that among the models used to treat stochastic demand inventory problem, “Approximation method” surpasses other models in absence of exact solution to the problem as depicted in table 1. However, approximation of reality only substantiates assumption that does not guarantee sustainable production system. Hence, more effort is required in the area
to achieve the development of models that can provide the goal of achieving exact solution than approximation to address stochastic demand inventory problem for sustainable production system particularly in multi-stage production environment.

5. RECOMMENDATION

It is established from this literature appraisal that available models provide only approximate solution than exact solution on the account of stochastic nature of demand in multi-stage production environment. We recommend further research in this area to strive to achieve exact solution which guarantees sustainable production system than approximate solution which does not ensure sustainable system. Therefore, future research direction may beam search light on machine learning tool for prediction of stochastic demand inventory problem which may predict more accurately near exact solution of the problem than approximation.

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