Synopsis of The Proposed thesis entitled

SOME DECISION MAKING PROBLEMS IN INVENTORY CONTROL SYSTEM UNDER DIFFERENT ENVIRONMENTS

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Contents

Part-I : Introduction and Solution Methodologies

Chapter-1

1.1. Introduction:

Operations Research (OR) is a brunch of applied mathematics which encompasses a wide range of problem-solving techniques and methods applied in the pursuit of improved decision-making and efficiency, such as simulation, mathematical optimization, queuing theory, different stochastic-process models, econometric methods, data envelopment analysis, neural networks, expert systems, decision analysis, analytic hierarchy process etc. In 1957 Churchman *et al.*[10] defined OR as the application of scientific methods, techniques and tools to decision making problems (DMP) involving the operations of systems so as to provide these in the control of the operations with optimum solutions to the problem.

The requirement of the methods of OR was firstly felt during the Second World-War $(1939 - 45)$. A team of investigators and scientist were employed by the Allies (principally Britain, the Soviet Union, and the US) to use the limited resources (foods, weapons, medicines etc.) properly and to send these resources to different battle fields safely within a limited budget and man power from different service centers.

Since that time, operational research has expanded into a field and widely used in industries ranging from petrochemicals to airlines, finance, logistics, and government, moving to a focus on the development of mathematical models that can be used to analyze and optimize complex systems, and has become an area of active academic and industrial research.

1.2. Motivation and Objective of the Thesis

1.2.1. Motivation of the Thesis: Study of inventory control began during the early twentieth century and was continuously supported by several researchers according to the growing necessity in reality and this process is still going on.

Uncertainty is observed in the real life inventory / production-inventory problems and this type of uncertainty may occur in the form of random [13, 9, 7, 5, 3], fuzzy [12, 11, 14, 16], fuzzy-random [8, 6, 1], etc. In the literature, there are several models on credit period formulated with one level trade credit only i.e. suppliers offers credit period to its retailers. But in practice, retailer too might offer a credit period to his / her customers to stimulate the market demand. Beside this, at the present volatile economic conditions through out the world, one cannot ignore the effect of inflation and time value of money specially in developing countries like India, Bangladesh etc. [4, 2, 17].

In-spite of several studies on the above mentioned inventory control systems, there are some gaps which inspired us to develop and solve some inventory / production-inventory models in different environments.

In chapter-3 an inventory model is considered under some real life assumptions which were not considered all together included in previous studies.

i) **The market demand (D) is depends on the customer's retail price which is of the form $D(s) = as^{-b}$ where, $a > 0,\ b > 1$ and s is the customer's retail price.**
ii) **The items are deteriorating with a date of expiration and the rate of deterioration is a increasing function of time. Thus the rate of deterioration gets its maximum value (1) at the time of expiration, i.e. when the product is spoiled / becomes obsolete.**
iii) **Retailer shares a part of his /her credit length to the customers to attract more customer.**

Though this problem was initially investigated by Mahata [15], but there were several mistakes in the formulation and evaluation. This promoted us to make an investigation of such real-life problem correctly (chapter-3).

In manufacturing systems, production of defective / imperfect units is almost a natural phenomenon. This imperfect units are produced after the passage of some time from the commencement of production. Now-a-days, due to competitive market, offer of trade credit is very common amongst the traders. Normally, both supplier and retailer offer the trade credits to their respective customers and the amount of credit period depends on their respective stocks. **These real life practices promoted us to investigate a problem of a two layer supply chain for imperfect items with rework and two-level trade credits (Chapter-4). Chapter-4 is formulated on basis of the following considerations.**

i) **The production system undergo an out-of-control (starting point of imperfect production) state from an in-control state. A mixture of perfect and imperfect quality items are produced by the manufacturer.**
ii) **The rework process is one of common criterion to control the amount of imperfect units. In this study, rework process is applied and some non-repairable items are sold at reduced price where the demand of the customer is considered as stock dependent.**
iii) **Two level credit sharing is considered in this supply chain, where full payment of the customers indicates the end of a replenishment cycle.**

The business period of seasonal products is limited, varies from year to year. This time period can be fitted to a probability distribution i.e. may be considered as random. Demand of these items normally increases with time. For example, at the beginning of winter seasons, demand of warm garments is less and increases with time as the cold increases. Thus the production houses of seasonal products also varies with time and it is adjusted against the trended demand. **This physical phenomenon prompted us to take up the problem of a production house having two production plants for the production of a above mentioned seasonal product in Chapter-5. This study is different from the existing literature in the following aspects.**

i) **In this EPQ model, two production houses under a single management are considered to control the stock out situation under a random environment.**
ii) **The randomness of the different parameters of the model are removed using chance constraint method and taking expected value.**
iii) **The production rates are unknown function of time and the demand rates are known functions of time.**
iv) **None has investigated a two plant production-inventory models with dynamic production rate, trended demand, random shortage (occurs only at one production house) under a random planning horizon.**

A production problem with shortages for a seasonal product is also considered in **Chapter-6**. In addition to random business period, sometimes both production and demand of a seasonal product depend on the current stock level of the product in the go-down. Normally, at initial stages, the set-up cost is sometimes more and decreases at later stages as the production cycle increases. Learning effects in different cycles may be introduced in set-up cost. Again, with the passage of times, laborers are trained and the unit production cost also decreases with the increase of cycles. **These natural phenomena in production systems prompted us to take a production problem with shortages with above mention features. Chapter-6 includes the following assumptions which are not considered in the previous studies.**

i) **The present production-inventory model involves stock dependent production rate and stock dependent demand rate over a random planning horizon.**
ii) **The present model is developed with and without shortages and the unit production rate is also considered as crisp, random, fuzzy and fuzzy-random in nature.**
iii) **Learning effect with the increase of cycles is introduced in set-up cost and unit production cost.**

In supply chain business of seasonal products, supplier makes stocks of a product for wholesaler who purchases the item in a lot. A supplier decides the amount of stock depending upon the demand and selling price fixed by himself. All these relations are normally defined by fuzzy words such as low, medium, high, very high and very low. Similarly, from supplier sides, his / her purchasing price varies with his / her purchased amount. This relation is also expressed by verbal words- low, high and medium which are imprecise in nature. **Such a normal supplier-wholesaler business phenomenon prompted us to take a supply chain model with two level and single level fuzzy logic, i.e. fuzzy inference in Chapter-7. As the computation of these problems becomes cumbersome, here an appropriate Genetic Algorithm has been developed for solution. As usual, random planning horizon with normal distribution for seasonal products is incorporated in this model (Chapter-7).**

It is usually seen in reality that a single business man, say wholesaler, he/she makes the stocks of different items at a go-down and sells the items at different showrooms. These items may be seasonal products which deteriorates also. It is obvious that demand of an item depends on its price. It is very difficult to express this relation in a functional form. Rather, very often, it is expressed in linguistic terms using 'low', 'high', 'medium'. Again, selling price is subjected to discounts depending upon the purchased amount in the forms of AUD, IQD and combination of AUD and IQD (IQD in AUD). For multi-items, some constraints such as space and budget constraints are imposed and these may be imprecise (fuzzy) in nature. **These physical considerations forced us to investigate a model of deteriorating multi-item with linguistically price dependent demand allowing different price discounts under imprecise resource constraints. Thus Chapter-8 contains an inventory model which is unique in the following considerations.**

i) **There are very few supply-chain models for deteriorating items with fuzzy inference expressed verbally using 'words'.**
ii) **Till now, none has used three types of price discount (AUD, IQD, AUD in IQD) in a supply-chain model connecting through fuzzy inferences and sharing the part of the commission with customers.**
iii) **No supply-chain is available with MRP and commission on this following fuzzy rules.**

iv) Use of random planning horizon is very limited and none has used it in connection with fuzzy inferences.
v) Appropriate GA is developed connecting random planning horizon, fuzzy logic and price discount.
vi) For the first time, surprise function, possibility for resource constraints are used in a supply-chain model.

Seasonal products do have several characteristics such as random business period etc. as mentioned earlier. For an item, relations between price and demand, quantity purchased and trade credits are well known. i.e. if price is more, demand is less and vice-verse, if purchased quantity is high, trade credit period is more, etc. These relations are normally expressed linguistically in business systems. These are mathematically expressed by fuzzy inferences. The difficulty lies in expressing these parameters by fuzzy membership functions. In reality, all available data or expert's opinions are deterministic. From past experiences, these collected crisp data are used to form the fuzzy membership functions. **All the above facts influenced us to formulate and solve an EPQ model for deteriorating items under random planning horizon with some linguistic relations between demand, selling price, trade credit and ordered quantity forming fuzzy membership functions from available raw data and using the appropriate developed Genetic Algorithm for solution (Chapter-9). Thus the basic contributions of this chapter are as follows:**

i) Normally, in the inventory models with trade credit, amount of trade credit is given deterministically (a numerical value) depending on the ordered quantity. A relation is presented by a mathematical expression in crisp way. Similarly, a deterministic mathematical expression may be available connecting price and demand. In practice, often these relations are expressed by "words" linguistically. Here, linguistic relations between (price, demand) and (ordered quantity, credit period) are considered.
ii) A new method of payment of dues of retailer to supplier is presented and a lemma is presented which assures the validity of the new method. A comparative study has been provided with the conventional method.
iii) The business period of the seasonal products are finite and varies every year. Thus the time period of these products are assumed as random having a probability distribution.
iv) The construction of membership function (MF) from the market / business data is very important for the model with fuzzy inferences. Here, a methodology is presented for the construction of MF from the marketing experts' opinions.
v) GA is very appropriate for the solution of inventory models with fuzzy logic. Here an appropriate GA has been developed for this purpose.

1.2.2. Objective of the Thesis:

The main objectives of the thesis are

i) to develop some inventory / production-inventory model (s) in different types of environments (deterministic, random, fuzzy, fuzzy-random, etc.) from realistic point of view.
ii) to develop / modify some solution techniques (GA, MOGA, GRG etc.) and to apply these methods for the solution of above mentioned inventory / production-inventory models.
iii) to convert the uncertain models into the corresponding deterministic single or multi-objective problems by using different appropriate techniques (Fuzzy Inference, Chance constraint technique, Possibility / Necessity measures etc.).

iv) to show different effects or relations of the models' parameters and decision variables through some numerical examples and to perform their sensitivity analyses.

1.2. Organization of the thesis: In the proposed thesis, some real life uncertain inventory problems are considered and solved. The proposed thesis is divided into following six parts and seven chapters.

Part-I : Introduction and Solution Methodologies

Chapter-1

1. Introduction

1.1. Definition and History of Operations Research

1.2. Basic Concepts and Terminologies

1.3. Historical Review on Inventory Control System

1.4. Motivation and Objective of the Thesis

1.5. Organization of the Thesis

Chapter-2

2. Solution Methodologies

2.1. Mathematical prerequisites

- Crisp Set Theory
- Random Set Theory
- Chance Constraint Method
- Fuzzy Set Theory
- Fuzzy Logic and Fuzzy Inference
- A Method for Construction of a Fuzzy Number
- Fuzzy-random variable and its properties

2.2. Optimization in Crisp Environment

- Single-Objective Optimization Problem
- Gradient Based Solution Techniques for Single-Objective Optimization
- Optimal Control Theory (Pontryagin Maximum Principle)
- Soft Computing Techniques for Optimization

2.3. Multi-Objective Optimization Problem

- Solution Techniques for Multi-Objective Programming Problem in Crisp Environment

Part-II: Inventory Models in Crisp Environment

Chapter-3

• Note On: Partial trade credit policy of retailer in economic order quantity models for deteriorating items with expiration dates and price sensitive demand.

In this supply chain, a credit-worthy retailer frequently receives a permissible delay on the entire purchase amount without collateral deposits from his/her supplier (i.e., an up-stream full trade credit). By contrast, a retailer usually requests his/her credit-risk customers to pay a fraction of the purchase amount at the time of placing an order, and then grants a permissible delay on the remaining balance (i.e., a down-stream partial trade credit). Also, in selecting an item for use, the selling price of that item is one of the decisive factors to the customers. It is well known that the higher selling price of item decreases the demand rate of that item where the lesser price has the reverse effect. Hence, the demand rate of an item is dependent on the selling price of that item. In addition, many products such as sessional fruits and vegetables, pharmaceutical, volatile liquids etc. are not only deteriorate continuously but also have their expiration dates. However, only a few researchers take the expiration date of a deteriorating item into consideration. For the objective function sufficient conditions for the existence and uniqueness of the optimal solution are provided with an object to maximize the profit of the retailer. The GA process has been applied to determine the optimal pricing and inventory policies for the retailer. Finally, numerical examples are presented to illustrate the proposed model and the effect of key parameters on optimal solution is examined.

Part-III: Inventory Models in Random, Fuzzy and Fuzzy-Random Environment

Chapter-4

• Two layer supply chain model of deteriorating items with rework and two level credit period.

In this chapter, a single period SCM model is considered for a manufacturer with multiple retailer. A mixture of perfect and imperfect quality items are produced by the manufacturer and supplies them to the retailer's. Every Retailer achieves an up-stream credit and shares it partially to his / her customers. The defective rate is random in nature which follows an uniform distribution and certain percentage of defective items are reworked as a perfect quality items. Set-up cost of the manufacturer is linearly dependent on the production rate. Also the open end customer demand at each of the retailers depends on the displayed stock of the retailer. The whole model is formulated as profit maximization problem to maximize the SCM profit. The model is solved numerically using GRG method.

Chapter-5

• Two plant optimal production problem in random time horizon.

This chapter presents a time-dependent production policy for a single item which are produced from two plants situated at different location under a single management. The rate of demand and the rate of production at these plants are different. Demands of the item are primarily met locally from the respective plants but if a stock-out situation occurs in a plant, immediately some stock from the other plant (if available) is rushed to the stock-out plant. So the shortage is allowed only at one plant and inventory stock situation occurs at another. The demand at the different plants are known function of time whereas the production rate at the plants are unknown functions of time and taken as control variable. The planning horizon, the production cost, holding cost, shortage cost, and transportation costs all are random in nature. The model is formulated as a cost minimization problem in the form of an integral. The optimum results are obtained using Kuhn-Tucker conditions and Generalized Reduced Gradient (GRG) technique. The model is illustrated by numerically and optimal results are presented in both tabular and graphical form.

Chapter-6

• Optimum Production Policy for a Production Inventory Model in Random Time Horizon.

A profit maximization production inventory model with linearly stock dependent demand is developed in random time horizon under inflation and time value of money. The time period is random and follows exponential distribution with known mean. The unit production rate is partly stock dependent and decreases as the stock increases. At the end of the time period excess amount of stock (if any) is sold at a reduced price. This model is developed with and without shortages under the assumption that the shortage is fully backlogged. The unit production cost is considered as crisp, random and fuzzy in nature and different models are formulated for different types of unit production costs. Optimal result of the different type of models are obtained using a gradient based non-linear optimization technique- Generalized Reduced Gradient(GRG) method. All the models are illustrated with some numeric data and some sensitivity analysis are also presented.

Part-IV: Inventory Models with Fuzzy Logic

Chapter-7

• A Supply Chain Model with Fuzzy Logic under Random Planning Horizon via Genetic Algorithm.

In this model fuzzy logic is introduced in a single management Supply Chain Model (SCM) with m suppliers and one wholesaler having n showrooms for sale, to make the dealings among the chain members more meaningful and profitable in a random business period which follows normal distribution with known mean and variance. The suppliers with limited capacity offer

some fuzzy cost discount depending on the ordered amount following one parameter fuzzy inference. The target of the wholesaler is to purchase the required amount of the item from the suppliers achieving maximum possible cost discounts. The quantity supplied by the wholesaler to showrooms for sale depends not only on the respective demand at that place but also on the selling price (i.e. mark-up) of the units following some two parameters fuzzy rules. The chance constraint technique is used to express the randomness of the planning horizon. The above mentioned SCM is formulated as a profit maximization problem with respect to the wholesaler using fuzzy logic(FL) and optimized using a real coded genetic algorithm (GA). Finally, to illustrate the model, a practical example is considered. Raw data from a rice selling merchant are collected and represented as imprecise numbers. The linguistic relations are derived and linguistic terms are quantified. Then the model is formulated for maximum profit with respect to the said merchant and solved using FL and GA. The behavior of profit and required quantity are plotted against selling price (mark-up).

Chapter-8

• A Deteriorating Multi-item Inventory Model with Price Discount and Variable Demands via Fuzzy Logic under Resource Constraints.

An inventory model of deteriorating seasonal products with Maximum Retail Price (MRP) for a wholesaler having showrooms at different places under a single management system is considered under random business periods with fuzzy resource constraints. The wholesaler replenishes the products instantaneously and earns commissions on MRP which vary with the ordered quantities following All Unit Discount (AUD), Incremental Quantity Discount (IQD) or IQD in AUD policy. Demand at showrooms are imprecise and related to selling prices by verbal words following fuzzy logic. The wholesaler shares a part of commission with customers. The business periods follows normal distribution and converted to deterministic ones through chance constraint technique. The fuzzy space and budget constraints and fuzzy relations are defuzzified using possibility measures, surprise function and Mumdani fuzzy inference technique. The model is formulated as profit maximization for the wholesaler and solved using a real coded Genetic Algorithm (GA) and illustrated through some numerical examples and some sensitivity analysis. A real-life problem of a developing country is presented, solved using the above mentioned procedures and an appropriate inventory policy is suggested.

Chapter-9

• An EPQ Model for Deteriorating items under Random Planning Horizon with some Linguistic Relations between Demand, Selling Price and Trade Credit, Ordered Quantity.

An environment friendly Economic Production Quantity (EPQ) model of a single item is presented in this chapter in which the business in each cycle starts with shortage and ends with the end of stock. The whole problem is formulated to maximize profit of the manufacturer with random business period and the randomness is removed by chance constrained method. This model involves selling price dependent demand and purchased raw material dependent credit period which are described by two sets of linguistic relations under fuzzy logic. In addition, after the end of credit period, due raw-material cost (DRC) is paid to the source as soon as it can be possible and a lemma is presented in support of this approach. A comparison is drawn between this approach and the old payment policy (i.e. DRC is paid to the end of the cycle). The model is optimized by a real coded genetic algorithm (GA)

developed for this purpose with tournament selection, arithmetic crossover and polynomial mutation. The model is illustrated with different sets of numerical examples for different scenarios. A practical application has also been demonstrated with real world data. Some sensitivity analysis are presented graphically.

Part-V : Summary and Future Extension

Chapter-10

10.1. Summary

In this thesis, total seven virgin inventory /production-inventory models, of which one is in crisp, three in random / fuzzy-random and three in fuzzy environments are formulated and solved.

- The models are formulated with linguistic relations, in-control and out-control states, advanced payment, trade credit policy, inflation of money and many more criteria which are visible in recent management system.
- The models are developed for different types of demands like stock dependent demand, time dependent demand, price dependent demand, credit period dependent dynamic demand and fuzzy demand.
- The models are transformed to deterministic ones by using method of Fuzzy Inference, Possibility, Necessity, Credibility measures, method of chance constraint, etc.
- For the solution of single and multi-objective models with/without constraints, different optimization techniques such as Genetic Algorithm (GA), Multi-objective GA (MOGA), Generalized Reduced Gradient method (GRG) etc. are developed / modified and used. The appropriate solution methods are developed for different models.
- The models are illustrated with appropriate numerical examples and the optimum results are presented numerically and graphically. Moreover, the obtained results are discussed as managerial insights.
- In practice, all available past data / experts' opinions are deterministic. An appropriate method is presented in the thesis to formulate fuzzy membership functions from available crisp data / experts' opinions.
- Several inventory / production-inventory models for seasonal products with random business periods, imprecise resource constraints, conditional trade credit, etc. have been developed and solved.

10.2. Future Extension

- Each model presented in the thesis can be extended to include realistic features of inventory / production-inventory systems. The presented models can also be formulated in other types of uncertain environments, such as**:** rough, fuzzy-rough, rough-fuzzy, bi-random, bi-fuzzy, etc.
- In the inventory models only some specific types of resource constraints are used as random, fuzzy etc. The limited resource can also be taken as intuitionstic fuzzy, type-2 fuzzy, etc.
- There are various optimization techniques such as Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Geometric Programming (GP), etc which are not

applied to the models in this dissertation. So, these methods can be developed for the present models, if possible and applied for optimal solutions.

- For the models with fuzzy inferences, only Mamdani's method has been used. Other inference methods (such as, Sugeno type) can also be used to handle fuzzy relations by changing the models appropriately.
- Here, one method for formation of fuzzy membership function from raw crisp data has been presented. Other appropriate methods can also be developed for this purpose.
- In the thesis, two supply-chain models are developed with two level trade credit period. For the supplier-wholesaler-retailer supply chain, three level trad credit period can be conceived and applied.

Therefore, there is a huge scope to extend the research works presented in this thesis.

Part-VI: Bibliography and Indices

- **Bibliography**
- **Indices**

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List of Publications

A. List of Published Papers

- A deteriorating multi-item inventory model with price discount and variable demands via fuzzy logic under resource constraints.
  Computer & ***Industrial Engineering. 66 (2013) 976-987, Elsevier.***

- An EPQ Model for Deteriorating items under Random Planning Horizon with some Linguistic Relations between Demand, Selling Price and Trade Credit, Ordered Quantity.
  Journal of Mathematics and Informatics. 6 (2016) 73-92, **House of Scientific Research.**

B. List of Communicated Papers

- A Supply Chain Model with fuzzy logic under Random planning Horizon via Genetic Algorithm.
  Communicated to ***Fuzzy Information and Engineering. (Elsevier).***

- Optimum Production Policy for a Production Inventory Model in Random Time Horizon.
  Communicated to ***Journal of Intelligent Manufacturing. (Springer).***

- Two plant optimal production problem in random time horizon.
  Communicated to ***Applied Mathematical Modelling. (Elsevier).***

- Two layer supply chain model of deteriorating items with rework and two level credit period.
  Communicated to ***C*****omputer and Operations Research. (Elsevier)**

- Note On: Partial trade credit policy of retailer in economic order quantity models for deteriorating items with expiration dates and price sensitive demand.
  Communicated to ***European Journal of Operational Research. (Elseveier).***