BULLWHIP EFFECT (BWE) IN SUPPLY CHAIN MANAGEMENT (SCM) SYSTEM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
in
Mechanical Engineering

By
SOUMYA. ADITYA. OHID

Department of Mechanical Engineering

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CERTIFICATE

This is to certify that the thesis entitled, “ **Bullwhip Effect In Supply Chain Management** ” submitted by Sri/Ms “ **Soumya. Aditya. Ohid** “: in partial fulfillment of the requirements for the award of Master of Technology/ Bachelor of Technology Degree in “ **Mechanical** ” Engineering with Specialization I n” **Production** ” at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him / her under my / our supervision and guidance.

To the best of my/our knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

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SOUMYA. ADITYA. OHID

THE ABSTRACT

TO QUANTIFY THE BULLWHIP EFFECT (BWE) IN SUPPLY CHAIN MANAGEMENT (SCM) THROUGH GRAPHICAL TREATMENTS

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request, or demand. The supply chain not only includes the manufacture and suppliers, but also transporters, warehouses, retailers, and finally the end consumers themselves

The objective of every supply chain is to maximize the overall value generated. The value a supply chain generates is the difference between what the final product is worth to the customer and the effort the supply chain expends in filling the customer's request.

Supply chain management involves the management of flows of information, product, or funds between and among stages in a supply chain to maximize total supply chain profitability

An important phenomenon in SCM, known as the bullwhip effect, which suggests that the demand variability increases as one moves up a supply chain. It is **1989** that **Sterman** first introduced regarding this effect. Since then, worldwide researches have been carried out by various authors to study different aspects of SCM, causing the bullwhip effect and suggested a number of methods to reduce its effect.

The impact of the bullwhip effect is to increase Manufacturing cost , Inventory cost, Replenishment lead time, Transportation cost $ Labor cost for shipping and receiving, for building surplus capacity and holding surplus inventories. The impact of the bullwhip effect is also to decrease 'Level of Product Availability', since More run out of stocks in supply chain, and to decrease 'Relationship Across the Supply Chain', since each stage tends to blame other stages of the supply chain

There are so many minor causes which gives rise to bullwhip effect. But, they can never be quantified through mathematical equations, however, can be controlled through effective managerial levers. Some of theses causes can be pointed out as below,

- Lack of supply chain coordination
- Lack of information sharing
- Lack of trust among the members in SC
- Lack of proper incentive scheme
- Lack of proper trained sales forces………etc

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The major causes which increase in variability are projections of future demand expectations, which result in over-exaggerated responses to changes in demand.

In **1997 Lee et al**. identified five major causes of the bullwhip effect which was all the consequence of the rational behavior of the supply chain members:

They are the use of

- Demand Forecasting
- Batch purchasing OR Ordering Lots
- Replenishment lead times
- Rationing & Supply Shortages
- Price Fluctuations and Safety Stock

The loss due to this can be quantified through mathematical equations, and can be controlled effectively, if the factors affecting the bullwhip effect are analyzed properly through proper method.

All previous works were only limited on quantifying the bullwhip effect based on common methods of reducing its impact. However, with all these previous works, it is difficult to obtain graphical illustration of the bullwhip effect

Our work differs from all previous works mainly because it shifts the focus of the well established and extensively researched order-up-to-level policy and instead looks at all the replenishment policies that are somewhat different. We want to introduce **Z- Transfer function's frequency response plot to study the graphical illustration for the occurrence of the bullwhip effec**t. However, there are some limitations to the method used. The choice of the replenishment policies is limited since they have to be inherently periodic review policies and have to satisfy the linearity condition

As a result of our research finding, we have suggested the organizations always implementing well known order-up-to-level replenishment policy due to lowest associated fixed cost and variable cost, that it is not always advantageous to implement said policy. While, implementing the said policy, they should also consider the loss due to corresponding bullwhip effect. If the bullwhip reduction is going to incur more benefits than the higher inventory management cost, they should rather consider implementing some other replenishment policies than the said well known order-up-to-level replenishment policy

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Chapter-1

AN INTRODUCTION TO SUPPLY CHAIN MAMAGEMENT (SCM) & BULLWHIP EFFECT (BWE) IN IT

Supply chain & its basic layout
Bullwhip Effect
Origin of the Concept
Causes
Impacts
Previous works
Objective
Use of Basic Theories
Use of Software

CHAPTER – 1

AN INTRODUCTION TO SCM AND THE BULL WHIP EFFECT IN IT

1.1 ABOUT SCM & ITS BASIC LAYOUT FORMS

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request, or demand. The supply chain not only includes the manufacture and suppliers, but also transporters, warehouses, retailers, and finally the end consumers themselves. Within each organization, such as a manufacture , the supply chain includes all functions involved in receiving and filling a customer request . These functions include, and customer service. In simple the different stages of a supply chain can be as below.

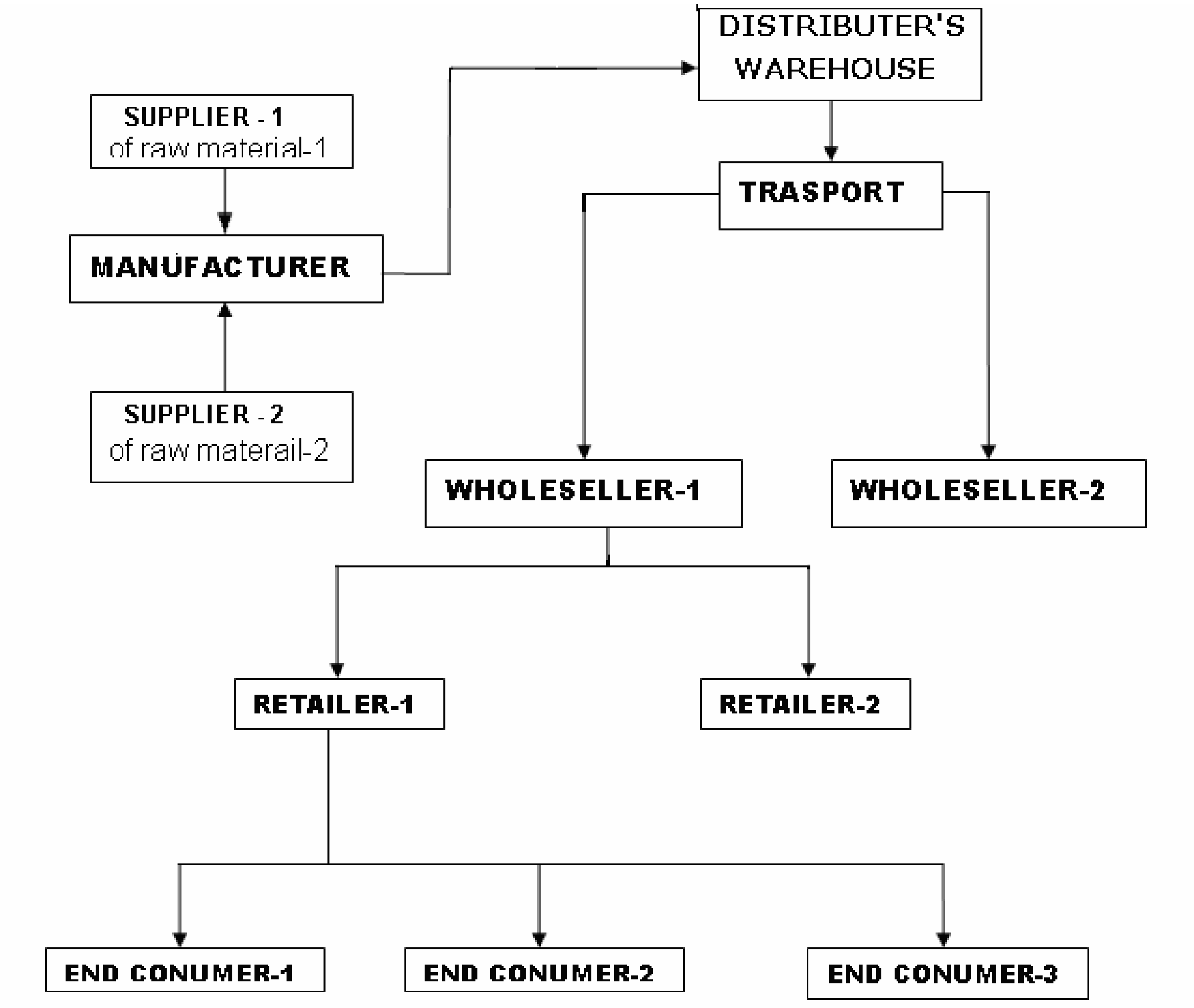


FIG- 1. 1

Consider a customer walking into a manufacture to purchase an item. The supply chain begins with the customer and their need for item. The next stage of supply chain is the manufacturer’s retail shop that the customer visits. The manufacture stocks its shelves using inventory that may have been supplied from a finished- goods warehouse that the manufacturer manages or from a distributor using trucks supplied by a third party. The distributor in turn is stocked by the manufacturer. The manufacturer receives raw materials from a variety of suppliers who may themselves have been supplied by lower tier suppliers. For example , packaging materials may come from Tenneco packaging while Tenneco receives raw materials to manufacture the packaging from other supplier.

A supply chain is dynamic and involves the constant flow of information, product, and funds between different stages. For example, manufacturer provides the product, as well as pricing and availability information to the customer. The customer transfers funds to the manufacturer. The manufacturer conveys point-of-sales data as well as replenishment order to the warehouse or distributor, who transfers the replenishment order via trucks back to the store. The manufacturer transfers funds to the distributor after the replenishment. The distributor also provides pricing information and sends delivery schedule to the manufacturer. Similar information, material, and funds flows take place across the entire supply chain.

1.2 OBJECTIVE OF SUPPLY CHAIN

The objective of every supply chain is to maximize the overall value generated. The value a supply chain generates is the difference between what the final product is worth to the customer and the effort the supply chain expends in filling the customer’s request. For most commercial supply chain, value will be strongly correlated with the supply chain profitability, the difference between the revenue generated from the customer and the overall cost across the supply chain. For example, a customer purchasing a computer from Dell pays $2000, which represents the revenue the supply chain receives. Dell and other stages of the supply chain incur costs to covey information, produce components, stores them, transport them, transfer funds, and so on. The difference between the $2000 that the customer paid and the sum of all costs incurred by the supply chain to produce and distribute the computer represents the supply chain profitability. Supply chain profitability is the total profit to be shared across all supply chain stages. The higher the supply chain profitability, the more successful is the supply chain. Supply chain success should be measured in terms of supply chain profitability and not in terms of the profits at an individual stage.

Having defined the success of a supply chain in terms of supply chain profitability, the next logical step is to look for sources of revenue and cost. For any supply chain, there is only one source of revenue: the customer. At manufacturer, a customer purchasing an item is the only one providing cash flow for the supply chain. All other cash flow are simply fund exchanges that occur within supply chain given that different stages have different owners. When a manufacturer pays its supplier, it is taking a portion of the customer provides and passing that money on to supplier. All flows of information, product, or funds generate costs within the supply chain. Thus, the appropriate management of these flows is a key to supply chain success. Supply chain management involves the management of flows between and among stages in a supply chain to maximize total supply chain profitability

1.3 BULL WHIP EFFECT AND THE ORIGIN OF THE CONCEPT

An important phenomenon in SCM, known as the bullwhip effect, which suggests that the demand variability increases as one moves up a supply chain. It is **1989** that **Sterman** first introduced regarding this effect. Common practical effects of this variance amplification were found in cases of companies **Procter&Gamble** (Dealing with mainly detergent) and **Hewlett-Packard** (Dealing with manly computers and its components), and are presented to students worldwide through the business game **“Beer Game”** developed at MIT. Since then, Worldwide researches have been carried out by various authors to study different aspects of SCM, causing the bullwhip effect and suggested a number of methods to reduce its effect. The various aspects SCM may laid down in brief as below.

- Designing & Building proper network of SCM
- Planning & managing inventories in SCM
- Sourcing , Transporting and pricing the products
- Coordinating different stages of SCM for more overall benefit

1.4 THE MINOR CAUSES OF BULLWHIP EFFECT IN SCM AND THEIR REMEDIES

The minor causes which give rise to bullwhip effect is the lack of supply chain coordination. The manufacturer suffers a great loss due to this , but the loss due to this can never quantified through mathematical equations, however, can be controlled through effective managerial levers. Some of the causes which give rise to "**The lack of supply chain coordination**" can and their remedies are discussed as below,

- Supply chain coordination studies the effect of action of each stages of supply chain on other stages
- Supply chain coordination improves if all stages of the chain take actions that together increase total supply chain profits
- A lack of coordination occurs either because different stages of supply chain have objectives that conflicts or because information moving between the stages gets delayed and distorted. Different stages of supply chain may have objectives that conflicts, if each stage has different owner. As a result, each stage tries to maximize its won profit, resulting in an action that often diminish total chain profits.

For example, consider a situation in which marketing is publishing the company's ability to provide large varieties of products very quickly; simultaneously , distribution is targeting the lowest cost means of transportation. In this situation, it is very likely that distribution will delay orders so it can get better transportation economy by grouping several orders together.

1.4.1 OBSTACLES TO THE LACK OF SUPPLY CHAIN COORDINATION

In brief, local maximization, increase in information delay, distortion and variability are the main obstacles. But for detail, major obstacles fall under five categories

1. Incentive obstacle
2. Information processing obstacles
3. Operational obstacles
4. Pricing obstacle
5. Behavioral obstacle

1.4.1.(i) Incentive obstacles

I. LOCAL MAXIMIZATION WITHIN FUNCTIONS OR STAGES OF SUPPLY CHAIN; Incentives that focus only on the local impact of an action results in decisions that do not maximize total supply chain profit.

II. SALES FORCE INCENTIVES; In many firms sales force incentives are proportional to quantity of sales during a period. But if quantity of sales to distributors and retailer (i.e Sale In) is more than that to final customer (Sale Through), then the firm may have a high jump in order at the beginning of next period

1.4.1.(ii) Information Processing Obstacles

I. FORCASTING BASED ON ORDERS AND NOT CUSTOMER DEMAND; Each stage fills order more than that placed by its down stream partner. A retailer anticipates a great future change for a small change in customer demand. A whole seller anticipates a still more change in future demand for a small change in retailer's order. Thus bull whip effect exists in the whole supply chain

II. LACK OF INFORMATION SHARING BETWEEN RETAILER AND MANUFACTURER; Motivated by periodic planned policy, a retailer may increase the size of order and the manufacturer interpreting large demand may place large orders with the supplier accordingly. But, as soon as the company finishes its promotion policy, order return to the normal

1.4.1.(iii) Operational Obstacles

I. ORDERING IN LARGE LOTS; Manufacturer often order in large lots to avail discounts and also to avail fixed cost associated with a order irrespective of any quantity. This may lead to a variability

II. LARGE REPLENISHMENT LEAD TIMES: The bull whip effect is magnified if replenishment lead times between stages are long. For example, If replenishment lead times is one month, then a retailer has to forecast much before one month whether demand will increase, accordingly place a order before one month

III. RATIONING AND SHORTAGE GAMING: Rationing scheme that allocate limited production proportional to orders placed by retailers lead to a magnification of bull whip effect. Under this scheme, if the supply available is 75% of the total orders received, each retailer receives 75% of their order. The net impact of this rationing scheme is to artificially inflate orders for the product. A retailer needing 75 units will order for order 100 units in hope that 75 will then be available. If the manufacturer is using these orders to forecast future demand, they will interpret the increase in orders as an increase in demand and may respond by building enough capacity to be to fill all orders received, then they suffer a great loss

1.4.1.(iv) Pricing Obstacles

I. LOTS SIZE BASED QUANTITY DISCOUNT; Trade promotion and other short term discounts offered by a manufacturer results in forward buying where a whole seller or retailer purchase large lots during the discounting period to cover demand during future periods. Forward buying results in large orders during the promotion period followed by very small orders after that

II. PRICE FLUCTUATIONS: The price fluctuation by a manufacturer also results in forward buying where a whole seller or retailer purchase large lots during the low price period to cover demand during the high price periods. Forward buying results in large orders during the low price period followed by very small orders after that

1.4.1.(v) Behavioral Obstacles

Behavioral obstacles refers to problems in learning within the organization that contribute to the bull whip effect. These problems are often related to the way the supply chain is structured and the communication between different stages. Some of the behavioral obstacles are as below:

I. Each stage of the supply chain views its action locally and is unable to see the impact of its action on other stages

II. Different stages of the supply chain react to the current local situation rather than trying to identify the root cause

III. Based on local analysis, different stages of the supply chain blame each other for the fluctuation, with successive stages in the supply chain becoming enemies rather than partner

IV. No stage of the supply chain learns from its actions over time because the most significant consequences of the actions any one stage takes occurs else where. The result is a vicious cycle where actions taken by a stage blames on other.
V. A lack of trust between the supply chain partners causes them to be opportunistic at the expense of overall supply chain performance. The lack of trust also results in significant duplication of efforts. More important information available at different stages is either not shared or is ignored because it is not trusted

1.4.2 MANAGERIAL LEVERS TO ACHIEVE COORDINATION

The following managerial actions in the supply chain increase total supply chai profits and moderate the bull whip effect

- Aligning of goals and incentives
- Improving information accuracy
- Designing operational performance
- Defining pricing strategies to stabiles orders
- Building partnership and trust

1.4.2.(i) aligning of goals and incentives:

a. ALIGNING INCENTIVE ACROSS FUCNTIONS: The objectives used by a stage to evaluate a decision is aligned with the firm's overall objective. All facility, transportation, and inventory decisions should be evaluated based on their impact on profitability and not total costs, or even worse, just local costs
b. PRICING FOR COORDINATION: A manufacturer can use lot size based quantity discount, if the manufacturer large fixed cost associated with each lot. For the product where a firm has the market power, a manager can use two-part tariffs and volume discount to help coordination. For a given demand uncertainty, manufacturer can use buy-back, revenue-sharing, and quantity – flexibility contracts to spur retailers to provide level of product availability that maximize supply chain profit

c. ALTERING SALES FORCE INCENTIVES FROM SELL-IN TO SELL-THROUGH: By providing increased incentives to sell through and reduced incentive to sell-in ie more incentive to customer & door to door sellers than to retailer & whole seller .This reduces forward buying

1.4.2.(ii) improving information accuracy:

(a) SHARING POINT OF SALES: A primary cause for the bull whip effect is the fact that each stage of supply chain uses orders to forecast future demand. However, sharing point of sales data across the supply chain can help reduce the bull whipeffect, because akll stages now respond to the same change in customer demand. Not detailed POS data but aggregate POS data is sufficient. Internet can be used to share POS data & current inventory positions of components. InE-commerce, Pos data is available in a form that canbe used easily shared.

(b) INPLEMENTING COLLABORATIVE FORECASTING $ PLANNING: Once the point of data is shared, different stages of the supply chain must forecast & plan jointly guarantee cmpletye coordination. The key is toensure that the entire supply chain is operating on a common ftrecast. That is there should not be any gap between what marketing agency plans to sell and what the manufacturer plans to sell. For example, if marketing agency runs apromotion policy, which the manuifacturer is not aware of, then even if both have some POS data, marketing forecast must differ from manufacturer's forecast. Use ofIT systems helps facilitate collaborative forecasting and planning within the supply chain

(c) DESIGNING SINGKLE STAGE CONTROL OF REPLENISHMENT:

1.4.2.(iii) improving operational performance:

a) REDUCING REPLENISHMENT LEAD TIME: By reducing the replenishment lead time, manager can decrease the uncertainty of demand during the lead time. A reduction in lead time is especially benefdicial for seasonal items (multiple orders with accurate forecast). This is particularly usefull for company producing large variety of products

(b) REDUCINGLOTS SIZE: This reduces fluctuation in order. However, to reduce lot sizes, the fixed cost associated with ordering, transportation and receiving each lot should be reduced. Computer assisted ordering, B2B E-commerce (i.e ordering trough web), elimination of purchase of order, reducing order processing associated with each replenishment order, can reduce said fixed cost. Manager can reduce lot sizes without increasing transportation cost by filling a truck using smaller lots from a variety of product. The cost of receiving can be reduced by adapting electronically identify content, count, and time of delivery and help reduce unloading time and increase cross dock efficiency. DEX & NEX (bard coding of pallets) are two receiving technology that allow the direct updating of inventory records, once the item count has been verified. This technology simplify the task of shipping, transporting, and receiving complex orders. Scheduling a regular days in advance for each customer can also reduce said fixed cost. For example, a customer can be asked to order on Monday each week, or at the beginning of each month.

(c) RATIONING BASED ON PAST SALES AND SHARE INFORMATION TO LIMIT GAMING: To diminish the bull whip effect, managers can design rationing scheme that courage the retailers from artificially inflating their orders in the case of shortages. one approach, referred to as **turn-and earn,** is to allocate the available supply based on past retailers sale rather than current retailer orders tying allocation to past sales. During low demand periods, this approach pushes retailers to try and sale more to increase allocation they receive during the periods of shortage. This approach also help the company to improve the accuracy of its won forecast and allocate production capacity accordingly. Once the capacity has been allocated appropriately across different product, it is likely that shortage situation will arise. The availability of flexible capacity can also help in this regard, because flexible capacity can easily be shifted from a product whose demand is lower than to expect one whose demand is higher than expected

1.4.2.(iv) designing pricing strategies to stabilize the orders:

The managers can diminish then bull whip effect by devising pricing policies that encourage retailers to order in smaller lots and reduce forward buying

(a) MOOVING FROM LOT SIZE-BASED TO VOLUME-BASED QUANTITY DISCOUNT: Volume-based quantity discount refers to total purchase during a specific periods, whereas, lot size based quantity discount refers to purchase in a single lot. Note that volume-based quantity discount can also be referred to as discount over a rolling time horizon

(b) STABLISING PRICING: The managers can dampen the bull whip effect by eliminating promotion to retailer and charging on EDLP. The elimination of promotion to retailers removes forward buying by retailers as they think no benefit from forward buying and purchase more only if they can sell more. Another approach is to tie the promotion rupees paid to the retailers to the amount of sell-through rather than the amount purchased by the retailer.

(c) BUILDING STRATEGIC PARTNERSHIP AND TRUST: A supplier can eliminate its forecasting effort if it trusts orders and forecast information received from the effort and at the same time, stages in supply chain can eliminate duplicated efforts on the basis of improved trusts and a better relationship. So, if trusts and strategic partnership are built among the stages in supply chain, then better coordination can be achieved among the stages in supply chain A better relationship lowers the transaction costs among the supply chain stages. Managerial levers that help a supply chain achieve better coordination fall into two broad categories. Action- oriented-lever include information sharing, changing of incentives, operational improvements, and stabilizing of pricing. Relationship-oriented-levers involve the building of cooperation and trust within the supply chain

1.4.2.(v) building strategic partnership and trust within supply chain:

Trust involve a belief that each stage is interested in other’s welfare and would not take action without considering impact on other stage. Coordination and trust within the supply chain help improve performance in many ways. For example,

(a) A manufacture can receive materials from a supplier without inspecting historically, supply chain relationship have been based either on powers or trusts. In a power based relationship, the stronger part dictates its view. Although exploiting power may be advantageous in the short term, its negative consequences are felt in the long term due to three main reasons as below

- Exploiting powers to extract unfair concessions can hurt a company once the balance of powers changes. Retailers may become more power full than the manufacturer. This reversal of powers has occurred over the last two decades in Europe and United States
- Exploiting powers results in one stage of supply chain maximizing its profit, often at the expense of other stages. This decreases total supply chain profits
- When a stage systematically exploits its power advantage the other stage seek ways to resist. In many instances where retailers have tried to exploit their power, manufacturer have sought ways to directly access the consumer. These include selling over the internet and setting up company’s stores. The result can be a decreases in supply chain profits because different stages are competiting rather than cooperating. Although everybody agrees that cooperation and trust in supply chain is available, these qualities are very hard to initiate and sustain. There are two views regarding how cooperation and trust can be built into any supply chain relationship. DETERNCE-BASED-VIEW, where the

partners involved use a variety of formal contracts to ensure cooperation. With the contracts in place, parties are assumed to behave in trusting manner purely for reason of self-interest. PROCESS-BASED-VIEW, where, trust and cooperation are built over time as a result of a series of interactions strengthen the belief in the cooperation of the power party. In most supply chain, power tends to be concentrated in relatively few hands. The concentration of powers required to build trust and cooperation, hurting supply chain performance in the long term

1.4.2.(vi) designing a relationship with cooperation and trust:

The key steps in designing effective supply chain partnership are as below

- ASSIGNING THE VALUE OF THE RELATIONSHIP: A common criterion is to increase total profits as result of the relationship. Equity should be the another important criterion while evaluating and designing a relationship. Equity measures the fairness of the division of the total profits between the parties involved. The next step is to clarify the contribution of each party as well as benefits that will accrue to each
- IDENTIFYING OPERATIONAL ROLES AND DECISION RIGHTS FOR EACH PARTY: While identifying operational role and division rights for different parties in a supply chain relationship, managers must consider the resulting interdependence between the parties. A source of conflict may arise if the tasks are divided in a way that makes one party more dependent on other. In this regard it can be pointed out that **sequential interdependence** implies that traditionally supply chain relationship have been sequential, with one stage completing all its tasks and then handing off to the next step. **Reciprocal interdependence** implies parties come together and exchange information and inputs in both directions. For example, DELL manufacturers computers, SONY manufacturers monitors and AIRBORNS takes the computers from DELL and monitors from SONY, merges the two and sends a

combined order to the consumer. For an order to be filled on time, all three parties must coordinate to complete their tasks. The advantages of reciprocal interdependence are that: It is more likely to result in a decisions that maximize supply chain profitability. It increases the interaction between two parties. It increases the chances of trust and cooperation if positive interaction occurs. Thus, greater reciprocal interdependence in allocation of operational roles and decisions rights increases the chances of an effective relationship

- CREATING EFFECTIVE CONTRACTS: It is difficult to design a contract for all possible future sentries. So while designing the partnership and initial contract, managers must promote trust by creating contract that encourage negotiation when unplanned contingencies arise. The contracts that involve overtime (the formal understanding and commitments) are likely to be much more effective than the contracts that are completely defined at the beginning of the partnership. So that over a long term, contracts can only play partial role in maintaining effective partnership. A good example is the relationship between caterpillar and its dealership in which either dealer or caterpillar can terminate agreements without cause with ninety days notice.
- DESIGNING EFFECTIVE CONFLICT RESOLUTION MECHANISM: Conflicts are bound to arise in any relationship. Unsatisfactory resolution cause the partnership to worsen. Once the process-based –trust is built between the parties, it facilitates conflicts resolution. Sharing of information over time helps relationship from deterrence-based –trust to process-based-trust. The specifications of rules and guidelines facilitates the sharing of information among the partners in the supply chain. To facilitate communication, regular and frequent meetings should be held between managers and staffs assigned to partnership. These meetings also provides a basis for resolution at higher level. Should resolution at higher level not take place

1.5 THE MAJOR CAUSES OF BULLWHIP EFFECT IN SCM

The major causes that increase in variability are projections of future demand expectations, which result in over-exaggerated responses to changes in demand.

In **1997 Lee et al**. identified five major causes of the bullwhip effect which were all the consequence of the rational behavior of the supply chain members: use of?

1.5.1 DEMAND FORECASTING: Manufacturer has to forecast in advance what will be the demand for the next year and accordingly design for all capacities and order for raw materials . There are so many methods to forecast demand for the next year. The manufacturer has to select an accurate method of forecasting the demand for which there will very less difference between forecast demand and actual demand

1.5.2 BATCH PURCHASING OR ORDERING LOTS: Manufacturer often order in large lots to avail discounts and also to avail fixed cost associated with a order irrespective of any quantity. This may lead to a variability

1.5.3 REPLENISHMENT LEAD TIMES: The bull whip effect is magnified if replenishment lead times between stages are long. For example, If replenishment lead times is one month, then a retailer has to forecast much before one month whether demand will increase, accordingly place a order before one month

1.5.4 RATIONING AND SUPPLY SHORTAGES: RATIONING AND SUPPLY SHORTAGES: Rationing scheme that allocate limited production proportional to orders placed by retailers lead to a magnification of bull whip effect. Under this scheme, if the supply available is 75% of the total orders received, each retailer receives 75% of their order. The net impact of this rationing scheme is to artificially inflate orders for the product. A retailer needing 75 units will order for order 100 units in hope that 75 will then be available. If the manufacturer is using these orders to forecast future demand, they will interpret the increase in orders as an increase in demand and may respond by building enough capacity to be to fill all orders received, then they suffer a great loss

1.5.5 PRICE FLUCTUATIONS AND SAFETY STOCK: Trade promotion and other short term discounts offered by a manufacturer results in forward buying where a whole seller or retailer purchase large lots during the discounting period to cover demand during future periods. Forward buying results in large orders during the promotion period followed by very small orders after that. Due to a time gap called Replenishment lead times between order placed for raw materials and raw materials received, manufacture has to maintain a safety stock of raw materials to continue the manufacturing during the said . However, if the manufacturer maintains too much inventory in the safety stock, it has to pay for unnecessary fixed cost associated with it. Again, if it maintains too low inventory in the safety stock, it may have to stop the manufacturing if by chance the raw materials runs out of the stock unexpectedly. There are so many methods to forecast for the safety stock during the replenishment lead times . The manufacturer has to select an accurate method of forecasting the inventories in the safety stock during this replenishment lead times for which the inventory position will just finish by the time of arrival of the order.

1.6 THE IMPACT OF THE BULLWHIP EFFECT

PERFORMANCE MEASURE	IMPACT	CAUSE
Manufacturing cost and inventory cost	Increases	For building excess capacity or holding excess inventory
Replenishment lead time	Increases	Scheduling at manufacture and supplier becomes difficult. At some times available capacity & inventory can not supply the orders coming in.
Transportation cost	Increases	Surplus transportation capacity needs to be maintained
Labor cost for shipping and receiving	Increases	Surplus labor needs to be maintained for shipping at distributors , retailers, and receiving at its suppliers
Level of product availability	Decreases	More run out of stocks in supply chain (supplier, manufacture, retailer) resulting in lost sales.
Relationship across the supply chain	Decreases	Each stage tends to blame other stages of the supply chain

1.7 ABOUT THE PREVIOUS WORKS ON SCM:

(**Mainly limited with finding the cause, and suggesting the methods of quantifying & reducing the effect**)

All previous works were only limited on quantifying the bullwhip effect based on common methods of reducing its impact. However, the special works which have some resemblance with our present work are as below:

- Lee et al (1997a, b), Lee et al (2000), Xu et al (2001) and Bai (2001) used more common statistical inventory control approach to explain the occurrence and to quantify the bullwhip effect..
- Transfer function analysis of inventory management system was first done by Simon (1952) by using the laplace transform.

- Due to discrete nature of periodic review replenishment systems, the usase of discrete *Z*-transform was introduced later by Towill (1999) to quantify the bullwhip effect

However, with all these previous works, it is difficult to obtain graphical illustration of the bullwhip effect.

1.8 OUR CONSIDERATION:

(To explain mainly the occurrence and to quantify the bullwhip effect through graphical illustration of the bullwhip effect)

Our work differs from all previous works mainly because it shifts the focus of the well established and extensively researched order-up-to-level policy and instead looks at all the replenishment policies that are somewhat different. We want to introduce **Z-** Transfer function's frequency response plot to study the graphical illustration for the occurrence of the bullwhip effect, However, there are some limitations to the method used. The choice of the replenishment policies is limited since they have to be inherently periodic review policies and have to satisfy the linearity condition.

1.9 THE BASIC REPLENISHMENT POLICIES:

In supply chain management system, we have two types of replenishment policies Those are as described below:

What is a replenishment policy: A replenishment policy consists of decisions regarding when to reorder and how much to reorder .

Types of replenishment policy: There are two types of replenishment policies used in Supply chain management. They are :

1) Continuous review replenishment policy
2) Periodic review replenishment policy

- **Continuous Review Replenishment Policy:** Inventory is continuously tracked and an order for a lot size "Q" is placed when the inventory declines to a reorder point

.

- **Periodic Review Policy:** Inventory status is checked at regular periodic intervals and an order is placed to raise the inventory level to a specified threshold based on demand forecast for the next year and the length of lead time.

We have selected only the “Periodic review replenishment policy” as it is responsive to our method of analysis (i.e Z- Transfer function’s frequency response analysis) . So, through the periodic review replenishment policy and simple exponential smoothing demand forecast, we have attempted to gauge the impact of demand forecasting and lead times on the bullwhip effect. It can be repeated again that Our work differs from all previous works mainly because it shifts the focus off of the well established and extensively researched order-up-to-level policy and instead looks at all the replenishment policies that are somewhat different.

1.10 THE TRANSFER FUNCTION:

The basis for calculating the transfer function of a particular replenishment policy is its replenishment rule. We represent the dynamics of the system through the construction of the causal-loop diagram. From here we construct a block diagram (Figure 1). The input in the block diagram of each of our replenishment policies is the demand signal, which is the only independent variable in the inventory replenishment system. The corresponding output on the opposite side of the diagram is the order quantity.

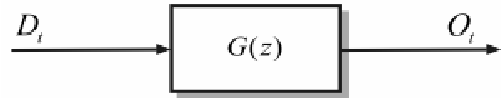


FIG- 1. 2
Block diagram representing the Transfer Function

1.11 THE LAPLACE TRANSFORM (ALSO CALLED S-TRANSFORM) :

The mathematical tool commonly used for the analysis and synthesis of continuous-time control system is the S-transform or the Laplace transform. In time control system a linear differential equation characterizes the dynamic of the system. To determine the system’s response to a given input such a differential equation must be solved.

Laplace transformation transforms a linear time-invariant differential equation into a simple algebraic equation in S. The inverse of Laplace transform form or S-Transform gives the actual solution to the differential equation. Any higher order differential equation, which is very difficult to be solved by general method of solution, can be easily solved by the method of laplace transform

In brief,

If, f (t) $\Rightarrow$ A time-domain equation

And, F (s) $\Rightarrow$ A Laplace-domain, or S-domain equation

Then, L [f (t)] = F (s)

And, L [F (s)] = f (t)

The formula used to solve a linear time domain equation are as below:

$$L.[t^n] = \frac{n!}{s^{n=1}}$$

$$L^{-1}\frac{1}{s-a} = e^{at}$$

$$L[f^n(t)] = s^n.L[f(t)] - s^{n-1}.f(0) - s^{n-2}.f^1(0) - s^{n-3}.f^2(0) - - - - - - - f^{n-1}(0)$$

1.12 THE Z-TRANSFORM:

The mathematical tool commonly used for the analysis and synthesis of decrete-time control system is the Z-transform. The role of Z-transform in descrete-time system is similar to that of the Laplace transform in continuous-time system. In a linear discrete-time control system, a linear difference equation characterizes the dynamics of the system. To determine the system's response to a given input such a difference equation must be solved. With the Z-transform method, the solutions to linear difference equation becomes algebraic in nature. The Z-transformation transforms a difference equation into a simple algebraic equation in Z, and the inverse of Z-Transform gives the actual solution to the difference equation. Any higher order difference equation, which is very difficult to be solved by general method of solution, can be easily solved by the method of Z-transform.

A difference equation is generally given by

$Y(k) = \sum_{h=0}^{h=k} X(h)$, where, the sampling period, k =0 , 1.0 , 2.0 , 3.0 - - - - - - so on

In other wards,

Y(0) = X(0)

Y(1) = X(0) + X(1)

Y(2) = X(0) + X(1) + X(2)

Y(3) = X(0) + X(1) + X(2) + X(3)

- - - - - -- - - - - - - - - - - - - - -
- -
- - - - - - - - - - - - -- - - -- - - -- --

Y(k) = X(0) + X(1) + X(2) + X(3) + - - - - - - - - X(k)

In brief , above equation can also be given in the form as below

Y(k) - Y(k-1)= X(k)

The Z-transform of the above equation is

$$Y(z) - z^{-1}.Y(z) = X(z)$$
$$\Rightarrow \frac{Y(z)}{X(z)} = \frac{1}{1 - z^{-1}}$$

The formula used for the Z-transformation of a simple linear time-domain equation is given by

$$Z.[X(t-nk)] = z^{-n}.X(z)$$
$$So,..if....X(t)=1$$
$$Then,..X(z) = Z[1] = \sum 1 \times z^{-k}$$
$$.............................. = 1 + z^{-1} + z^{-2} + z^{-3} + ------ + z^{-k}$$
$$.............................. = \frac{i}{1-z^{-1}}$$

The formulas used for the inverse Z-transformation of a simple linear equation in Z are as below

$$Z^{-1}[1] = \begin{cases} 1,......for,..k=0 \\ 0.,.....for,..k=1,2,3..------ \end{cases}$$

$$Z^{-1}\left[\frac{z^{-1}}{1-z^{-1}}\right] = \begin{cases} 1.0..,..for..,k=1,2,3..----- \\ 0.,......for.,k \le 0 \end{cases}$$

$$Z^{-1}\left[\frac{z^{-1}}{(1-z^{-1})^2}\right] = k.....for = 0.,1.,2.$$

And so on

1.13 THE BASIS OF REPLENISHMENT POLICIES FOR ORDER FORECASTING:

BOWMAN REPLENISHMENT RULE : The basis for our research is a general linear replenishment rule introduced by **Bowman (1963)**, which allows for order inventory smoothing.

$$O_t = \hat{D}_t + (1-\gamma)(O_{t-1} - \hat{D}_t) + \beta.(IP_t^T - IP_t)$$

Where,

O_t = The order quantity for the next period derived based on the forecast demand

O_{t-1} = The last placed order quantity in the previous time period

D_t = Demand forecast for the next period

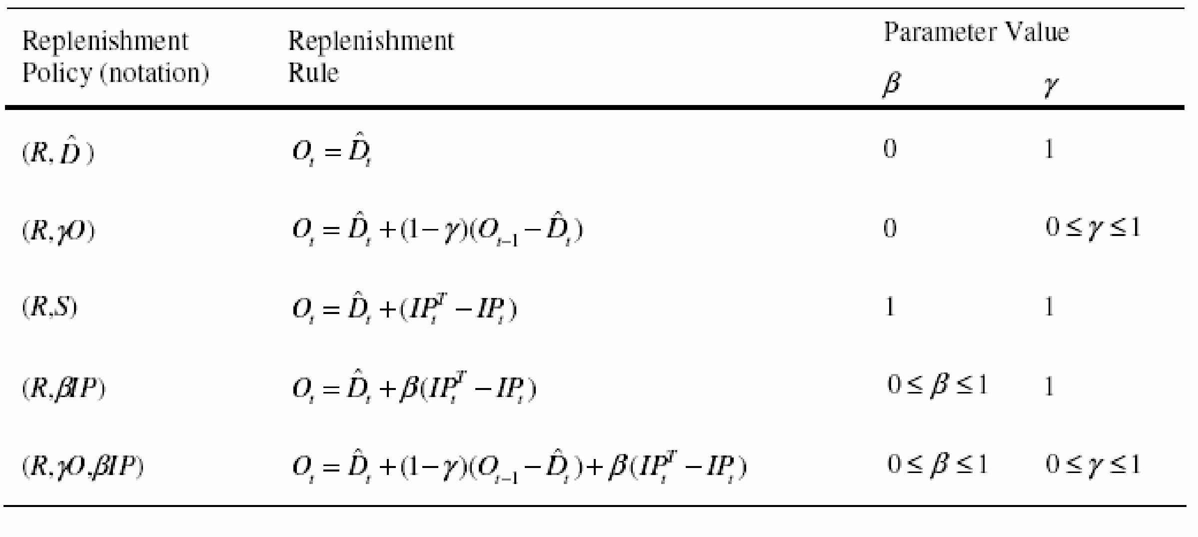
IP^T = The target inventory position for the next period

IP_t = The current inventory position

γ = The order quantity smoothing parameter
β = The inventory position smoothing parameter.

This replenishment rule is then broken down into four simpler replenishment rules through the manipulation of the parameters β and γ. In Table 1 we give an overview of all five analyzed replenishment policies and corresponding replenishment rules.

Table 1. The five analysed replenishment policies, their rules and corresponding parameter values.



Replenishment Policy (notation)	Replenishment Rule	Parameter Value	
		β	γ
$(R, \hat{D})$	$O_t = \hat{D}_t$	0	1
$(R, \gamma O)$	$O_t = \hat{D}_t + (1-\gamma)(O_{t-1} - \hat{D}_t)$	0	$0 \leq \gamma \leq 1$
(R, S)	$O_t = \hat{D}_t + (IP_t^T - IP_t)$	1	1
$(R, \beta IP)$	$O_t = \hat{D}_t + \beta(IP_t^T - IP_t)$	$0 \leq \beta \leq 1$	1
$(R, \gamma O, \beta IP)$	$O_t = \hat{D}_t + (1-\gamma)(O_{t-1} - \hat{D}_t) + \beta(IP_t^T - IP_t)$	$0 \leq \beta \leq 1$	$0 \leq \gamma \leq 1$

- The first replenishment rule $(R, \hat{D})$, , is basically a simple exponential smoothing equation, where, Order Quantity is just = Forecasted Demand for the next period.

- The 2nd replenishment rule $(R, \gamma O)$ allows for order quantity smoothing where parameter 'γ' has the same role as smoothing constant 'α' in simple exponential smoothing, and so we have,
  Order Size = Forecasted Demand + Smoothed Previous Year demand

- The third rule we derive from our original Bowman's rule is a **well known order-up-to-level policy, (*R,S*)** (Silver, Peterson, 1985), where, Order Size = Forecasted Demand + Smoothed Current Inventory Position. The policy is somewhat more complicated then the previous two, due to the introduction of new concepts into the replenishment rule, such as the inventory position, lead time and safety stock.

1.14 THE BASIS FOR CALCULATING SAFETY INVENRORY POSITION FOR EACH OF THE REPLENISHMENT RULE :

Method of calculation of the inventory position for (R, S), (R, βIP) & (R, γO, βIP) replenishment rule : We are particularly interested in changes in inventory position, which goes on to determine the order quantity. In periodic review policies, the time that elapses between two consecutive moments at which we review the stock level is review interval '*R*', which is defined in advance and is constant. The time it takes the manufacturer to fulfill its order is replenishment lead time 'L'. For example, if there is no lead time, an order placed at the end of the period *t* is received and taken into account at the start of the next review period '**t +R**'. It has to be noted that the key period over which protection is required is of duration '**R+L**' instead of just replenishment lead time '**L**'. In selecting the order-up-to-level '**S_t**' at time '**t**'**,** we must recognize that, once we have placed an order, no later orders can be received until time '**t + R + L**':

$$S_t = \hat{D}_t^{R+L} + SS_t$$

Thus $\hat{D}_t^{R+l}$ is forecast demand over 'R+L' periods $[\hat{D}_t^{R+l} = \hat{D}_t.(R+L)]$. SS $_t$ is a safety stock level $[SS_t = z.\hat{\sigma}_t^{R+L} = \hat{\sigma}\sqrt{R+L}]$ is an estimate of the standard deviation of the probability distribution of forecast demand over key period, R+L. To fulfill the linearity condition we have to rewrite the safety stock equation as, $SS_t = k.\hat{D}_t\sqrt{R+L}$, where standard deviation of the demand is written as a constant part of forecasted demand and *k* defines a desired service level times the ratio of the standard deviation over the forecast demand $[k.\hat{D}_t = z.\hat{\sigma}_t]$. We made this simplification so that there is only one new parameter, *k*, introduced into the replenishment rule; square root time dependence is therefore still preserved and the linearity condition satisfied.

1.14.1 CALCULATION OF TARGET INVENTORY POSITION FOR (R, S) RULE:

In order to make the (R,S) rule equations consistent with the notation used in Bowman's rule, we have to set R=1, so that the time between the previous and present ordering decision made at t-1 and t equals to 1. The time period R+L that determines the order-up-to-level and safety stock level will then be transformed into 1+T_L, where time R=1 corresponds to the review interval and time T_L to the replenishment lead time $[0 < T_L < \infty]$. It should be noted that this has not affected the generality of our model.

Again note that, if the targeted inventory position for the next year is simply replaced by IP_t , then the current inventory position IP_t must be replaced by IP_{t-1} So, the relevant equations for order-up-to-level (*R, S*) replenishment policy can finally be written as:

$$IP_t = \hat{D}_t .(1+T_L) + SS_t$$

$$...... = \hat{D}_t .(1+T_L) + k.\hat{D}_t .\sqrt{1+T_L}$$

$$Where,$$

$$..........IP_t = IP_{t-1} + O_{t-1} - D_t$$

1.14.2. CALCULATION OF TARGET INVENTORY POSITION FOR (R, BIP) RULE:

The (R, βIP) replenishment rule is a variation of the (R,S) rule that enables the inventory position smoothing through the loosening of the condition β=1. In the (R,S) rule the misalignment between the current inventory position and the target inventory position was taken into account as a whole, now the correction is partial. We can write the target inventory position as

$$IP_t^T = \hat{D}_t .T_L + SS_t$$

where the target inventory position is basically order-up-to-level reduced by the demand forecast for the next period. In (R,S) policy we increase the inventory position to the desired level by placing an order so that the current inventory position meets the order-up-to-level.

Since order-up-to-level reflects the expected (forecast) demand in the next time period $1+T_L$, we project our future demand expectations over the whole time period $1+T_L$. In (R, βIP) policy our expectations are projected only over a certain part of a time period $1+T_L$, defined by the inventory smoothing parameter β.

1.15 THE MATLAB

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation Algorithm development Data acquisition Modeling, simulation, and prototyping Data analysis, exploration, and visualization Scientific and engineering graphics Application development, including graphical user interface building MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar noninteractive language such as C or Fortran.

The name MATLAB stands for matrix laboratory. MATLAB was originally written to provide easy access to matrix software developed by the LINPACK and EISPACK projects. Today, MATLAB engines incorporate the LAPACK and BLAS libraries, embedding the state of the art in software for matrix computation. MATLAB has evolved over a period of years with input from many users. In university environments, it is the standard instructional tool for introductory and advanced courses in mathematics, engineering, and science

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In industry, MATLAB is the tool of choice for high-productivity research, development, and analysis. MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, simulation, and many others. The MATLAB System The MATLAB system consists of five main parts: Development Environment. This is the set of tools and facilities that help you use MATLAB functions and files. Many of these tools are graphical user interfaces. It includes the MATLAB desktop and Command Window, a command history, an editor and debugger, and browsers for viewing help, the workspace, files, and the search path. The MATLAB Mathematical Function Library.

This is a vast collection of computational algorithms ranging from elementary functions like sum, sine, cosine, and complex arithmetic, to more sophisticated functions like matrix inverse, matrix eigenvalues, Bessel functions, and fast Fourier transforms. The MATLAB Language. This is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create complete large and complex application programs. Graphics. MATLAB has extensive facilities for displaying vectors and matrices as graphs, as well as annotating and printing these graphs. It includes high-level functions for two-dimensional and three-dimensional data visualization, image processing, animation, and presentation graphics. It also includes low-level functions that allow you to fully customize the appearance of graphics as well as to build complete graphical user interfaces on your MATLAB applications. The MATLAB Application Program Interface (API). This is a library that allows you to write C and Fortran programs that interact with MATLAB. It includes facilities for calling routines from MATLAB (dynamic linking), calling MATLAB as a computational

Chapter-2

A BRIEF LITERATURE REVIEW

The books and journals referred to learn about

1) Overall aspect of SCM
2) The results of different researchers that been carried out on SCM till now

CHAPTER – 2

A BRIEF LITERATURE REVIEW

The following books and journals were studied to learn:

- About overall aspect of SCM,
- To know about the results of different researches that have been carried out on SCM till now.

SL.NO	**BOOKS AND JOURNALS COVERED FOR PRESENT PROJECT ANALYSIS**	**OVERALL SUBJECT MATTER LEARNT**
1	Sunil chopra & peter Meindi, Supply Chain Management, 2nd edition , Prentice-hall of India Pvt Ltd	For Planning, Designing & Building a supply Chain Net-work
2	Nagrath. I. J & Gopal. M., Control System Engineering, 3rd Edition, New Age International Publishers	For controlling the continuous system dynamic by the use of Laplace Transform
3	Katsuhiko & Ogata, Discrete-Time Control System, 2nd Edition, Prentice Hall International Edition	For controlling the intermittent system dynamic by the use of Z- Transform
4	Jennifer K. Ryan David Simchi-Levi □Zvi Drezner □Frank Chen Management Science/Vol. 46, No. 3, March 2000	For some statistical inventory control approach of calculating order quantity, inventory position based on forecast demand and lead time
5	Metters, R. 1996. Quantifying the bullwhip effect in supply chains.	For a comprehensive analysis of the bullwhip effect For order-up-to-level policy

	Proc. 1996 *MSOM Conf*. 264–269	*and the statistical Methods of finding order quantity*
6	Chen et al.: Quantifying the Bullwhip Effect in a Simple Supply Chain: The Impact of Forecasting, Lead Times, and Information. Management Science, 46/3 (2000), p. 436-443	For a comprehensive analysis of the bullwhip effect For order-up-to-level policy *and the statistical Methods of finding order quantity*
7	Bowman, E. H: Consistency and optimality in managerial decision making. Management Science, 9, (1963), p. 310-321	For a comprehensive analysis of the bullwhip effect For order-up-to-level policy *and the statistical Methods of finding order quantity*
8	Forrester J.: Industrial Dynamics, New York, MIT Press and John Wiley and Sons Inc., 1961	For important observation of bullwhip effect in supply chain management and the Illustration of the effect of the variance amplification on the bullwhip effect, in a series of case studies called,..
9	Lee, H., P. Padmanabhan, S. Whang. 1997a. The bullwhip effect in supply chains. Sloan Management Rev. 38 93–102	For comprehensive study on the five major causes of the bullwhip effect in order-up-to-lelvel inventory management system Such as; demand forecasting, batch purchasing, lead times, supply shortages and price fluctuations And as to how these five major causes were all the consequence of the rational behaviour of the supply chain members
10	Lee, H., P. Padmanabhan, S. Whang. 1997b. Information distortion in a supply chain: The bullwhip effect. Management Sci. 43 546–58.	For comprehensive study on the five major causes of the bullwhip effect in order-up-to-lelvel inventory management system Such as; demand forecasting, batch purchasing, lead times, supply shortages

		and price fluctuations And as to how these five major causes were all the consequence of the rational behaviour of the supply chain members
11	Baganha, M., M. Cohen. 1995. The stabilizing effect of inventory in supply chains. Oper. Res. Forthcoming	For demonstration on the existence of the bullwhip effect , identifying its possible causes, and a statistical methods for reducing its impact
12	Kahn, J. 1987. Inventories and the volatility of production. The Amer. Econom. Rev. 77 667–679	For the statistical inventory control approach of calculating targeted inventory and the effect of inventory position on the bullwhip effect
13	Simon, H.A.: On the application of servomechanism theory in the study of production control. Econometrica 20, (1952), p. 247-268	For Laplace transfer function analysis of order-up-to-level inventory management systems based on continuous review policy
14	Towill R. Dennis: Fundamental theory of bullwhip induced by exponential smoothing algorithm. MASTS Occasional Paper No. 61, Cardiff University, (1999).	For Z-Transfer function analysis of order-up-to-level inventory management systems based on periodic review policy
15	Sterman, J. D. 1989. Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. Management Sci. 35 321–339	For so many major and minor causes on bullwhip effect and some suggested methods effective managerial levers to their impact
16	Johnson, M. E., H. L. Lee, T. Davis, R. Hall. 1995. Expressions for item bill rates in periodic inventory systems. Naval Res. Logist. 42 39–56	For most effective cost analysis on inventory management based on both periodic review policy and continuous review policy

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Chapter-3

THE DETAIL ANALYSIS ON THE BULL WHIP EFFECTS BASED ON SIMPLE EXPONENTIALLY SMOOTHED DEMAND FORECASTING WITHOUT AFFECTED BY TREND FACTOR

The basis of demand forecasting
The transfer function analysis
Frequency response analysis
Frequency response plot analysis by MATLAB
Research findings

CHAPTER – 3

THE DETAIL ANALYSIS ON THE BULL WHIP EFFECTS FOR DIFFERENT REPLENISHMENT POLICIES BASED ON SIMPLE EXPONENTIALLY SMOOTHED DEMAND FORECASTING WITHOUT AFFECTED BY TREND FACTOR

3.1 THE BASIS FOR DEMAND FORECASTING

For each of the rule, we have used common method of simple exponential smoothing to estimate a demand forecast for the next period, that is

$$\hat{D}_t = \hat{D}_{t-1} + \alpha.(D_t - \hat{D}_{t-1})$$

Where,

$\hat{D}_t$ = The demand forecast for the next period

$\hat{D}_{t-1}$ = The demand forecast made in the previous period

α = The demand forecast exponential smoothing parameter, which has major impact on the bullwhip effect

D_t = The observed customer demand from the previous period,

3.2 THE TRANSFER FUNCTION ANALYSIS:

3.2.1 THE TRANSFER FUNCTION ANALYSIS FOR FORECASTED DEMAND

$$\hat{D}_t = \hat{D}_{t-1} + \alpha.(D_t - \hat{D}_{t-1})$$

$$...... = \hat{D}_{t-1} + \alpha.D_t - \alpha.\hat{D}_{t-1}$$

$$...... = \alpha.D_t + (1-\alpha).\hat{D}_{t-1}$$

$$\Rightarrow \alpha.D_t = \hat{D}_t - (1-\alpha).\hat{D}_{t-1}$$

Treating the above equation as a linear difference equation of time , we have Z-Transform form of the above equation is as below

$$\alpha.D_z = \hat{D}_z - (1-\alpha).Z^{-1}.\hat{D}_z$$

$$\Rightarrow \alpha.D_z = [1-(1-\alpha).Z^{-1}].\hat{D}_z ---------------(0)$$

3.2.2 TRANSFER FUNCTION ANALYSIS FOR ORDER TO DEMAND RATIO FOR $(R, \hat{D})$ REPLENISHMENT POLICY:

For $(R, \hat{D})$ policy, we have, $O_t = \hat{D}_t \Rightarrow O_z = \hat{D}_z$

So, simply by replacing O

So, simply by replacing O_z by $\hat{D}_z$ in equation-(0) , We have transfer function for the $(R, \hat{D})$ replenishment policy as below

$$\alpha.D_z = [1-(1-\alpha).Z^{-1}].O_z$$

$$\Rightarrow \alpha.Z.D_z = [Z-(1-\alpha)].O_z$$

$$\Rightarrow \frac{O_z}{D_z} = \frac{\alpha.Z}{Z-(1-\alpha)} ---------------------(1)$$

3.2.3 TRANSFER FUNCTION ANALYSIS FOR ORDER TO DEMAND RATIO FOR $(R, \gamma O)$ REPLENISHMENT POLICY:

The equation to the replenishment policy is,

$$O_t = \hat{D}_t + (1-\gamma)(O_{t-1} - \hat{D}_t)$$

The Z-Transform form of the above equation is as below

$$O_z = \hat{D}_z + (1-\gamma).Z^{-1}.O_z - (1-\gamma).\hat{D}_z$$

$$\Rightarrow [1-(1-\gamma).Z^{-1}].O_z = [1-(1-\gamma)].\hat{D}_z$$

$$\Rightarrow \frac{Z-(1-\gamma)}{Z}.O_z = \gamma.\hat{D}_z$$

Now substituting the value of $\hat{D}_z$ from equation –(0), we have

$$\frac{Z-(1-\gamma)}{Z}.O_z = \gamma.\frac{\alpha.Z}{Z-(1-\alpha)}.D_z$$

$$\Rightarrow \frac{O_z}{D_z} = \frac{\alpha.\gamma.Z^2}{[Z-(1-\gamma)].[Z-(1-\alpha)]}$$

3.2.4 TRANSFER FUNCTION ANALYSIS FOR ORDER TO DEMAND RATIO FOR (R.S) REPLENISHMENT POLICY:

The equation to the replenishment policy is, $O_t = D_t + IP_t^T - IP_t$

Where, $IP_t \Rightarrow$ current inventory position

And, $IP_t^T \Rightarrow$ Target inventory position for the next period i.e Inventory position is forecasted for the next period and as already discussed, it represented by the equation as below

$$IP_t^T = \hat{D}_t.(1+T_L) + k.\hat{D}_t.\sqrt{1+T_L}$$

Now, if, IP_t^T is represented simply by IP_t, then the current inventory position must given by IP_{t-1}^T

So, the alternative forms of the above two equations are,

$$IP_t = \hat{D}_t.(1+T_L) + k.\hat{D}_t.\sqrt{1+T_L}$$

And, $$O_{t-1} = \hat{D}_{t-1} + IP_t - IP_{t-1}$$

The Z-Transform form of above two equations are as below

$$IP_z = [(1+T_L) + k.\sqrt{1+T_L}].\hat{D}_z$$

$$And......Z^{-1}.O_z = Z^{-1}.\hat{D}_z + IP_z - Z^{-1}.IP_z$$

$$\Rightarrow O_z = \hat{D}_z + Z.IP_z - IP_z$$

$$\Rightarrow O_z = \hat{D}_z + (Z-1).IP_z$$

$$\Rightarrow O_z = \hat{D}_z + (Z-1).[(1+T_L + k.\sqrt{1+T_L})].\hat{D}_z$$

$$\Rightarrow O_z = [1+(Z-1)(1+T_L + k.\sqrt{1+T_L})].\hat{D}_z$$

$$\Rightarrow O_z = [1+(Z-1)(1+T_L + k.\sqrt{1+T_L})].\frac{\alpha.Z}{Z-(1-\alpha)}.D_z$$

$$\Rightarrow O_z = \frac{\alpha.Z.[1+(Z-1)(1+T_L + k.\sqrt{1+T_L})]}{Z-(1-\alpha)}.D_z$$

$$\Rightarrow \frac{O_z}{D_z} = \frac{\alpha.(Z-1).(1+T_L + k.\sqrt{1+T_L})}{Z-(1-\alpha)} + 1$$

3.3 FREQUENCY RESPONSE ANALYSIS:

The frequency response analysis is obtained just by replacing ‘Z’ by ‘ω’ in the Z- transfer function, that is

if Z- transfer function is $G(z) = \frac{O_z}{D_z}$

Then, its amplitude frequency response will be, $M_z(\omega T) = \left|\frac{O_{i\omega t}}{D_{i\omega t}}\right| = G(\omega T)$

The frequency response plot gives the output-input amplitude change A_2/A_1 for sine waves of frequencies ‘ω’, ranging from ‘0 to π’ radians per sampling period ‘ T ’. Since the bullwhip effect can be defined as a variance amplification of orders over demand, the amplitude frequency response plot gives us the magnitude of the bullwhip effect for a sinusoidal demand patterns of frequencies w Î [0, π/T].

3.4 FREQUENCY RESPONSE PLOT ANALYSIS THROUGH MATLAB FOR ORDER TO DEMAND RATIO IN EACH OF THE REPLENISHMEN POLICIES:

3.4.1 FOR $(R,\hat{D})$ POLICY

The frequency response plots for different values of Alpha

The frequency response equation for the policy is

$$M(\omega T)=\left|\frac{O_{i\omega t}}{D_{i\omega t}}\right|=\left|\frac{\alpha.e^{i\omega t}}{e^{i\omega t}-(1-\alpha)}\right|$$

where, $Z=e^{i\omega t}$, t=1.0 , and α=0.1, 0.3, & 0.6

THE MATLAB PROGRAMES

```
 >> clc
>> clear all
>> alpha= ? ;
>> t=1.0;
>> n=1.0;
>> for w=0:0.1:15
z=exp(i*w*t);
M(n)=((alpha*z)/(z-1+alpha));
n=n+1;
end
>> M1=real(M);
>> M2=imag(M);
>> xind=0:0.1:15;
>> plot(xind,M1);
>> xlabel('w');
>> ylabel('M');
>> title('Fig. for R,D policy without trend & alpha= ? ');
>> axis([0 15 0 1.5])
```

THE PLOTS

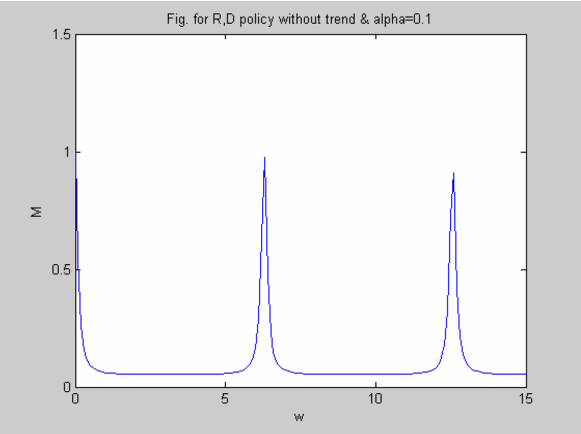

Fig. for R,D policy without trend & alpha=0.1

FIG- 3. 1. (i)

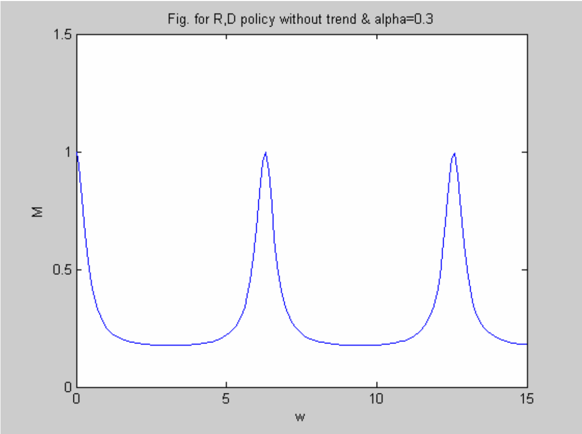

Fig. for R,D policy without trend & alpha=0.3

FIG- 3 1. (ii)

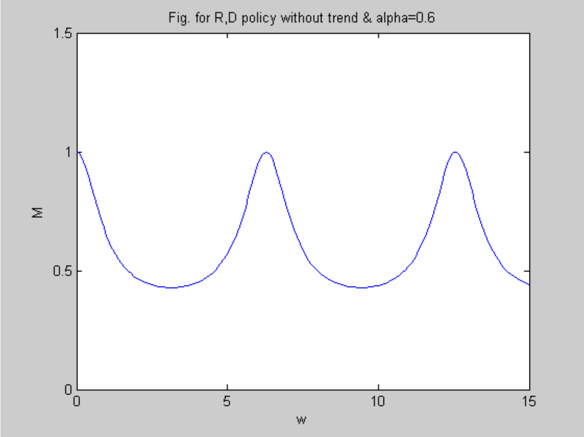

FIG- 3. 1. (iii)

Obviously Bull whip effect increases with the increase of Alpha

3.4.2.(i) FOR (R, γO) POLICY

The frequency response plots for different values of Alpha at constant value of Gamma

The frequency response equation for the policy is $M(\omega T) = \left| \frac{O_{i\omega t}}{D_{i\omega t}} \right|$,

where, $\frac{O_z}{D_z} = \frac{\alpha.\gamma.Z^2}{[Z-(1-\gamma)][Z-(1-\alpha)]}$, $Z = e^{i\omega t}$, t=1.0 , γ= 0.1,
and α=0.1, 0.3, & 0.6

THE MATLAB PROGRAMES

```
>> clc
>> clear all
>> alpha= ? ;
>> gamma= 0.1 ;
>> t=1.0;
>> n=1.0;
>> for w=0:0.1:15
z1=exp(i*2*w*t);
z=exp(i*w*t);
M(n)=((alpha*gamma*z1)/((z-1+gamma)*(z-1+alpha)));
n=n+1;
 end
 >> M1=real(M);
```

```
>> M2=imag(M);
>> x=0:0.1:15;
>> plot(x,M1);
>> xlabel('w');
>> ylabel('M=abs.Oz/Dz');
>> title(' FIG. for (R,YO) Policy without trend factor with alpha= ? ,
    gamma= 0.1, without trend factor’) ;
 >> axis([0 15 -0.2 1.2])
```

THE PLOTS

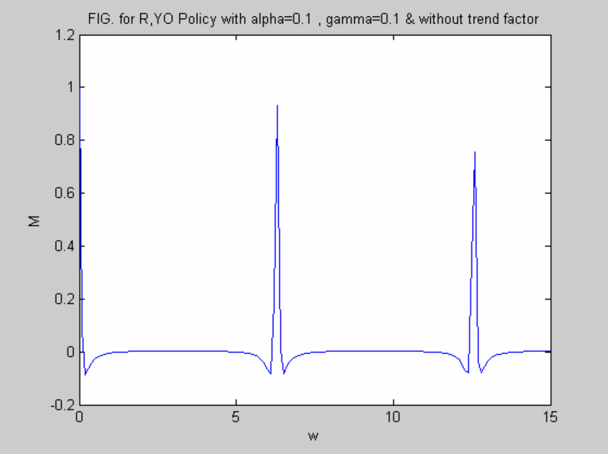

FIG- 3. 2. (i)

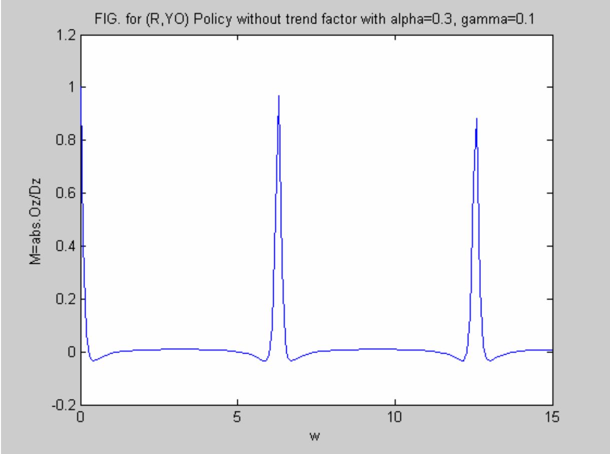

FIG- 3. 2. (ii)

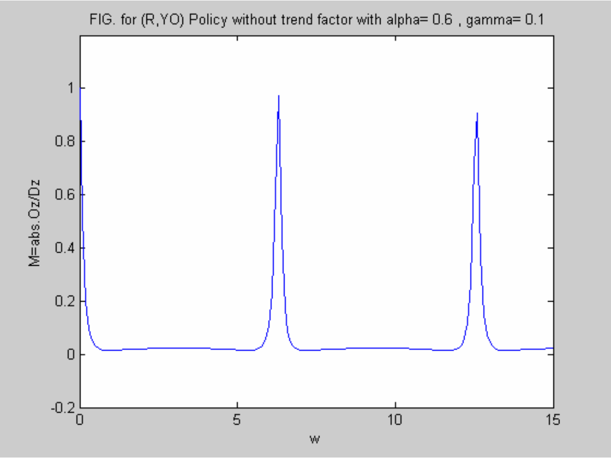

FIG- 3. 2. (iii)

Obviously Bull whip effect increases with the increase of Alpha at constant value of Gamma

3.4.2.(ii) FOR (R, YO) POLICY

The frequency response plots for different values of Gamma at constant value of Alpha

The frequency response equation for the policy is $M(\omega T) = \left|\frac{O_{i\omega t}}{D_{i\omega t}}\right|$

where, $\frac{O_z}{D_z} = \frac{\alpha.\gamma.Z^2}{[Z-(1-\gamma)][Z-(1-\alpha)]}$, $Z = e^{i\omega t}$, t=1.0 , α=0.1

and γ= 0.1, 0.3, & 0.6

THE MATLAB PROGRAMES

```
>> clc
```

```
>> clear all
>> alpha= 0.1 ;
>> gamma= ? ;
>> t=1.0;
>> n=1.0;
>> for w=0:0.1:15
z1=exp(i*2*w*t);
z=exp(i*w*t);
M(n)=((alpha*gamma*z1)/((z-1+gamma)*(z-1+alpha)));
n=n+1;
 end
 >> M1=real(M);
 >> M2=imag(M);
 >> x=0:0.1:15;
 >> plot(x,M1);
 >> xlabel('w');
 >> ylabel('M=abs.Oz/Dz');
 >> title(' FIG. for (R,YO) Policy without trend factor with alpha= ? ,
     gamma= 0.1, without trend factor') ;
  >> axis([0 15 -0.2 1.2])
```

THE PLOTS

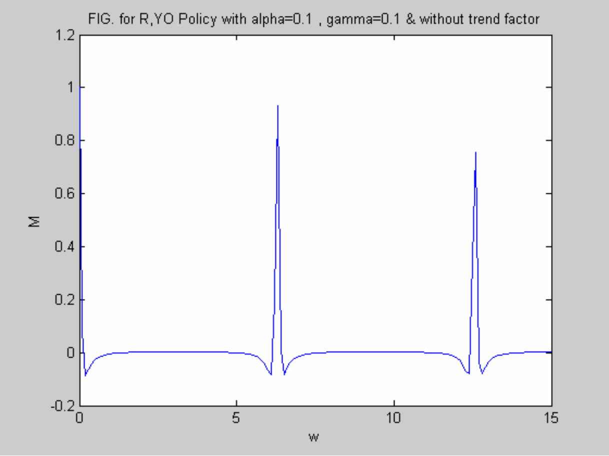

FIG- 3. 3. (i)

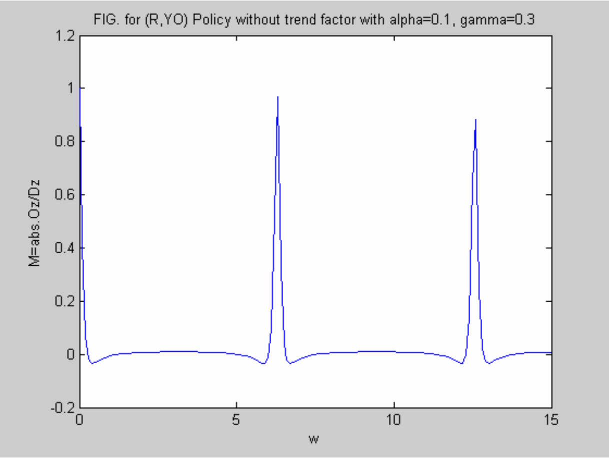

FIG- 3. 3. (ii)

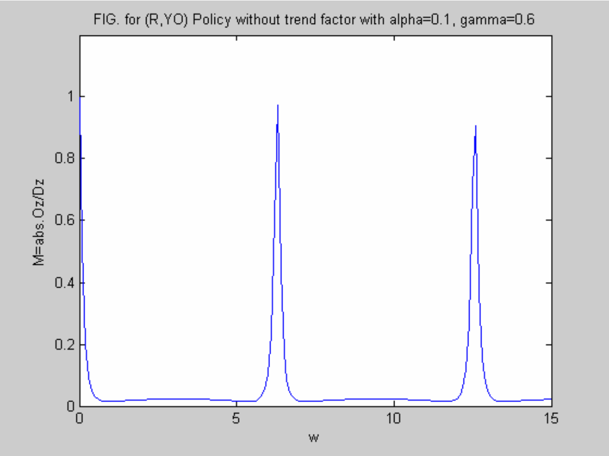

FIG- 3. 3. (iii)

Obviously Bull whip effect increases with the increase of Gamma at constant value of Alpha

3.4.3.(i) THE PLOTS FOR (R.S) POLICY

The frequency response plots for different values of Alpha at constant value of lead Time

The frequency response equation for the policy is $M(\omega T) = \left|\frac{O_{i\omega t}}{D_{i\omega t}}\right|$

where, $\frac{O_z}{D_z} = \frac{\alpha(Z-1)(1+T_L+k\sqrt{1+T_L})}{Z-(1-\alpha)} + 1$, $Z = e^{i\omega t}$, t=1.0, k=0.5 ,

T_L=2.0 , and α=0.1, 0.3, & 0.6

THE MATLAB PROGRAMES

```
 >> clc
 >> clear all
 >> alpha= ? ;
 >> L= 2.0 ;
 >> k=0.5;
 >> t=1.0;
 >> n=1.0;
 >> for w=0:0.1:15
 z=exp(i*w*t);
M(n)=(((1+L+k*(sqrt(1+L)))*alpha*(z-1))/(z-1+alpha))+1;
 n=n+1;
 end
 >> M1=real(M);
 >> M2=imag(M);
 >> x=0:0.1:15;
 >> plot(x,M1);
 >> xlabel('w');
 >> ylabel('M=abs.Oz/Dz');
 >> title(' FIG. for (R,S) Policy without trend factor with alpha=0.3 ,
           Lead  Time=2.0 &    Constant K=0.5 ');
 >> axis([0 15 1 3.5])
```

THE PLOTS

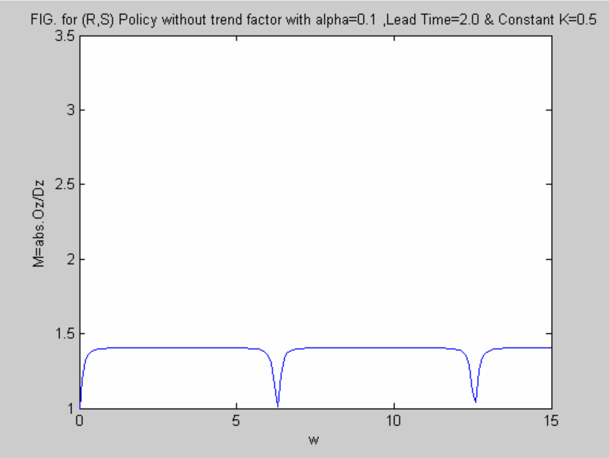
FIG. for (R,S) Policy without trend factor with alpha=0.1 ,Lead Time=2.0 & Constant K=0.5

FIG- 3. 4. (i)

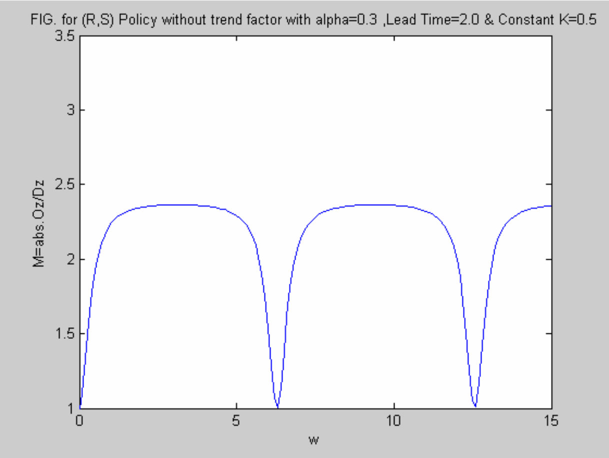
FIG. for (R,S) Policy without trend factor with alpha=0.3 ,Lead Time=2.0 & Constant K=0.5

FIG- 3. 4. (ii)

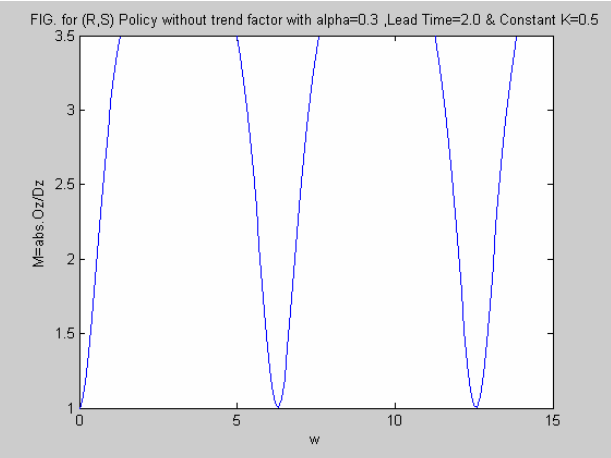
FIG. for (R,S) Policy without trend factor with alpha=0.3 ,Lead Time=2.0 & Constant K=0.5

FIG- 3. 4. (iii)

Obviously for (R, S) policy Bull whip effect also increases with the increase of Alpha at constant value of Lead Time

3.4.3.(ii) THE PLOTS FOR (R.S) POLICY

The frequency response plots for different values of lead Time at constant value of Alpha

The frequency response equation for the policy is $M(\omega T) = \left|\dfrac{O_{i\omega t}}{D_{i\omega t}}\right|$

where, $\dfrac{O_z}{D_z} = \dfrac{\alpha(Z-1)(1+T_L+k\sqrt{1+T_L})}{Z-(1-\alpha)} + 1, Z = e^{i\omega t}$, t=1.0, k=0.5
α=0.1, and T_L=2.0 , 4.0 , 6.0 ,

THE MATLAB PROGRAMES

```
        >> clc
       >> clear all
       >> alpha= ? ;
       >> L= 2.0 ;
       >> k=0.5;
      >> t=1.0;
      >> n=1.0;
      >> for w=0:0.1:15
      z=exp(i*w*t);
  M(n)=(((1+L+k*(sqrt(1+L)))*alpha*(z-1))/(z-1+alpha))+1;
     n=n+1;
      end
    >> M1=real(M);
    >> M2=imag(M);
    >> x=0:0.1:15;
    >> plot(x,M1);
   >> xlabel('w');
   >> ylabel('M=abs.Oz/Dz');
   >> title(' FIG. for (R,S) Policy without trend factor with alpha=0.3 ,
         Lead Time=2.0 &    Constant K=0.5 ');
   >> axis([0 15 1 3.5])
```

THE PLOTS

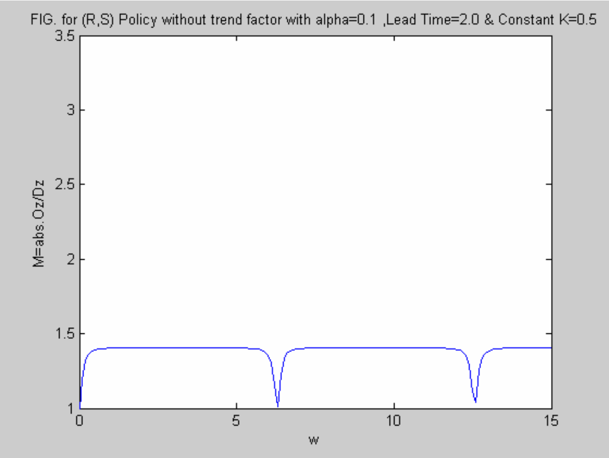
FIG. for (R,S) Policy without trend factor with alpha=0.1 ,Lead Time=2.0 & Constant K=0.5

FIG- 3. 5. (i)

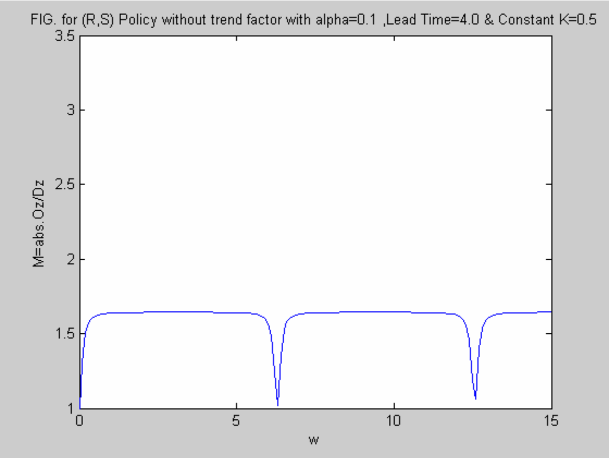
FIG. for (R,S) Policy without trend factor with alpha=0.1 ,Lead Time=4.0 & Constant K=0.5

FIG- 3. 5. (ii)

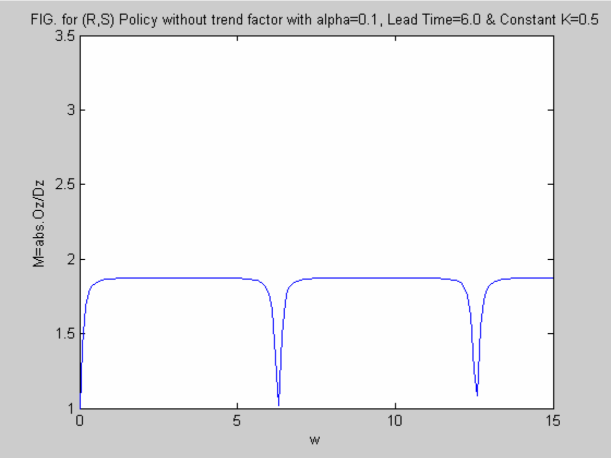
FIG. for (R,S) Policy without trend factor with alpha=0.1, Lead Time=6.0 & Constant K=0.5

FIG- 3. 5. (iii)

Obviously Bull Whip effect increases with the increase of lead Time at constant value of Alpha

3.5 COMPARISON OF BULL WHIP EFFECTS IN $(R,\hat{D})$, (R,YO), AND (R,S)

REPLENISHMENT POLICIES BASED ON SIMPL EXPONENTIAL DEMAND FORECASTING WITHOUT AFFECTED BY TREND FACTOR

The plots below show the variations of order to demand ratio in $(R,\hat{D})$, (R,YO), and (R,S) replenishment policies within the certain frequency level for α=0.3, γ=0.5 , k=0.5, and T_L=2.0 without the effect of trend factor and seasonal factor, from which the extents of bull whip effect in the three said policies can be easily distinguished

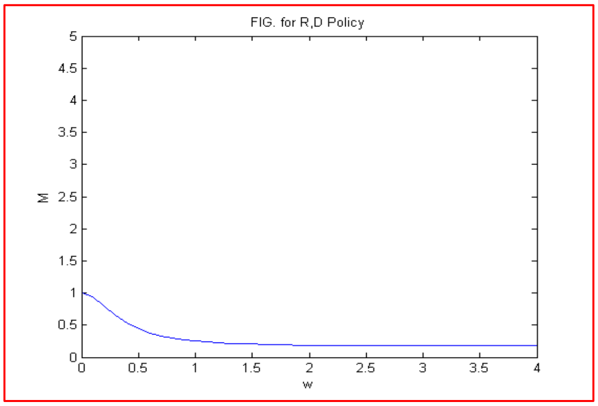

FIG- 3. 6. (i)
specially for the (R ,D) policy

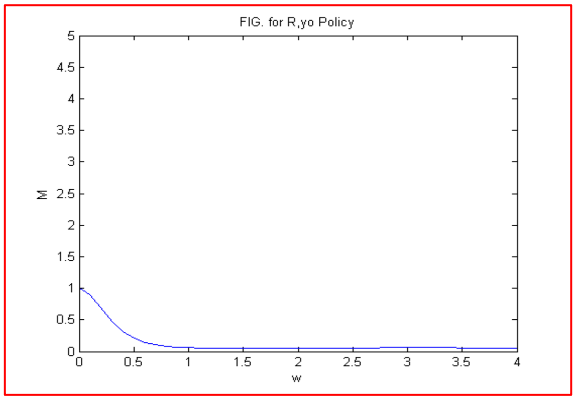

FIG- 3. 6. (ii)
specially for the (R ,γO) policy

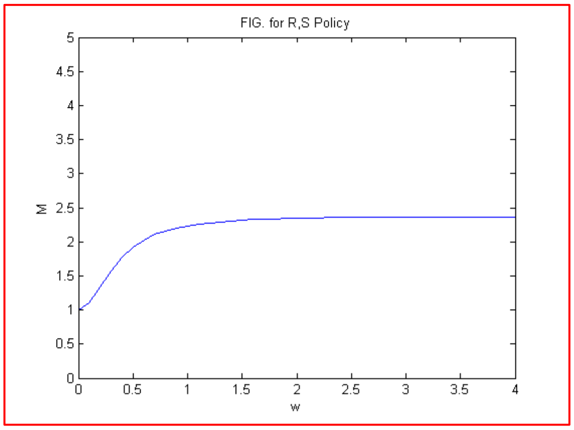

FIG- 3. 6. (iii)
specially for the (R ,S) policy

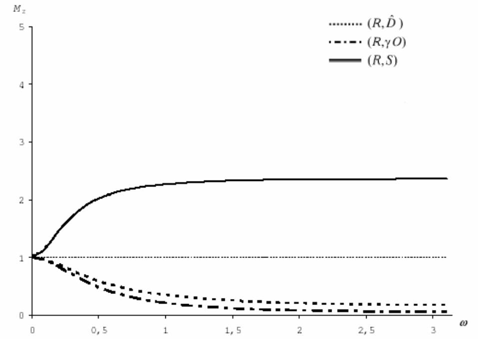

Figure 3. The frequency response plot for the replenishment rules analysed (α= 0.3, γ=0.5, T_L=2, k=0.5).

FIG- 3. 6. (iv)
combined plots for (R ,D) , (R ,γO) ,& (R ,S) policies

3.6 CAUSE OF SO VARIATION OF BULLWHIP EFFECT :

Our conclusion regarding the cause of So variation in order w.r.t demand and the concerned bullwhip effect corresponding to each of the three polices { $(R, \hat{D})$, $(R, O\gamma)$,and (R, S) } which are extensively studied by us till now are as blow

FOR $(R, \hat{D})$ AND $(R, O\gamma)$ POLICIES:

The equations to the replenishment policies are

$O_t = \hat{D}_t$ ----------------- for $(R, \hat{D})$ policy

$O_t = \hat{D}_t + (1-\gamma)(O_{t-1} - \hat{D}_t)$ ------ for $(R, O\gamma)$ policy

Where, $\hat{D}_t = \hat{D}_{t-1} + \alpha.(D_t - \hat{D}_{t-1})$ for both the policies

Through transfer function analysis we showed that there is no bullwhip effect if we use $(R, \hat{D})$ or $(R, O\gamma)$ replenishment policy. On the contrary, they both tend to lower the amplification of the orders over the demand. Order quantity in $(R, \hat{D})$ policy equals the forecast demand $\hat{D}$ for the next period;

This means that the policy response to the change in actual demand D_t will always be smaller because of the demand forecast smoothing α. With $(R, O\gamma)$) policy we have another contribution to bullwhip reduction through order quantity smoothing γ. If we are experiencing a rise in demand, a smaller rise in forecast demand, as in $(R, \hat{D})$ policy, follows.

There is also a negative contribution due to the misalignment between the last placed order Quantity O_{t-1} and the demand forecast , which additionally lowers the change in order quantity O_t .Consequently, the variability of orders is even lower.

FOR (R.S) POLICY, OR ORDER-UP-TO-LEVEL POLICY :

The equation to the replenishment policy is $O_{t-1} = D_{t-1} + IP_t - IP_{t-1}$

Where, $\hat{D}_t = \hat{D}_{t-1} + \alpha.(D_t - \hat{D}_{t-1})$

we showed that we can expect the bullwhip effect to occur. If we want to explore the causes for variance amplification we must take a closer look at the dynamics of the replenishment systems analyzed. The original Bowman's $(R, \gamma O, \beta IP)$ rule as shown below

$$O_t = \hat{D}_t + (1-\gamma)(O_{t-1} - \hat{D}_t) + \beta.(IP_t^T - IP_t)$$

consists of three parts. The first two - demand forecast and order quantity smoothing α and γ are clearly not the generators of increased variance, as was demonstrated in the analysis of $(R, \hat{D})$ and $(R, O\gamma)$ policies. So let us look closer at the third part: inventory position smoothing β. For (R, S) policy β=1 and the policy equation is

$$O_{t-1} = D_{t-1} + IP_t - IP_{t-1}$$

So, when we place a new order O_t, order-up-to-level is corrected based on forecast demand. Order quantity O_t is now determined by adding the extent of misalignment between the current inventory position and the target inventory position . We have already said the target inventory position reflects our future demand expectations over a lead time [since $IP_t^T = \hat{D}_t.(R + T_L) + k.\hat{D}_t.\sqrt{R + T_L}$]

The longer the lead time , further into the future our expectations are projected. Let us say that we observe a rise in demand. Accordingly, we forecast the future demand using simple exponential smoothing [$\hat{D}_t = \hat{D}_{t-1} + \alpha.(D_t - \hat{D}_{t-1})$] nonetheless. This rise in forecast will not be considered only in the next period, but will be projected over the whole of the lead time through the correction of the target inventory position

[since, $IP_t^T = \hat{D}_t.(R + T_L) + k.\hat{D}_t.\sqrt{R + T_L}$]. The tendency of rising demand will be considered over a proportionally longer time period (the review interval 'R" plus the production delay due to lead time T_L. In the case of long lead times , even minor changes in end-consumer demand can result in a much higher target inventory position IP_t^T

The extent of misalignment $[IP_t^T - IP_t]$ between the current inventory position and the target inventory position will be greater and consequently the order quantity will be proportionally higher.

If a drop in demand occurs in the next period, our reaction will again be exaggerated and will show in the excessive decrease in order quantity. This, of course, leads to high variance amplification - the bullwhip effect. This was the reason that inventory position smoothing is introduced into the original Bowman's rule

$$O_t = \hat{D}_t + (1-\gamma)(O_{t-1} - \hat{D}_t) + \beta.(IP_t^T - IP_t)$$

With the choice of low inventory position smoothing parameter β values, we do not take into account the misalignment between the current inventory position and the target inventory position to the full extent. As a result we effectively shorten the time over which we project our expectations about future demand. Changing expectations will be therefore reflected over a shorter period of time, which will result in bullwhip reduction.

We are going to confirm this fact after deriving the transfer function and drawing the frequency response plots for the other two policies[such as $(R, \beta IP)$) and $(R, \gamma O, \beta IP)$ which are left to be researched latter on. Choosing low β value must lead to bullwhip effect elimination. In the extreme case of β =0, the expectations are projected only over the review interval, which means the current demand forecast will be relevant only until the time of the next ordering decision.

Chapter-4

THE DETAIL ANALYSIS ON THE BULL WHIP EFFECTS BASED ON SIMPLE EXPONENTIALLY SMOOTHED DEMAND FORECASTING BEING AFFECTED BY TREND FACTOR

The basis of demand forecasting
The transfer function analysis
Frequency response analysis
Frequency response plot analysis by MATLAB
Research findings

CHAPTER – 4

THE DETAIL ANALYSIS ON THE BULL WHIP EFFECTS FOR DIFFERENT REPLENISHMENT POLICIES BASED ON SIMPLE EXPONENTIALLY SMOOTHED DEMAND FORECASTING BEING AFFECTED BY TREND FACTOR

4.1 THE BASIS FOR DEMAND FORECASTING

For each of the rule, we have used common method of simple exponential smoothing to estimate a demand forecast for the next period, that is

$$\hat{D}_t = \alpha.D_t + (1-\alpha).\hat{D}_{t-1} + \phi.(\hat{D}_{t-1} - \hat{D}_{t-2})$$

Where, Φ = The Trend Factor and in most cases its value is taken = 1 - α

$\hat{D}_t$ = The demand forecast for the next period

$\hat{D}_{t-1}$ = The demand forecast made in the previous period

α = The demand forecast exponential smoothing parameter, which has major impact on the bullwhip effect

D_t = The observed customer demand from the previous period,

4.2 THE TRANSFER FUNCTION ANALYSIS:

4.2.1 TRANSFER FUNCTION ANALYSIS FOR FORECASTED DEMAND:

As discussed above, the equation representing the forecasted demand is

$$\hat{D}_t = \alpha.D_t + (1-\alpha).\hat{D}_{t-1} + \phi.(\hat{D}_{t-1} - \hat{D}_{t-2}).. ------(0)$$

Treating the above equation as a linear difference equation of time, we have Z-Transform form of the above equation is as belo

$$.....\hat{D}_z = \alpha.D_z + (1-\alpha).z^{-1}.\hat{D}_z + \phi.(z^{-1}.\hat{D}_z - z^{-2}.\hat{D}_z)$$

$$\Rightarrow \hat{D}_z = \alpha.D_z + \frac{1-\alpha}{z}.\hat{D}_z + \phi.\left(\frac{\hat{D}_z}{z} - \frac{\hat{D}_z}{z^2}\right)$$

$$\Rightarrow z^2.\hat{D}_z = \alpha.z^2.D_z + \hat{D}_z.z.(1-\alpha) + \phi.(z.\hat{D}_z - \hat{D}_z)$$

$$\Rightarrow \left\{z^2 - z.(1-\alpha) - \phi.(z-1)\right\}.\hat{D}_z = \alpha.z^2.D_z$$

$$\Rightarrow \hat{D}_z = \frac{\alpha.z^2}{z^2 - z.(1-\alpha) - \phi.(z-1)} \times D_z .. ------- (0)$$

4.2.2 TRANSFER FUNCTION ANALYSIS FOR ORDER TO DEMAND RATIO IN $(R, \hat{D})$ REPLENISHMENT POLICY<u>:</u>

For $(R, \hat{D})$ policy, we have, $O_t = \hat{D}_t \Rightarrow O_z = \hat{D}_z$

So, simply by replacing O$_z$ by $\hat{D}_z$ in equation-(0) , We have transfer function for the $(R, \hat{D})$ replenishment policy as below

$$......O_z = \frac{\alpha.z^2}{z^2 - z.(1-\alpha) - \phi.(z-1)} \times D_z$$

$$\Rightarrow \frac{O_z}{D_z} = \frac{\alpha.z^2}{z^2 - z.(1-\alpha) - \phi.(z-1)} .. ------------- (1)$$

4.2.3 THE TRANSFER FUNCTION ANALYSIS FOR ORDER TO DEMAND RATIO IN $(R, \gamma O)$ REPLENISHMENT POLICY<u>:</u>

The equation to the replenishment policy is,

$$O_t = \hat{D}_t + (1-\gamma)(O_{t-1} - \hat{D}_t)$$

The Z-Transform form of the above equation is as below

$$O_z = \hat{D}_z + (1-\gamma).Z^{-1}.O_z - (1-\gamma).\hat{D}_z$$

$$\Rightarrow [1-(1-\gamma).Z^{-1}].O_z = [1-(1-\gamma)].\hat{D}_z$$

$$\Rightarrow \frac{Z-(1-\gamma)}{Z}.O_z = \gamma.\hat{D}_z$$

Now substituting the value of $\hat{D}_z$ from equation –(0), we have

$$\frac{Z-(1-\gamma)}{Z}.O_z = \gamma.\frac{\alpha.Z^2}{Z^2 - Z.(1-\alpha) - \phi.(Z-1)}.D_z$$

$$\Rightarrow \frac{O_z}{D_z} = \frac{\alpha.\gamma.z^3}{[Z^2 - Z.(1-\alpha) - \phi.(Z-1)]}$$

4.2.4 THETRANSFER FUNCTION ANALYSIS FOR ORDER TO DEMAND RATIO IN (R.S) REPLENISHMENT POLICY:

The equation to the replenishment policy is, $O_t = D_t + IP_t^T - IP_t$

Where, $IP_t \Rightarrow$ current inventory position

And, $IP_t^T \Rightarrow$ Target inventory position for the next period i.e Inventory position is forecasted for the next period and as already discussed, it represented by the equation as below

$$IP_t^T = \hat{D}_t.(1+T_L) + k.\hat{D}_t.\sqrt{1+T_L}$$

Now, if, IP_t^T is represented simply by IP_t, then the current inventory position must given by IP_{t-1}^T

So, the alternative forms of the above two equations are,

$$IP_t = \hat{D}_t.(1+T_L) + k.\hat{D}_t.\sqrt{1+T_L}$$

And, $$O_{t-1} = \hat{D}_{t-1} + IP_t - IP_{t-1}$$

The Z-Transform form of above two equations are as below

$$IP_z = [(1+T_L) + k.\sqrt{1+T_L}].\hat{D}_z$$

$$And......Z^{-1}.O_z = Z^{-1}.\hat{D}_z + IP_z - Z^{-1}.IP_z$$

$$\Rightarrow O_z = \hat{D}_z + Z.IP_z - IP_z$$

$$\Rightarrow O_z = \hat{D}_z + (Z-1).IP_z$$

$$\Rightarrow O_z = \hat{D}_z + (Z-1).[(1+T_L + k.\sqrt{1+T_L})].\hat{D}_z$$

$$\Rightarrow O_z = [1+(Z-1)(1+T_L + k.\sqrt{1+T_L})].\hat{D}_z$$

$$\Rightarrow O_z = \left\{1+(Z-1).\left(1+T_L + K.\sqrt{1+T_L}\right)\right\}.\frac{\alpha.Z^2}{Z^2 - Z.(1-\alpha) - \phi.(Z-1)} \times D_z$$

$$\Rightarrow O_z = \left\{\frac{\alpha.Z}{Z^2 - Z.(1-\alpha) - \phi.(Z-1)} + \frac{(Z-1).(1+T_L + K\sqrt{1+T_L})}{Z^2 - Z.(1-\alpha) - \phi.(Z-1)}\right\}.D_z$$

$$\Rightarrow \frac{O_z}{D_z} = \left\{\frac{\alpha.(Z-1).\left(1+T_L + K.\sqrt{1+T_L}\right)}{Z^2 - Z.(1-\alpha) - \phi.(Z-1)} + 1\right\} \times Z \times D_z$$

$$\Rightarrow \frac{O_z}{D_z} = \frac{\alpha.Z.(Z-1).\left(1+T_l + k.\sqrt{1+T_L}\right)}{Z^2 - Z.(1-\alpha) - \phi.(Z-1)} + Z$$

4.3 THE FREQUENCY RESPONSE ANALYSIS:

The frequency response analysis is obtained just by replacing ‘Z’ by ‘ω’ in the Z- transfer function, that is

if Z- transfer function is $G(z) = \frac{O_z}{D_z}$

Then, its amplitude frequency response will be, $M_z(\omega T) = \left|\frac{O_{i\omega t}}{D_{i\omega t}}\right| = G(\omega T)$

The frequency response plot gives the output-input amplitude change A_2/A_1 for sine waves of frequencies ‘ω’, ranging from ‘0 to π’ radians per sampling period ‘ T ’. Since the bullwhip effect can be defined as a variance amplification of orders over demand, the amplitude frequency response plot gives us the magnitude of the bullwhip effect for a sinusoidal demand patterns of frequencies w Î [0, π/T].

4.4 FREQUENCY RESPONSE PLOT ANALYSIS THROUGH MATLAB FOR ORDER TO DEMAND RATIO IN EACH OF THE REPLENISHMENT POLICIES:

4.4.1.(i) FOR $(R,\hat{D})$ POLICY

The frequency response plots for different values of Alpha at constant trend

The policy equation is $M(\omega T) = \left|\frac{O_{i\omega t}}{D_{i\omega t}}\right| = \left|\frac{\alpha.Z^{2}}{Z^{2}-(1-\alpha).Z-(Z-1).\phi}\right|$

where, $Z = e^{i\omega t}$, t=1.0, Φ=0.1, and α=0.1, 0.3, & 0.6

THE MATLAB PROGRAMES

```
>> clc
>> clear all
>> alpha= ?;
>> phi= 0.1 ;
>> t=1.0;
>> n=1.0;
>> for w=0:0.1:15
z1=exp(i*w*t);
z2=exp(2*i*w*t);
M(n)=((alpha*z2)/(z2-(1-alpha)*z1-phi*(z1-1)));
 n=n+1;
 end
 >> M1=real(M);
 >> M2=imag(M);
 >> x=0:0.1:15;
 >> plot(x,M1);
 >> Title('FIG.For (R,D) Policy with alpha= ? & trend factor(phi)=0.1');
 >> xlabel=('w');
 >> ylabel('M=abs.Oz/Dz');
 >>
```

THE PLOTS

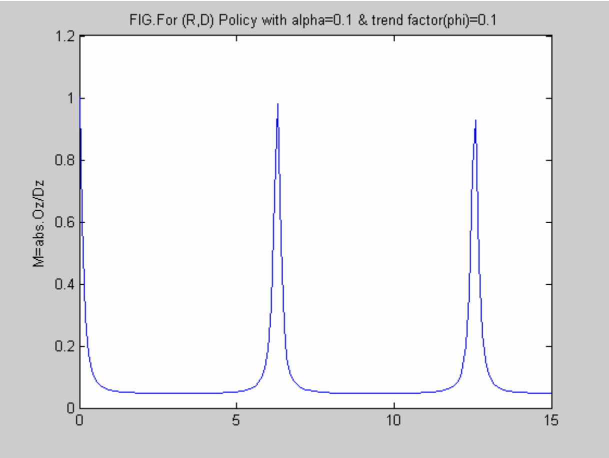

FIG- 4 .1 . (i)

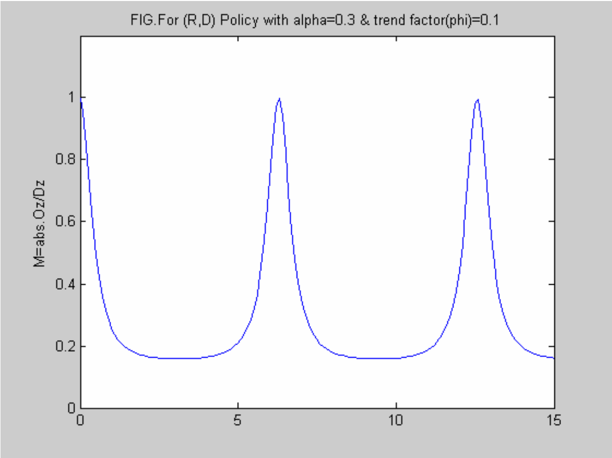

FIG- 4 .1 . (ii)

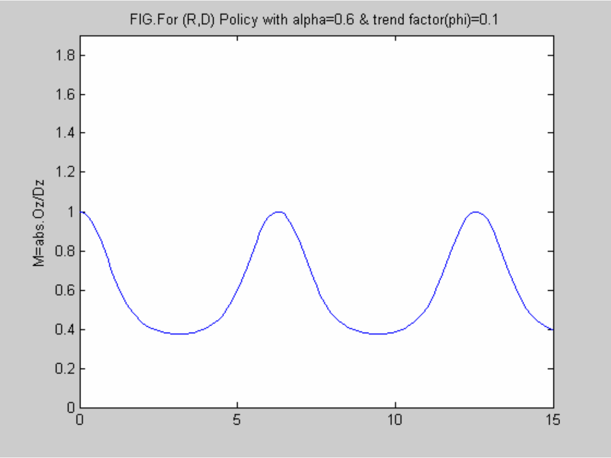

FIG- 4 .1 . (iii)

Obviously BHE increases with the increase of α at constant Φ

4.4.1.(ii) FOR $(R,\hat{D})$ POLICY

The frequency response plots for different values of trend factor Φ at constant α

The policy equation is $M(\omega T) = \left|\dfrac{O_{i\omega t}}{D_{i\omega t}}\right| = \left|\dfrac{\alpha.Z^2}{Z^2-(1-\alpha).Z-(Z-1).\phi}\right|$

where, $Z = e^{i\omega t}$, t=1.0, Φ=0.1, and α=0.1, 0.3, & 0.6

THE MATLAB PROGRAMES

```
>> clc
>> clear all
>> alpha= 0.3;
>> phi= ? ;
>> t=1.0;
>> n=1.0;
>> for w=0:0.1:15
z1=exp(i*w*t);
z2=exp(2*i*w*t);
M(n)=((alpha*z2)/(z2-(1-alpha)*z1-phi*(z1-1)));
n=n+1;
end
>> M1=real(M);
>> M2=imag(M);
>> x=0:0.1:15;
>> plot(x,M1);
>> Title('FIG.For (R,D) Policy with alpha=0.3 & trend factor(phi)= ? ');
>> xlabel=('w');
>> ylabel('M=abs.Oz/Dz');
>>
```

THE PLOTS

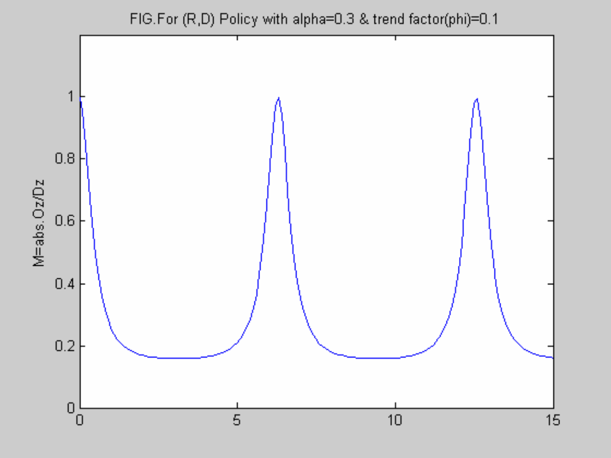

FIG- 4. 2. (i)

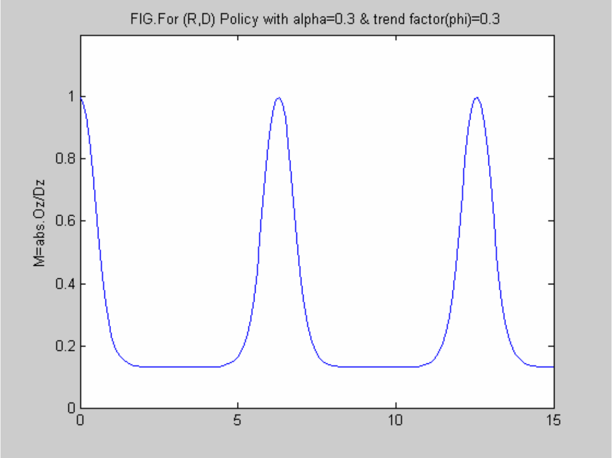

FIG- 4 .2 . (ii)

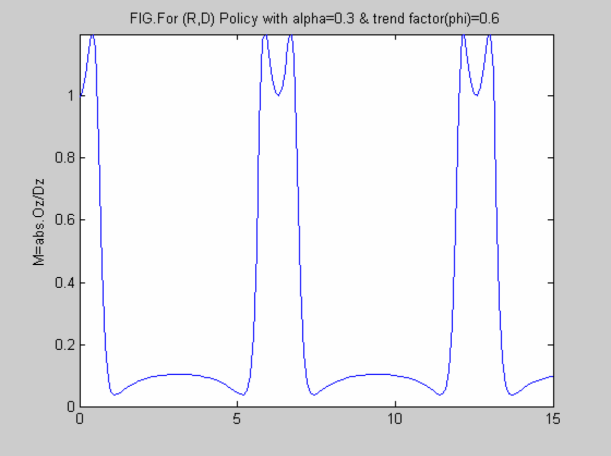

FIG- 4 . 2 . (iii)

Obviously BHE decreases with the increase of Φ at constant α

4.4.2.(i) FOR $(R,\gamma O)$ POLICY

The frequency response plots for different values of α at constant Y and Φ

The policy equation is $M(\omega T)=\left|\frac{O_{i\omega t}}{D_{i\omega t}}\right|=\left|\frac{\gamma.\alpha.Z^2}{Z^2-(1-\alpha).Z-(Z-1).\phi}\right|$

where, $Z=e^{i\omega t}$, t=1.0, Y=0.3, Φ=0.3, and α=0.1, 0.3, & 0.6

THE MATLAB PROGRAMES

```
>> clc
>> clear all
>> alpha=0.3;
>> gamma=0.1;
>> phi=0.1;
>> t=1.0;
>> n=1.0;
>> for w=0:0.1:15
z1=exp(i*w*t);
z2=exp(2*i*w*t);
z3=exp(3*i*w*t);
M(n)=((alpha*gamma*z3)/(z2-(1-alpha)*z1-phi*(z1-1)));
n=n+1;
end
>> M1=real(M);
>> M2=imag(M);
>> x=0:0.1:15;
>> plot(x,M1);
>> xlabel=('w');
>> ylabel('M=abs.Oz/Dz');
>> Title('FIG.For (R,YO) Policy with alpha= ?, & gamma=0.3 & trend
            factor(phi)=0.3');
>> axis([0 15 -.02 1.2])
>>
```

THE PLOTS

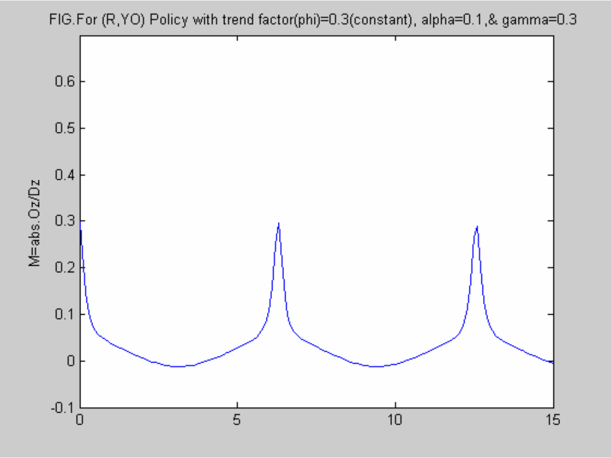

FIG- 4. 3. (i)

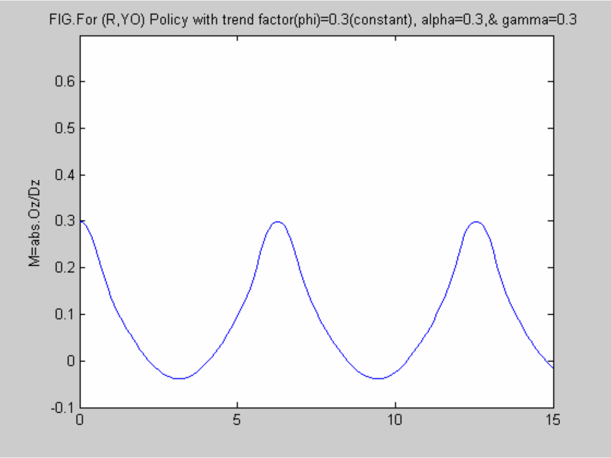

FIG- 4. 3. (ii)

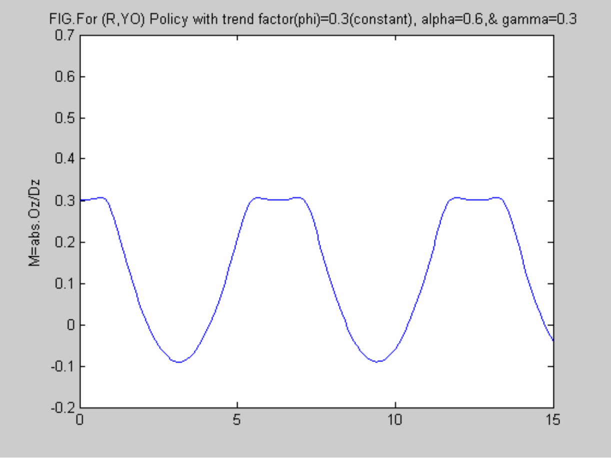

FIG- 4. 3. (iii)

Obviously BHE decreases with the increase of α at constant values of Y & Φ

4.4.2.(ii) FOR $(R, \gamma O)$ POLICY

The frequency response plots for different values of Y at constant α and Φ

The policy equation is $M(\omega T) = \left|\frac{O_{i\omega t}}{D_{i\omega t}}\right| = \left|\frac{\gamma.\alpha.Z^2}{Z^2 - (1-\alpha).Z - (Z-1).\phi}\right|$

where, $Z = e^{i\omega t}$, t=1.0, α=0.3, Φ=0.3, and Y= 0.1, 0.3, & 0.6

THE MATLAB PROGRAMES

```
 >> clc
>> clear all
>> alpha=0.3;
>> gamma=?;
>> phi=0.3;
>> t=1.0;
>> n=1.0;
>> for w=0:0.1:15
z1=exp(i*w*t);
z2=exp(2*i*w*t);
z3=exp(3*i*w*t);
M(n)=((alpha*gamma*z3)/(z2-(1-alpha)*z1-phi*(z1-1)));
n=n+1;
end
>> M1=real(M);
>> M2=imag(M);
>> x=0:0.1:15;
>> plot(x,M1);
>> xlabel=('w');
>> ylabel('M=abs.Oz/Dz');
>> Title('FIG.For (R,YO) Policy with alpha= ?, & gamma=0.3 & trend
            factor(phi)=0.3');
>> axis([0 15 -.02 1.2])
>>
```

THE PLOTS

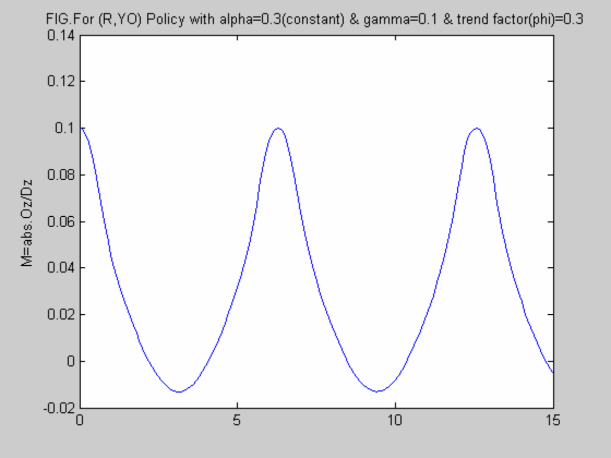

FIG- 4. 4. (i)

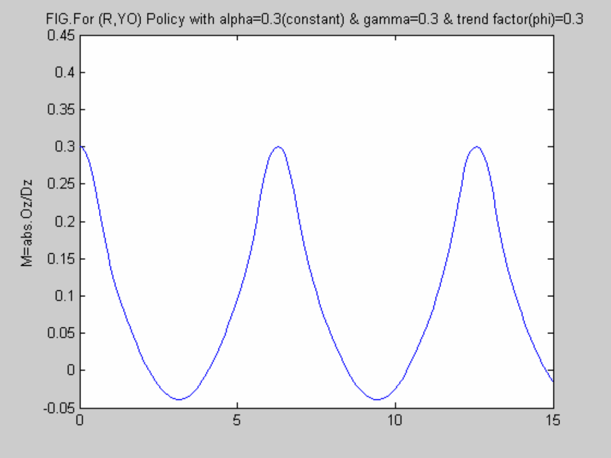

FIG- 4. 4. (ii)

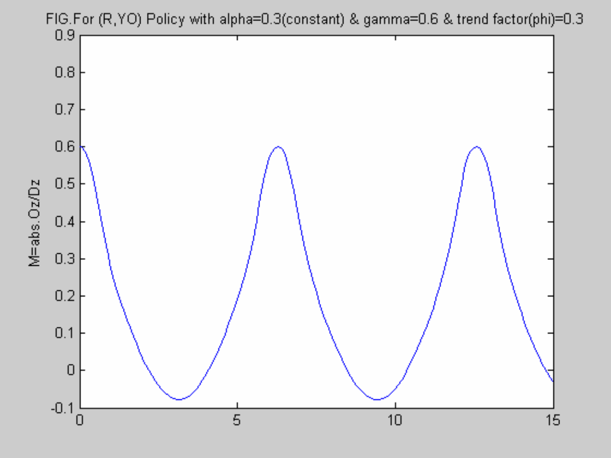

FIG- 4. 4. (iii)

Obviously BHE decreases with the increase of Y at constant values of α & Φ

4.4.2.(iii) FOR $(R,\gamma O)$ POLICY

The frequency response plots for different values of Φ

at constant Y and α

The policy equation is $M(\omega T) = \left|\frac{O_{i\omega t}}{D_{i\omega t}}\right| = \left|\frac{\gamma.\alpha.Z^2}{Z^2-(1-\alpha).Z-(Z-1).\phi}\right|$

where, $Z = e^{i\omega t}$, t=1.0, α=0.3, Y= 0.3, and Φ=0.1, 0.3, & 0.6

THE MATLAB PROGRAMES

```
 >> clc
>> clear all
>> alpha=0.3;
>> gamma=?;
>> phi=0.3;
>> t=1.0;
>> n=1.0;
>> for w=0:0.1:15
z1=exp(i*w*t);
z2=exp(2*i*w*t);
z3=exp(3*i*w*t);
M(n)=((alpha*gamma*z3)/(z2-(1-alpha)*z1-phi*(z1-1)));
n=n+1;
end
>> M1=real(M);
>> M2=imag(M);
>> x=0:0.1:15;
>> plot(x,M1);
>> xlabel=('w');
>> ylabel('M=abs.Oz/Dz');
>> Title('FIG.For (R,YO) Policy with alpha= ?, & gamma=0.3 & trend
              factor(phi)=0.3');
>> axis([0 15 -.02 1.2])
>>
```

THE PLOTS

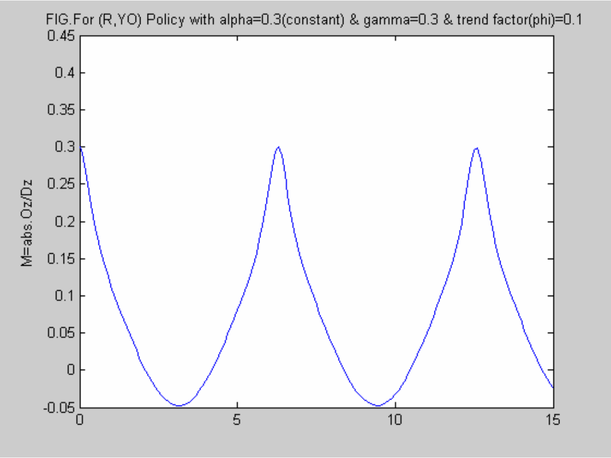

FIG- 4. 5. (i)

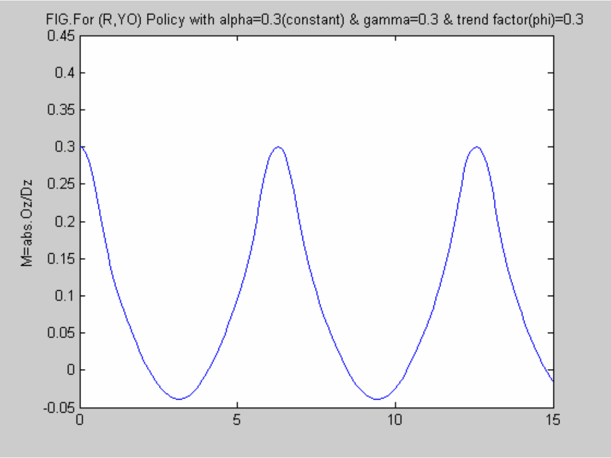

FIG- 4. 5. (ii)

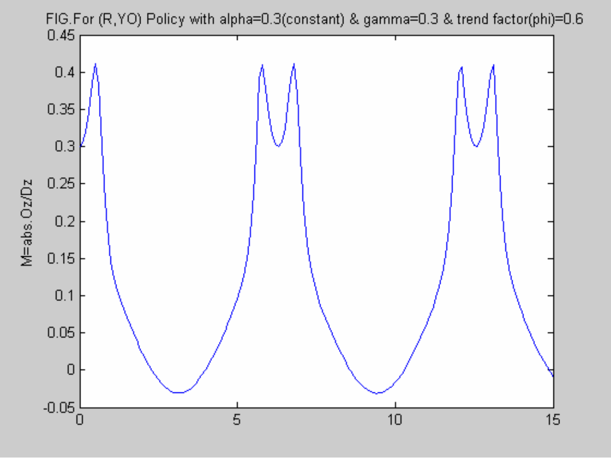

FIG- 4. 5. (iii)

Obviously BHE increases with the increase of Φ at constant values of α & Y

4.4.3.(i) FOR (R, S) POLICY

The frequency response plots for different values of α at constant Φ and T_L, the lead time

The policy equation is $\frac{O_z}{D_z} = \frac{\alpha.Z.(Z-1)(1+L+k\sqrt{1+L})}{Z^2-(1-\alpha).Z-\phi.(Z-1)} + Z$,

where, $Z = e^{i\omega t}$, t=1.0, Φ=0.3, T_L= 2.0, and α= 0.1, 0.3, & 0.6

<u>THE MATLAB PROGRAMES</u>

```
 >> clc
>> clear all
>> phi=0.3;
>> L=2.0;
 >> alpha=?;
 >> k=0.5;
 >> t=1.0;
 >> n=1.0;
 >> for w=0:0.1:15
 z1=exp(i*w*t);
 z2=exp(2*i*w*t);
 M(n)=((alpha*z1*(z1-1)*(1+L+k*sqrt(1+L)))/(z2-(1-alpha)*z1-phi*(z1-1)))+z1;
 n=n+1;
 end
 >> M1=real(M);
 >> M2=imag(M);
 >> x=0:0.1:15;
 >> plot(x,M1);
 >> xlabel=('w');
 >> ylabel('M=abs.Oz/Dz');
 >> Title('FIG.For (R,S) Policy with trend factor(phi)=0.3(constant), L=2.0
          & alpha=? ');
>> axis([0 15 0.0 4.0])
>> axis([0 15 0.0 4.5])
>>
```

THE PLOTS

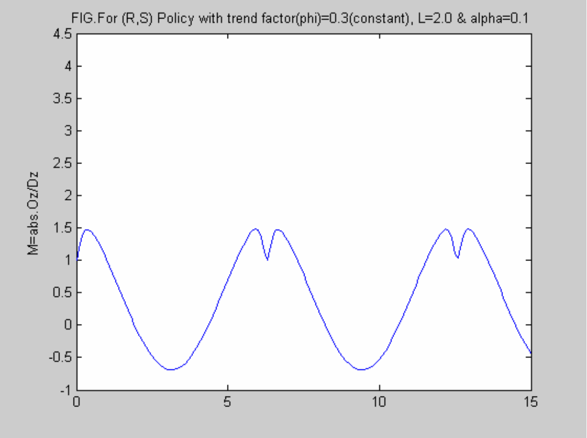

FIG- 4. 6. (i)

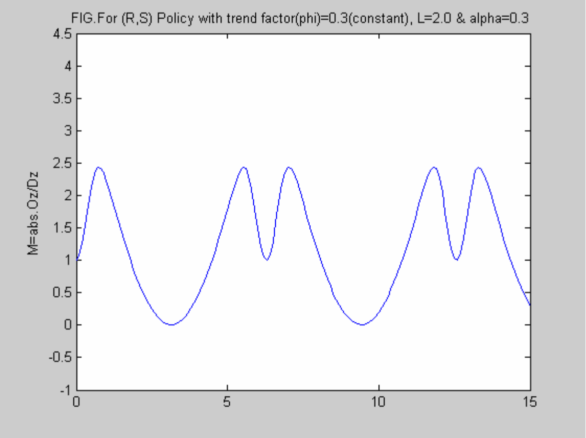

FIG- 4. 6. (ii)

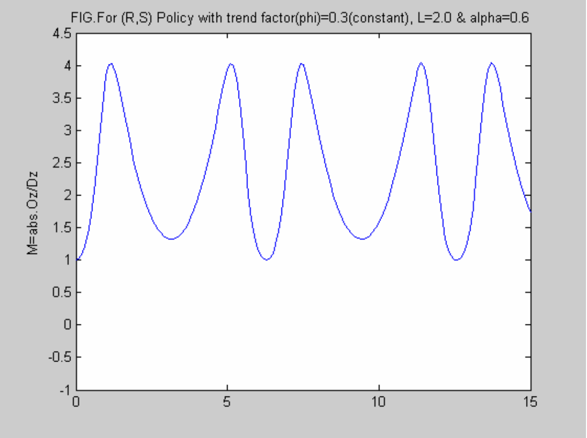

FIG- 4. 6. (iii)

Obviously BHE increases with the increase of α at constant values of Φ & T_L

4.4.3.(ii) FOR (R, S) POLICY

The frequency response plots for different values of T_L , the lead time at constant Φ and α

The policy equation is $\frac{O_z}{D_z} = \frac{\alpha.Z.(Z-1)(1+L+k\sqrt{1+L})}{Z^2-(1-\alpha).Z-\phi.(Z-1)} + Z$,

where, $Z = e^{i\omega t}$, t=1.0, Φ=0.3, α= 0.3 , and T_L= 2.0 & 4.0

THE MATLAB PROGRAMES

```
 >> clc
>> clear all
>> phi=0.3;
>> L=?;
 >> alpha=0.3;
 >> k=0.5;
 >> t=1.0;
 >> n=1.0;
 >> for w=0:0.1:15
 z1=exp(i*w*t);
 z2=exp(2*i*w*t);
 M(n)=((alpha*z1*(z1-1)*(1+L+k*sqrt(1+L)))/(z2-(1-alpha)*z1-phi*(z1-1)))+z1;
 n=n+1;
 end
 >> M1=real(M);
 >> M2=imag(M);
 >> x=0:0.1:15;
 >> plot(x,M1);
 >> xlabel=('w');
 >> ylabel('M=abs.Oz/Dz');
 >> Title('FIG.For (R,S) Policy with trend factor(phi)=0.3(constant), L=2.0
          & alpha=? ');
>> axis([0 15 0.0 4.0])
>> axis([0 15 0.0 4.5])
>>
```

THE PLOTS

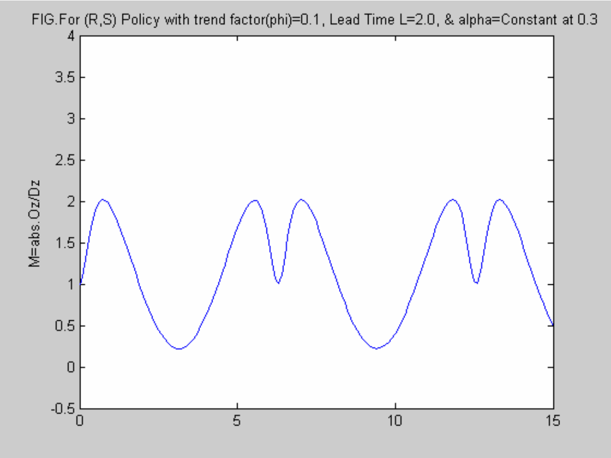

FIG- 4. 7. (i)

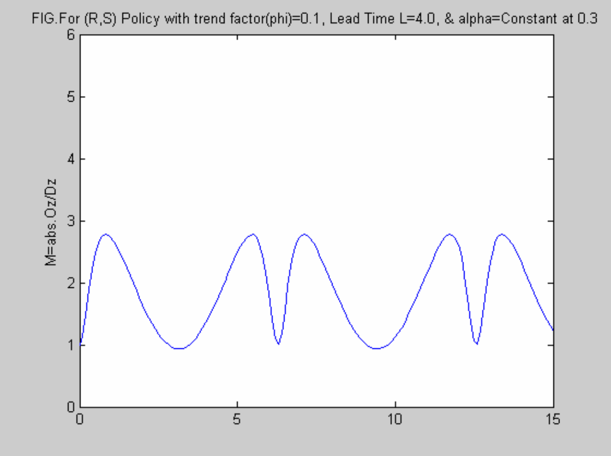

FIG- 4. 7. (ii)

Obviously BHE increases with the increase of T_L at constant values of Φ & α

4.4.3.(iii) FOR (R,S) POLICY

The frequency response plots for different values of Φ at constant α , and T_L , the lead time

The policy equation is $\frac{O_z}{D_z} = \frac{\alpha.Z.(Z-1)(1+L+k\sqrt{1+L})}{Z^2-(1-\alpha).Z-\phi.(Z-1)} + Z$,

where, $Z = e^{i\omega t}$, t=1.0, Φ=0.3, α= 0.3 , and T_L= 2.0 & 4.0

THE MATLAB PROGRAMES

```
 >> clc
>> clear all
>> phi=?;
>> L=2.0;
 >> alpha=0.3;
 >> k=0.5;
 >> t=1.0;
 >> n=1.0;
 >> for w=0:0.1:15
 z1=exp(i*w*t);
 z2=exp(2*i*w*t);
 M(n)=((alpha*z1*(z1-1)*(1+L+k*sqrt(1+L)))/(z2-(1-alpha)*z1-phi*(z1-1)))+z1;
 n=n+1;
 end
 >> M1=real(M);
 >> M2=imag(M);
 >> x=0:0.1:15;
 >> plot(x,M1);
 >> xlabel=('w');
 >> ylabel('M=abs.Oz/Dz');
 >> Title('FIG.For (R,S) Policy with trend factor(phi)=0.3(constant), L=2.0
            & alpha=? ');
>> axis([0 15 0.0 4.0])
>> axis([0 15 0.0 4.5])
>>
```

THE PLOTS

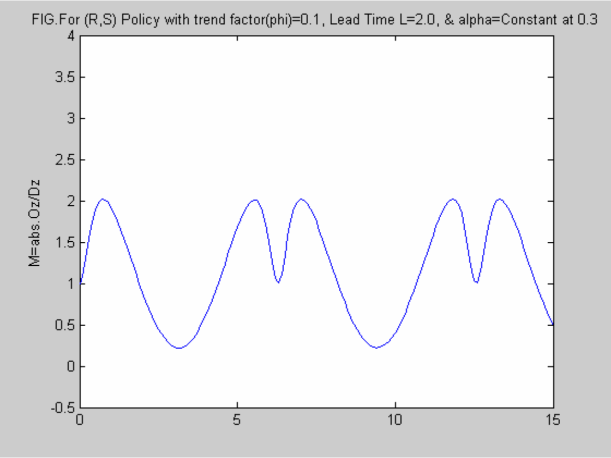

FIG- 4. 8. (i)

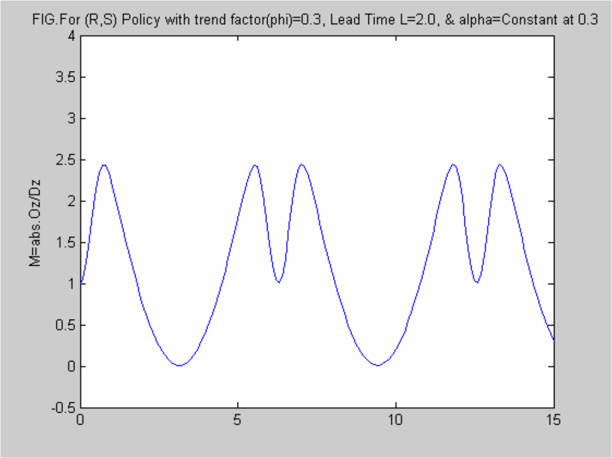

FIG- 4. 8. (ii)

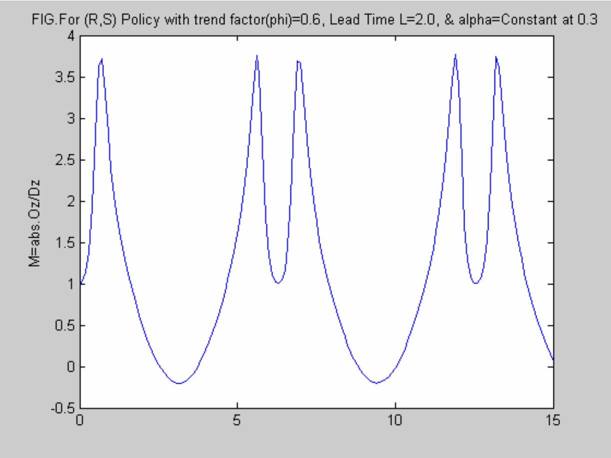

FIG- 4. 8. (iii)

Obviously BHE decreases with the increase of Φ at constant values of T_L & α

4.5 COMPARISON OF BULL WHIP EFFECTS IN $(R,\hat{D})$, (R,YO), AND (R,S) REPLENISHMENT POLICIES BASED ON SIMPLE EXPONENTIALLY SMOOTHED DEMAND FORECASTING BEING AFFECTED BY TREND FACTOR

The plots below show the variations of order to demand ratio in $(R,\hat{D})$, (R,YO), and (R,S) replenishment policies within the certain frequency level for α=0.3, γ=0.5 , k=0.5, Φ=0.7 and T_L=2.0 , from which the extents of bull whip effect in the three said policies can be easily distinguished

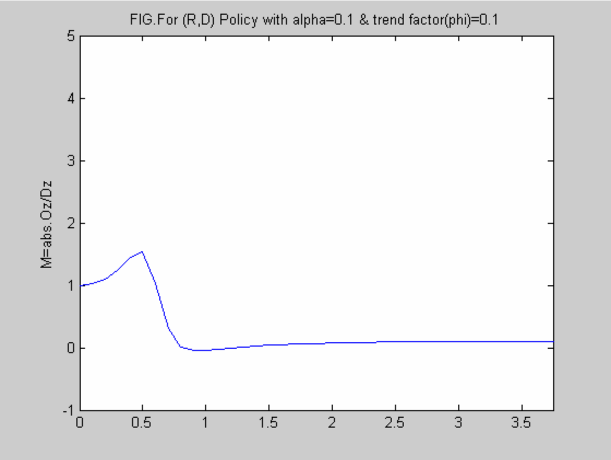

FIG- 4. 9. (i)

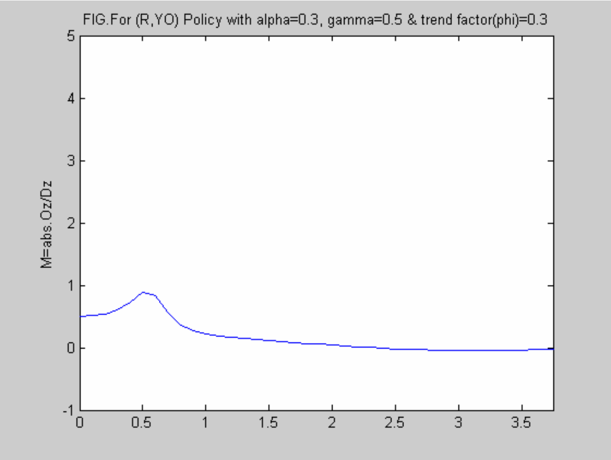

FIG- 4. 9. (ii)

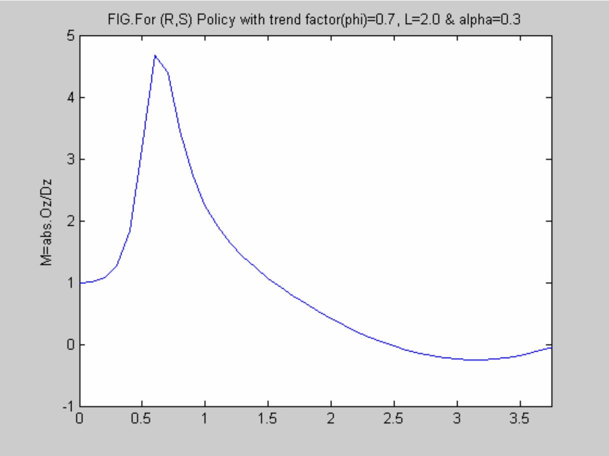

FIG- 4. 9. (iii)

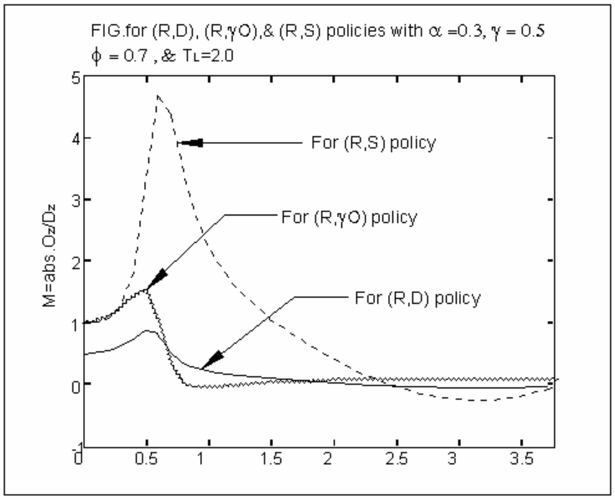

FIG- 4. 9. (iv)

RESULT DISCUSSION AND IMPLICATION TO MANAGERS

FOR BOTH THE CASES WHEN THE SAID DEMAND FORECASTING IS BEING AFFECTED BY AND NOT

AFFECTED BY TREND FACTOR

The conclusion that replenishment policy is the generator of bullwhip effect and corresponding recommendation for industrial application

RESULT DISCUSSION AND IMPLICATION TO MANAGERS

Our research findings concludes replenishment policy as a generator of the bullwhip effects and accordingly we suggest following recommendation for industrial application as discussed below:

1) FOR SIMPLE EXPONENTIALLY SMOOTHED DEMAND FORECASTING WITHOUT AFFECTED BY TREND FACTOR:

From **FIG- 3. 6,** we find that

For demand forecasting, we have $\hat{D}_t = \hat{D}_{t-1} + \alpha.(D_t - \hat{D}_{t-1})$

or $(R, \hat{D})$ policy, we have, $O_t = \hat{D}_t$

For $(R, \gamma O)$ policy, we have, $O_t = \hat{D}_t + (1-\gamma)(O_{t-1} - \hat{D}_t)$

For (R, S) policy , we have, $O_{t-1} = D_{t-1} + IP_t - IP_{t-1}$

This imply that

Bullwhip effect for (R.S) **policy > that for** $(R, \hat{D})$ **policy > that for** $(R, \gamma O)$ **policy.**

However,

as referring to previous works [16-Lit. Rev] the total cost (total variable cost + total fixed cost)

for (R.S) **policy < that for** $(R,\hat{D})$ **policy < that for** $(R,\gamma O)$ **policy**, **and that is why the said (R,S) policy has been the well known order-up-tolevel policy , and is mostly adopted in many industry**

Thus, (R,S) policy has the lowest total costs, while the costs for $(R,\hat{D})$ and $(R,\gamma O)$ policies are the highest. But, our research proves the opposite effect for the bullwhip effect, which is higher for policies with lower total costs. The opposite is true because, increase in supply chain variability leads to inefficiencies and high costs.

Based on this, the recommendation for choosing the appropriate replenishment rule depends on whether the benefits of the bullwhip effect reduction outweigh the higher inventory management costs. In companies where high variability of orders results in high costs (**either due to high ordering or production switching costs**), the reduction in bullwhip effect can lead to significant cost savings. Such companies should consider implementing a replenishment policy such as $(R,\hat{D})$ or $(R,O\gamma)$ policy. The company that wants to be highly responsive and for which an increase in variability does not incur high costs, would best use the order-up-to-level policy i.e (R, S) policy.

2) FOR SIMPLE EXPONENTIALLY SMOOTHED DEMAND FORECASTING BEING AFFECTED BY TREND FACTOR:

Referring to **FIG- 4. 9,** we find that

- BHE for all the three policies first increase up to a review frequency of 0.5, and after that decrease. However, that for (R, S) policy continuously decrease up to a review frequency of 3.0, and then decrease, whereas, those for $(R,\hat{D})$ & (R,YO) policies don't continuously decrease but become constant after a review frequency of near about 1.5.
- Maximum BHE for all the three policies occur at lower review frequency i.e 0.5, where, maximum BHE for (R,S) policy is much higher than that for

(R, YO) policy, and maximum BHE for (R, YO) policy is slightly larger than that for $(R, \hat{D})$ policy.

- Minimum BHE for (R,S) policy, which occurs at higher review frequency (i.e 3.0) is smaller than the corresponding BHE for $(R, \hat{D})$ & (R, YO) policies at same review frequency
- Most manufacturer adopt (R,S) policy since, it incurs lowest fixed cost and variable cost. However, our finding suggests that the manufacturer adopting this policy, must do so only at higher review frequency levels, so that they can also simultaneously decrease the BHE. On the other hand, increasing review frequency will increase the fixed cost and variable cost slightly larger, however, the benefits due to decrease in BHE may be more advantageous than the corresponding increase of fixed and variable cost

Future Scopes

Work left incompleted due to lack of time

FUTURE SCOPES

Due to availability limited time, following works could not be completed in time, and are now left as future works. They are as below

- Analysis on Bull Whip Effects for other two policies $(R, \beta IP)$, and $(R, \gamma O, \beta IP)$ based on simple exponentially smoothed demand forecasting not being affected by trend factor and seasonal factor
- Analysis on Bull Whip Effects for other two policies $(R, \beta IP)$, and $(R, \gamma O, \beta IP)$ based on simple exponentially smoothed demand forecasting being affected by trend factor but not seasonal factor

- Analysis on Bull Whip Effects for all the five policies $(R, \hat{D})$, $(R, O\gamma)$, (R, S) $(R, \beta IP)$ and $(R, \gamma O, \beta IP)$ based on the effect of seasonal factor and not being affected by trend factor

- Analysis on Bull whip effects for all the above said five policies based on simultaneous effects of both seasonal factor and trend factor

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