STUDY OF INVENTORY MODELS IN SUPPLY CHAIN MANAGEMENT

THESIS

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by

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Dedicated

to

all my Teachers, Mentors and Family members

who have always been a constant source of motivation

DECLARATION

I hereby declare that this thesis entitled **"STUDY OF INVENTORY MODELS IN SUPPLY CHAIN MANAGEMENT"** is being submitted in fulfilment of the requirement for the award of Degree of Doctor of Philosophy in the **DEPARTMENT OF MATHEMATICS** under **Faculty of Sciences of J.C. Bose University of Science and Technology, YMCA Faridabad**. It is a bona fide record of my original work carried out during 2012-2019 under guidance and supervision of **Dr. Neetu Gupta, Associate Professor, Department of Mathematics, J.C. Bose University of Science and Technology, YMCA, Faridabad.**

I further declare that the thesis does not contain any part of work which has been submitted for the award of any degree either in this university or any other university.

JYOTI

Registration Number: YMCAUST/Ph10/2011

CERTIFICATE

This is to certify that the thesis entitled **"STUDY OF INVENTORY MODELS IN SUPPLY CHAIN MANAGEMENT",** submitted in fulfilment of the requirement for the award of Degree of Doctor of Philosophy in the **DEPARTMENT OF MATHEMATICS** under **Faculty of Sciences of J.C. Bose University of Science and Technology, YMCA Faridabad**, is a bona fide record of work carried out during 2012-2019 under my guidance and supervision.

To the best of my knowledge, the work carried out by her is original in nature and has not been submitted for the award of any degree either in this university or any other university.

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ABSTRACT

Inventory management is a critical function of supply chain management. Ineffective management of inventory can lead to high costs, wastage of materials, reduced profit margins, and poor customer services. Given this challenge, inventory management has been considered as an optimization problem in many existing studies. Multiple strategies and models have been evaluated by researchers for achieving an optimum inventory management strategy. Some of the examples are: collaborative planning and replenishment, vendor-managed inventory (VMI), quick response, and economic order quantity modeling. This research is about selection and pilot testing of an optimal inventory management strategy for an auto parts manufacturer in North India. After literature review and analysis, it was found that VMI is a suitable inventory management strategy when the demands are stochastic and there are supply chain uncertainties. VMI was chosen as the appropriate strategy for the auto parts manufacturer. However, VMI is a complex strategy that can be implemented through multiple models. The models were studied, and an initial structural construct was formulated. Further, this research evolved a model of VMI implementation through three techniques linked in series: interpretive structural modeling, graph theory, and Markov Chain analysis using Monte Carlo approximation and Gibbs sampling provided the VMI strategy is built upon a number of overlapping variables on an infinite time series.

The interpretive structural modeling was the first technique to evolve the VMI performance variables (measures) using a qualitative approach taking help from supply chain professionals interviewed in the selected auto parts manufacturing company in North India. This technique helped in creating a chain of variables and also categorizing them as independent, dependent, linkage, and autonomous. The next step conducted was graph theory in which, quantitative values were assigned to the variables using a multi-level scale and formation of diagraphs. This step further categorized the variables as decisive, operative, and budgeting variables. Both these techniques resulted in high weightings for supply chain cost reduction (under various heads), customer service performance, and predictive analytics by gaining real time visibility into the supply chain events. These variables were used to design the pilot testing at the auto parts

manufacturer. The supply chain costs were divided into two broad heads: transportation costs and materials handling costs. The most crucial variable for customer service performance was timely delivery. Hence, lead time was chosen as the variable to be measured. Having these variables selected, it was found that the manufacturer does not have existing systems for real time visibility into the supply chain. Hence, a Markov Chain modeling method using Monte Carlo approximation and Gibbs sampling was designed to conduct predictive analytics of VMI performance. In this method, the variables were measured for 18 months out of which, nine months were prior to introduction of VMI and nine months were after introduction of VMI. To keep the pilot study simple, supply of only one product code supplied by a manufacturer (outsourced manufacturer) was converted into VMI model. The variables measured were considered as overlapping on an infinite time series (as per Monte Carlo approximation with Gibbs sampling). An internal variable in SAP software, called inventory performance index, was selected as the final indicator. The Pearson correlation coefficients between the performance measures and the inventory performance index of the product code (measured monthly) were taken as transition probabilities (as per recommendations in Monte Carlo approximation with Gibbs sampling).

A total of 16 present states of the four VMI performance variables were estimated every month ($2^4 = 16$) and 12 transition probabilities of the inventory performance index of the product code were estimated monthly. Based on the current state of the four variables, the next states of transition probabilities of the inventory performance index were estimated using a transition probability matrix. This process continued every month with an updated table of current states (as the correlation coefficients changes when the time series progresses by one month). This approach was suggested as the final model for VMI performance estimation as this research found VMI to be effective only through active monitoring and control of its most influencing variables. After introduction of VMI, the time series will witness a "cooling period" during which, the VMI performance will be subjected to intermittent shocks. During the cooling period, the inventory manager has to remain alert about the next state of transition probabilities of the inventory performance index, and undertake quick corrective actions. After the cooling period, the inventory manager may focus more on medium and long-term results only. Currently, it is difficult to estimate how long will be the cooling period. The future researchers are recommended to convert this model to multi-products and including higher number of variables. The future researchers may like to estimate a consolidated inventory performance index of multiple products through more complex Markov Chain or any other modeling.

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LIST OF ABBREVIATIONS

EOQ - Economic order quantity

MRP - Manufacturer resource planning

SCM - Supply Chain Management

VMI - Vendor Managed Inventory

JIT - Just in time

OEM - Original Equipment Manufacturer

TPM - Total Predictive Maintenance

RM - Reachability Matrix

SSIM - Structural Self Interaction Matrix

FRM - Final Reachability Matrix

BOV - Benefits of Vendor Managed Inventory

IPI - Inventory Performance Index

MHC - Materials Handling Cost

COTC - Cost of the components

LDT - Lead Time

ISM - Interpretive Structural Modelling

TQM - Total Quality Management

BPR - Business Process Engineering

SPQ - Standard Package Quantity

EPQ - Economic Production Quantity

JELS - Joint Economic Lot Sizing

1. INTRODUCTION

The chapter includes Background, terms and models of inventory management. The most reliable and successful inventory management techniques are also presented. A detailed literature review and explanation of Inventory management techniques and models is also presented, thesis organization and methods adopted for further study is also discussed.

1.1 BACKGROUND

Inventory Management comes to picture as soon as we explore the term inventory. Inventory is an essential element of Supply Chain Management and there is no possibility that this can be reduced to zero, so every company strives hard to reduce the level of inventories in order to reduce the costs. The companies in the present world of Globalization use various inventory management techniques to reduce the inventory size. In this chapter, we explained every term related to inventory management, role and responsibility of inventory management, the models used in inventory management and the techniques used for inventory management. We focused on the most used inventory management technique in industry i.e. Vendor Managed inventory. Vendor Managed Inventory started in 1980's and gave a new concept of direct refill of inventory. Researchers have different opinions regarding Vendor Managed Inventory. Its adoption in many industries have proved its need, still there is scope for improving and deriving the benefits. The last section gives us direction for further research.

1.1.2 INVENTORY MANAGEMENT

The term Inventory can be related to any business big or small. This can be exactly described in words by these definitions.

According to Cambridge dictionary, "*Inventory is a detailed list of all the things in a place*".

Another definition says, "*A complete listing of merchandise or stock on hand, work in progress, raw materials, finished goods on hand etc.*" [1]

The definition available on Wikipedia is, "*Inventory is the goods and materials that a business holds for ultimate goal of resale*".

Another source states that, "*Inventory often called merchandise, refers to goods and materials that a business holds for sale to customers in the near future*". [2]

Each definition uses the word materials and things, so in our term we define, "Inventory is a detailed list of all the goods and materials that a company/business holds with the ultimate goal of sale and profit". [1]

The growing market is demanding, so developing countries are also facing the issues related to inventory. Inventory needs to be managed at every step in order to avoid overstocking of goods and shortage of products to customers. Inventory needs to be maintained in a manner that it does not add to the costs of organization in the last fifteen years, large business units started using inventory management techniques for obtaining maximum profits as the sourcing now expanded globally. [3]
The term Inventory Management can be understood by going through these definitions:
According to one definition,
"*It is the process of monitoring of inventory or stored goods. It is an essential component of supply chain management. It monitors the flow of goods from manufacturer to warehouse and then to the point of sale*" [4].

Inventory management can also be defined as,
"*A business process which is responsible for managing, storing, moving, arranging, counting and maintaining of inventory*" [3].

According to the business dictionary, [5].
"*Activities employed for maintaining optimum number or amount of each inventory item. The main goal is to give continuous flow of produced goods, sales and customer satisfaction at minimum costs"*

Inventory management has many major responsibilities to avoid stock out situations [1] and come over the Bull whip effect [2]as there is a huge cost involved in management of inventory. The management /supervising team has to maintain coordination between the manufacturer, warehouse location and market expectations. The next section will help us understand everything about Inventory Management in detail.

1.1.2 COSTS INVOLVED IN INVENTORY MANAGEMENT:

For better understanding of management of inventory, it is important understand the various costs involved in the process:

1. **Invested Capital cost:**

   For setting up any business, a huge capital cost is required and the invested capital cost is the cost we incur over this huge amount e.g. interest to bank on huge capital investment. This is a major component of cost invested by any business.

2. **Storage Cost:**

   For storing the goods at various stages, proper storage conditions are required to preserve them e.g. metal parts need to be preserved in a moisture free environment, a finished product needs to be sealed properly and stored. For storage, we need space, the cost involved is in the form of rent of the warehouse and initial set up in the warehouse for proper storage. These are the recurring expenses of the business house.

3. **Handling cost:**

   The cost of moving the inventory from one place to another e.g. from manufacturer to warehouse and then further to retailer. The cost involved in this handling process comes under this.

4. **Depreciation cost:**

   Some of the products especially in computer hardware and phones lose their value if they are stored for a long time. Some of the versions show decrease in sales in few days e.g. demand of a new mobile or new automobile is unpredictable though there is a pre-booking period.

5. **Administrative cost:**

   The cost involved in proper handling and maintenance of proper record of goods stored in warehouse, employees required e.g. security person and inventory manager at warehouse. The salary and other basic requirements of staff come under this cost [1]

6. **Obsolescence cost**:

   Some products loose value if proper storage conditions are not maintained e.g. in automobile parts if things are not stored properly they get rusted. In garment industry, also due to weather changes the demand for a particular item decreases which leads to long time storage and the product becomes obsolete.

7. **Insurance and taxes:**

   A business must take care of the taxes laid down by government and the cost of insurance. Insurance of goods and machinery is required to avert any major loss and taxes are according to the rules of government and are inevitable. It is a recurring expense for any enterprise.

These costs involved are the major driving force for implementing the various inventory control techniques. Inventory was managed in traditional set up too but then supply chains used to be simple and there was less management required. Nowadays the supply chains are complex, customer demands are changing, competition in market is increasing. To tackle with all these changes a proper management of inventory is required.

There are several reasons for manufacturers increasing focus on optimizing inventory by applying the latest tools and techniques for inventory control. Traditionally, competitive pressure has always driven manufacturers to seek enhanced capabilities to reduce inventory levels, to enhance service levels and supply availability. They have to maintain the right product inventory mix and level in each geography and channel. A key driver of the renewed focus on inventory lies in the recognition that traditional techniques are failing to reign in inventories in the wake of increased supply chain complexity.

1.1.3. BASIC TERMS FOR UNDERSTANDING INVENTORY MANAGEMENT:

Demand rate:

It is defined as, "The number of units of an item requested by customers in a unit time period".

Order Quantity:

The quantity expressed in units or currency that is ordered from a supplier or production division of factory is called the order quantity. [1]

Reorder point:

It can be expressed as a specific amount to which the inventory falls and the material is ordered [1]. It is generally expressed by a symbol R (in units).

Lead time:

It is exactly defined as the time elapsed between the time the material is ordered and the time when the material is received and is ready to be sold [1]. It depends mainly on the internal organization of the company.

Shortages and back orders:

The reorder point can be set at either zero value or a value equal to expected demand during lead time period. The selection of this value depends on the kind of product and business. In some businesses, the owner allows shortage as he is aware that his customers will wait during the lead time. For small products of daily use, one must keep the buffer stock during lead time. [2].

ABC analysis:

Alliance of items helps the managers in deciding which items require frequent attention. [2] These alliance techniques require frequent attention. These help to reduce excess storage or obsolete products, minimize stock out situation, effectively utilizes the time of staff involved. 'A' describes the high value items. 'B' describes the items with less value; 'C' describes the items with lowest value. A items constitute about 10-20% of all items, B contains about 30% of all items and C involves about 10% of all items.

Methods for estimation of inventory:

To evaluate the refilling of individual items, to ensure availability of all materials and to analyze inventory levels. Proper estimation of inventory is done, several methods that are used are**:**

- FIFO (first in first out):

  The oldest material available is used for estimating value of that item. Materials are sometimes available with cost difference. This technique is used for items that give very high turnover [1].

- LIFO (last in first out):

  The most recent stock is used to value the item; this method is generally used in manufacturing industry to reduce taxes [1].

- Average cost:

  In this method of estimation of cost, the cost of material is generally averaged which lies between the old and new stock. In manufacturing and maintenance environment this costing method is used [1].

- Order specific cost:

  This method of estimation is used for item to item basis. It is used when the requirement exists for keeping audit of actual costs [1].

- Standard cost:

  It is the cost maintained for an item for a particular period. All materials will have a same standard cost during this period. For components used in repair or rebuilding, these costs are generally used [2].

Net inventory:

The net inventory is the sum of on-hand and on-order inventory minus the accumulated back orders.

Lead time stock:

It is calculated as the average demand rate during the average lead time.

Economic order quantity (EOQ):

For rational decision making the order quantity of a product should be fixed, so that the sum of the annual ordering cost and annual holding cost associated with the quantity can be minimized.

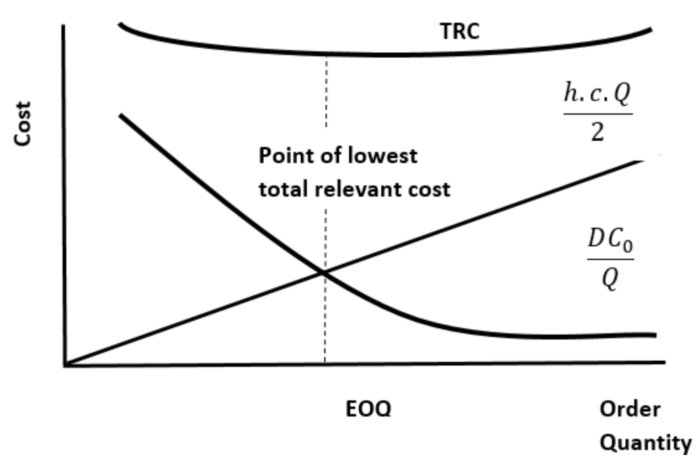

Figure 1: EOQ Plot

Total variable cost:

The total variable cost associated with any order quantity is the sum of the annual holding cost and the annual ordering cost.

Total cost $T_C = \frac{h.c.Q}{2} + \frac{DC_0}{Q}$

The formula for calculating the Economic order quantity is

$$Q^* = \sqrt{\frac{2DC_0}{h * c}}$$

Where

h= holding rate (in percentage)

c= unit price,

Q= order quantity

D= demand (annually)

C_0 =ordering cost per order

Calculation of economic order quantity (EOQ) are based on these assumptions:

1. The consumption of units during the period is known with certainty.
2. The cost of ordering remains constant throughout the period of analysis.
3. The costs involved in inventory remain constant throughout the period of analysis.
4. There are no discounts available on cash or varying quantities.
5. The whole quantity of inventory ordered is delivered in one batch.
6. The quantity for each stock item is optimally calculated separately.
7. The lead time remains constant and the order is always received on time with the total order quantity.

Supply chain management: Supply chain management is an effective process which starts as soon as a product is designed, the next step is procurement of product, third thing that comes into picture is planning and forecasting the whole process of production and distribution. Supply chain manages the fulfillment of all the orders as well as support required after sales. A company's worth in the Global market can be proved only with the help of effective supply chain management [6].

The companies especially related to automotive, mechanical and engineering goods are strongly influenced by export demands and growing international supply network. The global networks have created a pressure for maintaining affordable costs. Therefore, to have control over the cost and to gain competitive advantage over other rival companies; many companies are fully optimizing their supply chains. Effective supply chain management can bring advantage to any industry [6]. The various areas that are covered under supply chain are Customer interface management [7], performance measurement and control, managing inventory, organizing the supply chain, developing IT systems, risk management, performance measurement and control.

Supply chain performance is optimized by measuring the costs of coordination, quality control, wages, logistics etc. [2]

1.2 ROLE & RESPONSIBILITIES IN INVENTORY MANAGEMENT

The key responsibilities within inventory management function as described in literature are:

- Management related responsibilities,
- Responsibilities related to storage
- Responsibilities related to planning of materials
- Customer support related responsibilities

The detailed view of these can be given as:

Management related responsibilities:

The main responsibilities under this head are:

- To control the inventory costs.
- To establish the performance measures.
- To monitor the inventory performance.

- To centralize and decentralize the issues related to decision making
- To monitor that how cost effective the inventory maintaining activities are.
- To develop long term plans for new and existing parts acquisition, inventory levels, warehousing and distribution.
- To monitor the stock of obsolete items.
- To explore and use new information systems and technologically advanced tool.
- To monitor and analyze the whole inventory process.

Responsibilities related to storage:

Storage is an important and integral part of inventory management. The main responsibilities are:

- To maintain accurate record of inventory.
- To manage lay out plan of a store.
- To receive and store materials.
- To issue stock material and respond to material requests from customers.
- To conduct cycle count and annual physical count.
- To resolve any discrepancy in count of stored stock.
- To develop a proper route map for truck.
- To work in collaboration with purchasing department and resolve vendor problems related to timing, quality, quantity and delivery.

Responsibilities related to planning of materials

Inventory management is responsible for replenishment strategy and to determine the required quantity to meet customer needs. The responsibilities include:

- Using ABC system of inventory control.
- Projecting the demand for materials.
- Deciding upon stock and non- stock items.
- To maintain catalog of inventory items.
- To assist the purchasing department.

Responsibilities related to customer support:

To fulfill the customers demand on time, inventory management ensures that the material is ordered and delivered to customer on time. The responsibilities include:

- To ensure that the material requests are approved on time.
- To determine the need of products and schedule availability.
- To provide proper customer feedback regarding the level of service.
- To stick to inventory security and record keeping policies.

1.3 METHOD OF REFILLING INVENTORY STOCK:

The refilling of stock depends upon demand of stocks. According to Research results [7] for refilling stock manufacturer must be clear about the demand type: 'dependent demand' i.e. demand which depends on customers**,** it requires planned maintenance of stocks. 'Independent demand' means the demand is not under our control e.g. for maintenance of sold goods. The demand of stock for maintenance purpose is not predictable. 'Stable demand' is that in which the quantity or stock requirement is fairly known and is generally stable. Subject to the kind of demand, the refilling method is chosen.

Fixed schedule method of refilling stock:

It is used when both time and quantity for material are fixed. The material is stored for a small amount of time before getting used.

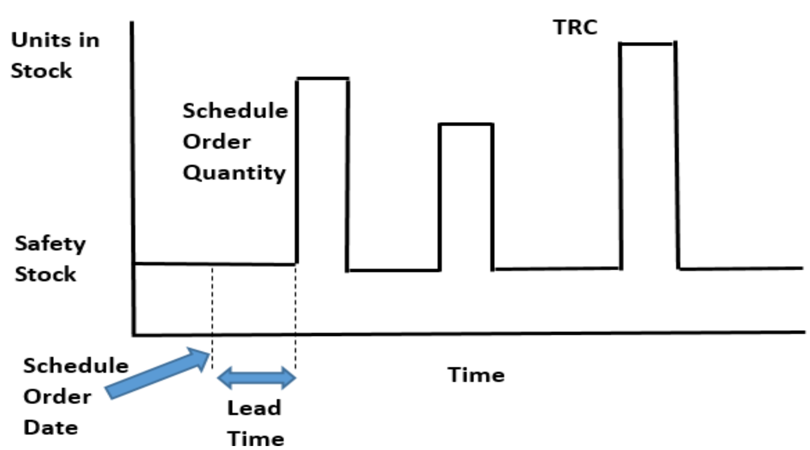

Figure 2: Fixed Schedule Method

Fixed order method of refilling [2]**:**

It is used when the quantity of material ordered remains stable but the timing of material delivery depends upon actual demand. This is used for seasonal demands like for a firm manufacturing air conditioning.

Two bin method: This is used for low value, repeatedly used material. The usage or requirement for these cannot be planned. 'Two bin method' is easy to implement and equally easy to use. For the first section of bin, items are used till it becomes empty, then the second section of bin is used which is the ordering point of the system.

Min-max method of refilling:

It is used for constantly changing demand; it is based on maximum and minimum amount of material required. In this the maximum and minimum number of items to be stocked and the requirement for safety stock are determined. When minimum value reached, the inventory stock is refilled. It doesn't depend upon the time in between

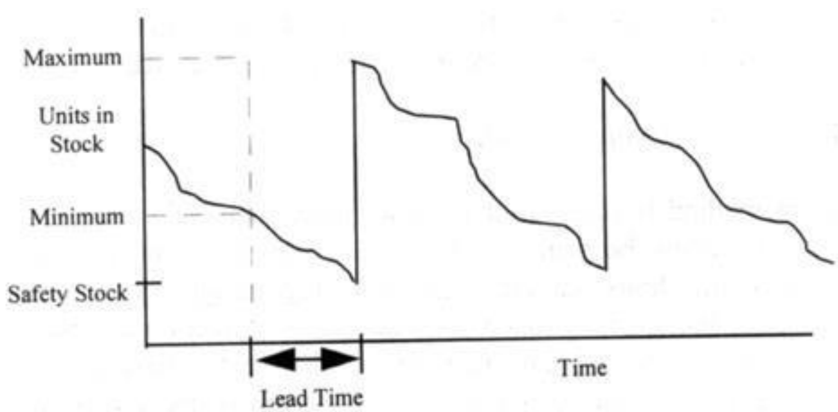

Figure 3: Min Max method of refilling

Fixed period refilling method [2]**:**

It is also known as fixed schedule method which is used for dependent demand i.e. requirements are known. This is applied when requirements are planned or can be forecasted.

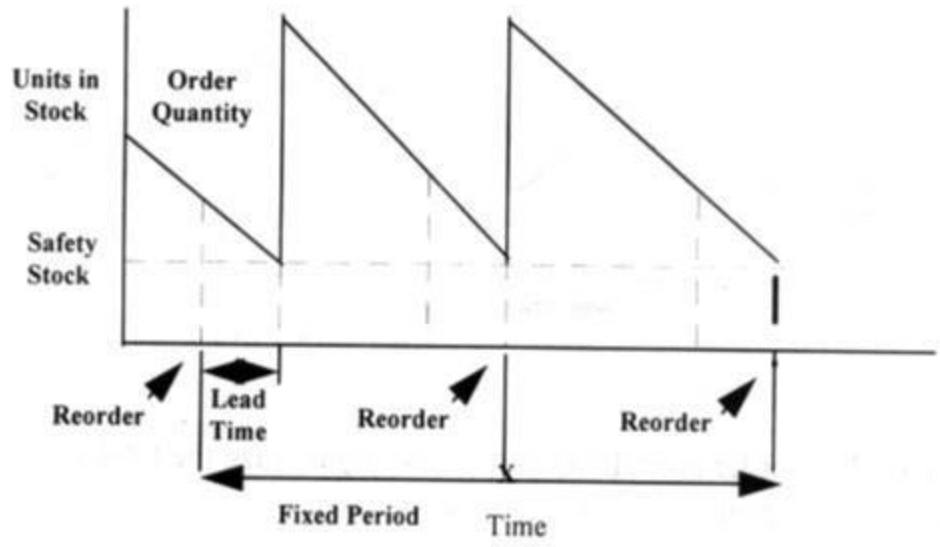

Figure 4: Fixed Period Refilling Method

1.4 METHODS FOR ESTIMATION OF INVENTORY:

To evaluate the refilling of individual items, to ensure availability of all materials and to analyze inventory levels. Proper estimation of inventory is done, several methods that are used are**:**

FIFO (first in first out): The oldest material available is used for estimating value of that item. Materials are sometimes available with cost difference. This technique is used for items that give very high turnover [1, 7].

LIFO (last in first out): The most recent stock is used to value the item, this method is generally used in manufacturing industry to reduce taxes.

Average cost: In this method of estimation of cost, the cost of material is generally averaged which lies between the old and new stock. In manufacturing and maintenance environment this costing method is used [1].

Order specific cost: This method of estimation is used for item to item basis. It is used when the requirement exists for keeping audit of actual costs [1].

Standard cost: It is the cost maintained for an item for a particular period. All materials will have a same standard cost during this period. For components used in repair or rebuilding, these costs are generally used.

1.5 INVENTORY MODELS:

These models differ due to the type of assumptions or the conditions available for inventory control. When all the parameters involved are well defined and there is certainty in value for all parameters, the model is called a **deterministic model** [1]. If the values of parameters are probabilistic i.e. when the parameters have random value, the model is called **stochastic model.** If the model parameters do not change overtime, it is static. If the model takes into account the various changes that take place, it is called **a dynamic model** [1].

While choosing a model for management of inventory, there are few things that must be taken into account:

1. Single item or many items: This parameter decides that whether we have only a single item to consider or there are multiple interconnected items. There is a harmonized control or whether replacement of products is allowed.
2. Time interval: This time interval also depends upon the type of item under consideration. If the item is required for a very small period, a single period model is required. When multiple periods need to be considered, a harmonized control is required between various items.
3. Number of locations: In general inventory of all items is not always available at a particular location. It is kept at more than one location. In multi layered networks, the orders are a part of demand at location of supply.
4. Depending upon the nature of products, consumable, deterioration, repairable or perishable etc. Deterioration of products is a natural process, it must be kept in mind while deciding the inventory policy.

5. Nature of demand: The demand for a particular item may be deterministic or probabilistic. The static demand doesn't change whereas dynamic demand is the changing demand that changes with time but the pattern of change is known. A stationary demand follows a probability distribution e.g. normal distribution, Gamma distribution, Poisson distribution and it is also assessed from past data. Non-stationary demand is the type of demand that changes with time or with change in the rate of growth. Demands can also be categorized as dependent or independent. Dependent demands occur when various products are linked with each other and depend upon the plan of production.
6. Supply process: it refers to conditions imposed in the process e.g. defining the minimum and maximum order value or order size.

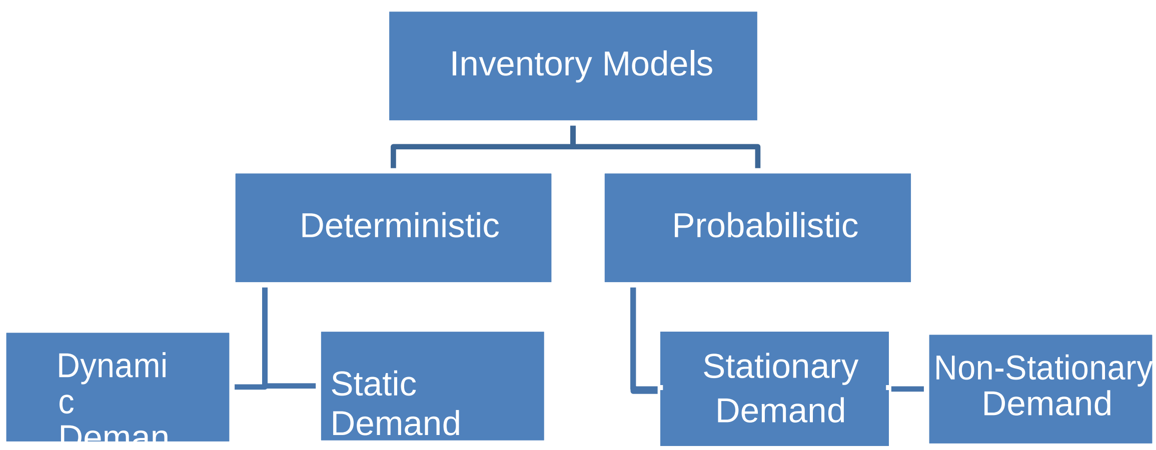

Figure 5: Demand modelling

1.5.1 CLASSIFICATION OF MODELS:

A proper classification of models was done in 2006 as:

Table 1: Classification of models

Classification	Type of model
By purpose	EOQ models EPQ models Joint economic lot sizing models
By period	Single period models Multi period models
By quantity of items	Single item models Multi item models
By type of inventory monitoring	Continuous review system model Periodic review system models.

Economic order quantity model: For a fixed size of inventory, the economic order quantity model is used. It is that quantity of product which minimizes the inventory carrying cost and the ordering cost. The model is derived under the following assumptions:

- Demand is consistent and is known over a period of time**.**
- No shortage is allowed.
- Lead time remains constant
- Quantity of order is received at once.

  Originally this model was proposed by Ford W. Harris, published in Factory, the magazine of management. This model was then adopted by many researchers. [8] [9]

Economic production quantity model: This model is generally used to determine the quantity which a company or retailer should order in order to reduce the inventory costs and balance the ordering cost and inventory carrying cost. Original EPQ model was designed by E.W.Taft (1918). This is an improved version of EOQ model. This classical EPQ model has been used by many researchers. This model provides an optimal solution for economic production model for inventory. [10] [11] [12]

Joint economic lot sizing model: Models that deal with the issues of inventory coordination between a seller and buyer, comes under this section. The buyer and supplier work in harmony to finalize an inventory strategy. [12]

Models depending on period: The period dependent models are of two types: single period model and multi period model. The difference between these kind of models is that in multi period model stocks left from the last time period can be used. Inventory and production decisions are interrelated to each other in real world problems, production is directly related to the quantity of inventory in store. Various researchers have used these single periods and multi period model [9] [13].

1.5.2 INVENTORY REFILLING TECHNIQUES:

The various inventory management techniques adopted by companies are:

1. **Materials Requirement Planning(MRP)**: This is the most common method used by manufacturers for planning their resources, the various points covered in MRP are inventory on hand commonly known as on hand balance, minimum order quantity, future demand, expected receipts, lead time and standard package quantity(SPQ). MRP generally optimizes the order quantities and delivery of products, ensures that the inventory items are available when required, also avoid wastage by ordering useful inventory. The drawbacks of using MRP are that it is based on very accurate and relevant data, a small mistake in calculation can cause loss. Very minor mistakes committed unintentionally can lead to stock out situations. Even in a perfectly managed scenario, it is found that MRP can be only 79% accurate.
2. **‘KANBAN’ method**: This is strong and highly appreciated method. This method is used only in developed countries though in process it is similar to traditional methods of controlling inventory. This method doesn’t rely upon the system data. The replenishment is triggered by a physical card. Kanban requires more discipline so before applying, it needs extensive planning. The planning process

for KANBAN consists of defining the rules, collecting the data, defining the solution process of KANBAN. It also requires planning regarding the limits for the system. Next step is to check and verify the working of system and final step is to count the inventory and fix up the mistakes. The system generally overcomes the challenges observed in MRP but manufacturers incur a variety of costs. The next is the Vendor Managed Inventory which overcomes the shortages of KANBAN and reduces the costs significantly.

3. **Vendor Managed Inventory**: This is defined as means of optimizing the whole supply chain performance in which the supplier accesses the customer's inventory data and supplier is equally responsible for maintaining inventory level required by customer. The order transactions that are normally generated by buyer is now monitored and initiated by the supplier itself. Instead of putting pressure on manufacturer only, the responsibility and authority are now shared in the whole replenishment process. For efficient and smooth working of VMI, some of the things that must be ensured are: reliable data should be provided to the supplier, assurance by the supplier that his information will not be shared with anyone, very clear visibility for sales and inventory should be available to the supplier. VMI is short to long term contract, the demand rates are appropriate and production environment can be suitably approximated. [14] [15] [16].

Vendor Managed inventory gave the manufacturer some advantage and complete control over inventory at customer's end. The decision to deliver goods and the time period of delivery was now decided by the manufacturer. The transportation cost which in traditional set up was borne by vendor is shared in the VMI agreement, the purchase orders are not necessary, manufacturer gets more authority and flexibility to deliver goods in such a balanced way that no shortage is faced at any customer's end.

As VMI treats both manufacturer and customer an important part of supply chain, it is adopted by many industries worldwide, few examples of VMI in industry are:

1. Procter & Gamble and Walmart were the first industries who actually introduced the world with benefits of Vendor Managed Inventory. There are many industries who adopted this for better management of inventory.

2. A Canadian milk and dairy products company, manages the products sold to customers who agree on a VMI agreement. Parmalat company controls, how much to ship to customers and when. The company has reduction in costs due to effective utilization of transportation facility and experienced stability in production.
3. In Germany, Siemens purchasing department uses both VMI and CI as sourcing methods. It requires supplier to manage, control and plan inventory.CI is used for products with huge purchasing volumes and VMI for low cost items.
4. Another example is a Turkish food company i.e. Eti group which agrees upon a VMI agreement with customers who agreed to build depot on their manufacturing sites.

Recently there are many studies being carried out on implementing VMI on grocery industry and pharmaceutical industry [17] [18] [19]. There are many case studies being carried out and researchers still think that only 30-40% benefits are achieved depending on literature. [20] [21]

1.6 PROBLEM DESCRIPTION

As per the literature reviewed, we have found that among the various inventory models used, the EOQ model is still the most trusted model among researchers. The technique of Inventory management that is adopted by all reknown industries nowadays is Vendor managed inventory. However, industries are still not achieving the maximum benefit out of VMI. Moreover, the success stories of VMI are still limited to industries that have huge capital investments, the small-scale manufacturers are nowhere in focus. We will focus our study on small scale auto parts manufacturers in our region i.e. the NCR. We will figure out all the expected outcomes of Vendor Managed Inventory through an in-depth review of literature available on VMI and interview of experts in supply chain management.

1.6.1 CHALLENGES RELATED TO THE WORK:

The literature reviewed on Vendor Managed Inventory and the various models followed in Vendor Managed Inventory gave us the following information:

- Although Vendor Managed Inventory is adopted successfully by Procter & Gamble, Walmart etc., still the middle scale industries and small business organizations are not aware of the benefits of adopting VMI. They are simply following one of the resource planning techniques without following any specific model.
- The models framed for inventory control in VMI are specific for a particular set of industry as most of the literature relates to the case study of specific type of industries.
- The inventory models in VMI are generally focussed on simple supply chains, research can still be carried out on complex supply chains.
- No quantification i.e. no numerical values are assigned to the benefits that can be obtained by inventory management processes.

1.6.2 METHODOLOGY AND TECHNIQUE ADOPTED:

1. The various inventory control techniques were analysed and thorough literature review done on various techniques.
2. For analysing the loopholes in SCM: As we studied VMI models and literature, it was found that VMI is being applied without a systematic approach. Most of the suppliers are aware of the benefits but are not focussed about the factors they need to focus upon. For listing out the various benefits/factors of VMI, literature review and interview method was used. All the benefits suggested by experts were identified.
3. To overcome these loopholes, a systematic model is required to be followed. We tried the Interpretive Structural Model to achieve the desired structured model. It is very beneficial for understanding the linkage/dependency of various factors and through MICMAC analysis, the factors that should be focussed upon are listed.
4. In our research, we also tried to quantify the benefits obtained from VMI. For the weightage given to various factors grouped under three main categories, we used graph theoretic approach to get the exact numerical value of benefit achieved and suggested further scope of improvement.

5. The cost analysis was done on an auto parts manufacturer who agreed to test the benefits of Vendor Managed Inventory. Both the costs, before applying Vendor Managed Inventory and after applying the model were calculated. The costs are assessed and detailed report prepared using time series analysis and Markov Chains.

1.7 ORGANISATION OF PRESENT WORK:

CHAPTER 1: INTRODUCTION TO INVENTORY MANAGEMENT

This chapter gives an introduction to inventory, supply chain management, need of maintaining inventory and comparison of traditional and new methods for inventory control. Uses of Inventory management techniques over other methods were discussed. A thorough review of literature on these techniques is done and research approach decided.

CHAPTER 2: LITERATURE REVIEW AND RESEARCH METHODOLOGY

In this chapter a thorough study of Vendor Managed Inventory is done, its advantages, drawbacks related to Vendor Managed Inventory are studied. We conclude this chapter by finding the future direction in Vendor Managed Inventory and the research methodology adopted.

CHAPTER 3: INTERVIEWS WITH SUPPLY CHAIN AND LOGISTICS PROFESSIONALS IN THE MANUFACTURING COMPANY SELECTED FOR PILOT STUDY

This chapter will focus on Vendor Managed Inventory and its scope in small scale industrial set ups, a questionnaire is set up to obtain the clear benefits that the supply chain expects after VMI. Each factor that needs to be included for further study is included in this study.

CHAPTER 4: VARIABLES INVOLVED IN SUCCESSFUL IMPLEMENTATION OF VENDOR MANAGED INVENTORY AND THEIR STRUCTURAL MODEL

This chapter will explain all the benefits listed out through interview of professionals/key position holders in SCM. This chapter will explain the complete structural model for optimising the benefits of supply chain. The linkage of factors will be very clear after analysis and conclusion drawn using the MICMAC analysis.

CHAPTER 5: QUANTIFICATION OF THE BENEFITS OF APPLYING VENDOR MANAGED INVENTORY ON AN INDUSTRY USING GRAPH THEORETIC APPROACH

This chapter includes the quantification /numerically assessing the benefits that are obtained under various heads. Graph theoretic approach is used for assessment of results. The results are then compared to maximum values that can be obtained. So, assessment is done regarding the scope of improvement.

CHAPTER6: PILOT STUDY IN AN INDUSTRY IN INDIA MANUFACTURING AUTO PARTS.

In this chapter, we adopt Markov chain analysis suitable for our manufacturer of small automobile parts and we will conclude the research work by showing the comparison of total costs of the system before applying Vendor Managed Inventory and after applying Vendor Managed Inventory using time series analysis.

CHAPTER7: CONCLUSIONS, RECOMMENDATIONS FOR FUTURE RESEARCH

We concluded our research and suggested directions for further research.

1.8 SUMMARY OF CHAPTER 1

This chapter is the introductory chapter of the thesis and provides an overview of the process of inventory management. First section of this chapter, section1.1 gives us details of the process of inventory management, all the basic terms related to inventory management are explained e.g. EOQ, lead time etc. A brief introduction to the term Supply Chain Management is also included in this section. Section 1.2 of this chapter explains the role and responsibilities within inventory management process. Section 1.3 describes the various methods of refilling stock in inventory management. Section 1.4 explains the details of methods used in industry for estimating inventory. Section 1.5 describes the various models that are adopted for inventory management, the techniques of inventory management used in industries. Finally, this chapter concludes by giving us direction for further study of Vendor Managed Inventory and exploring the literature on research methods and research techniques.

2. LITERATURE REVIEW AND RESEARCH METHODOLOGY

2.1 INTRODUCTION

This chapter presents a detailed review of literature most relevant to the topic under study. This review is divided into three sections. The Section 2.2 presents the most relevant challenges related to inventory management addressed by the vendor managed inventory strategy. Section 2.4 presents a focussed review of vendor managed inventory strategy and Section 2.5 presents a review of the factors influencing its success in managing inventory. Based on the reviews in Sections 2.4 and 2.5, the initial structural construct is formulated and presented. The last part of the chapter relates to review of the research methodology, philosophy and approach adopted in further chapters. The various methods and approaches are briefly explained and then the research method, approach is chosen that is appropriate for our research. This chapter provides us with a well- defined path for further research.

2.2 CHALLENGES IN INVENTORY MANAGEMENT

Inventory management is a process of estimating and stocking physical materials based on predictions of their demands. [22] When demands are certain, inventory can be built in large quantities for known future demands. In this scenario, the demands are deterministic and the inventory management follows a "push" approach. However, when demands are uncertain, inventory is built only when demands become certain up to an acceptable degree. In this scenario, demands are stochastic and the inventory management follows a "pull' approach. It is easier to manage inventory when demands are deterministic. The actual approach may differ based on the decoupling point of the customer orders [13] The make-to-stock decoupling point is at the finished goods inventory as demanded by the customer. The make-to-order decoupling point is at the raw materials inventory as the production begins only after receiving an order. The assemble-to-order decoupling point is at the inventory of semi-finished goods ready for assembly.

The key models of inventory management for deterministic demands are economic order quantity (EOQ) for single and multiple products, multi-period inventory (taking account of the known demand changes during different periods), redistribution of echelon holding costs, and multiproduct assembly systems [22] The key models of inventory management for stochastic demands are newsvendor solutions, additive and multiplicative demand-order relationships, backorder models, multiple period models (moving average), Markov chain decision processes, and time series forecasting (with and without adjustments for seasonal fluctuations) [22] [11] [23] . The inventory management approaches also need to account for uncertainty of lead times. Just like demand side variation patterns (deterministic and stochastic), inventory management is also affected by supply side patterns (example, deterministic and stochastic lead times) [9]. Uncertainty in lead times can affect the economics of inventory management significantly, specifically in multi-echelon supply chains and in reverse supply chains for warranties and spares services.

In real industrial scenarios, the demands may be a hybrid of deterministic and stochastic patterns. In such scenarios, a balance between push and pull approaches needs to be maintained. A third approach called discounted advance purchases may help in achieving such a balance [24]. This approach allocates the risks to both push and pull scenarios by sharing them between the suppliers and manufacturers. The suppliers get volume commitments based on stochastic demand forecasting methods in lieu of strategic discounts. The manufacturer absorbs costs of delayed inventory consumption by trading off the losses with the discounts offered. This strategy, however, fails when the demand fluctuation signals are faster than the lead times of deliveries. If the signals are false, they can cause flow of distorted demand information because of sudden variations in demand flows (demand waves with varying amplitude and frequencies), which gets amplified after passing each echelon while travelling upstream, as shown in Figure 6 [25] [26] [27] [28] [29] [30] [31]. Amplified distorted demand information can cause large amounts of unused inventories at each echelon. This is a dysfunction phenomenon called the Forrester (after J. Forrester who discovered this effect in complex multi-echelon supply chains) or Bullwhip effect. Forrester (Bullwhip) effect is the greatest challenge in inventory management as it can cause significant losses to manufacturers at all echelons that produce and create stocks based on distorted demand information. These losses occur primarily when the demand information flow is not synchronised accurately with the actual lead-time delays of the deliveries. In reality, delays in both demand information flow and lead times of deliveries contribute to this effect. A real-time visibility into the demands and the lead times is the most effective way to reduce or eliminate bullwhip effect.

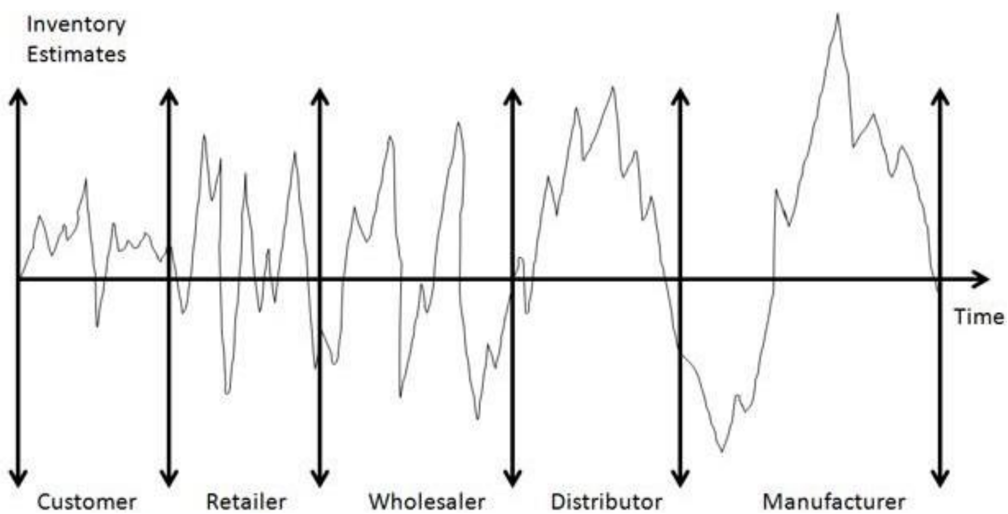

Figure 6: Illustration of Forrester (Bullwhip) effect (Illustrated by [31])

System dynamics methods have revealed the complexity of inventory management in modern business scenarios [32]. Creating system dynamics diagrams and running continuous and discrete simulations to identify the causal loops reflect the sensitivity of running inventory policies such that all the priorities of procurements can be reassigned. This method can help in evaluating multiple schedules mapped with the inventory policies and selecting an optimum one for customer deliveries. Such model driven approaches help in more demand focussed inventory management strategies, which are: *just-in-time (JIT) controls and vendor-managed inventory (VMI)* [10] [32]. However, such strategies may be fully loaded in the favour of the manufacturers thus lacking the incentives needed for the suppliers [33]. There may be many factors enabling success of these strategies. This research is focussed on the factors influencing successful VMI strategy. JIT is reflected as a major benefit of vendor-managed inventory and hence is included in this research. The subsequent sections present a review of VMI strategy and its success factors.

2.3 VENDOR MANAGED INVENTORY (VMI) REVIEW

VMI is a strategic engagement between manufacturers and their suppliers [34]. Under this engagement, the suppliers manage the flow of materials and information, and hold stocks based on direct assessment of demands generated at the coupling points with the customers. It is a complex strategy that cannot be generalised as it incorporates uniqueness of strategic and operations objectives and goals, resources, structures, capabilities, processes, products, integration, policies, laws, regulations, and technology of a specific industry. The traditional management practices assisting VMI are just in time (JIT), total quality management (TQM), materials requirements planning (MRP), total productive maintenance (TPM), enterprise resources planning (ERP), and business process reengineering (BPR).

VMI rides on closely integrated communication, collaboration, and information sharing structures and the technologies enabling those [34]. In traditional industries, organisational, cultural, financial, and operational barriers are key hurdles to VMI. Yet, VMI strives on its efficiency and effectiveness promises and ability to deliver riding on technology enhancements and automation as evident in the modern supply chains [35]. Based on timely and accurate information collection, VMI supports a manufacturer to effectively face uncertainties in demands through appending of additional capacities, reducing ordering costs, reducing inventory carrying costs, and improving just-in-time replenishment ability by responding to demand uncertainties dynamically [35] [8] [36]

VMI can potentially reduce or eliminate the practices of bulk ordering, beer gaming and safety stocking (explained in the next paragraph) [28] [29]. These are major benefits to inventory management. On the contrary, the suppliers benefit by continuous and guaranteed ordering, and reduced competition per ordering cycle [36]. However, the information sharing and lead times management needs to be highly effective to enable VMI performance [35]. Success of VMI depends critically on the collective manufacturing and stocking capacities of the suppliers, and sustenance of net lead-time commitments of all collaborating suppliers.

Getting back to the primary challenge of demands fluctuations through distorted information flow (bullwhip effect), the suppliers at their respective echelons maintain additional safety stocks to face the uncertainties whenever they perceive high demands (beer gaming), and practice order rationing whenever they perceive drops in demands [28] [29]. However, if the actual demand situation reverses (than expected), suppliers may face significant stock overflow or stock out situations. VMI is an opportunity for the suppliers to connect with the information systems of their customers and reduce demand uncertainties. Through VMI arrangements, suppliers can reduce the risk of bullwhip effect considerably by converting a transient waveform of alternating impulses due to uncertainties into a step of demand [28]. This can be achieved by continuously computing performance metric of integral of time multiplied by absolute error in forecasting. Continuous measurements of absolute error in forecasting helps in identifying and eliminating false demand peaks induced during non-business as usual scenarios (like, large number of advertisements and promotional campaigns, and special discount schemes) [29]

To achieve the ability of identifying false demand peaks continuously, a full VMI framework needs to be implemented, as presented in Figure 7 [28] [29]. This framework suggests that the vendor needs to be outsources integrated inventory control at the production inputs (raw materials), factory outputs (finished products), despatch outputs (packaged and forwarded products), and vending outputs (products delivered to customers or displayed for sale). The key information inputs to the VMI controls are factory input stocks, factory completions, finished goods stocks, goods in transit, vending stocks, service levels (of deliveries), and sales completed. These inputs can be entered into a system dynamics modelling and simulations software to study the dynamics of production and distribution lead times, key replenishment signals, noises in the signals (distortions), and feasible target stocks based on the business targets. The suppliers can generate a just-in-time flow scheduling of materials flow to avoid stock overruns and stock out scenarios at the echelon points in time. In this way, the threats leading to bullwhip risk can be controlled at their sources.

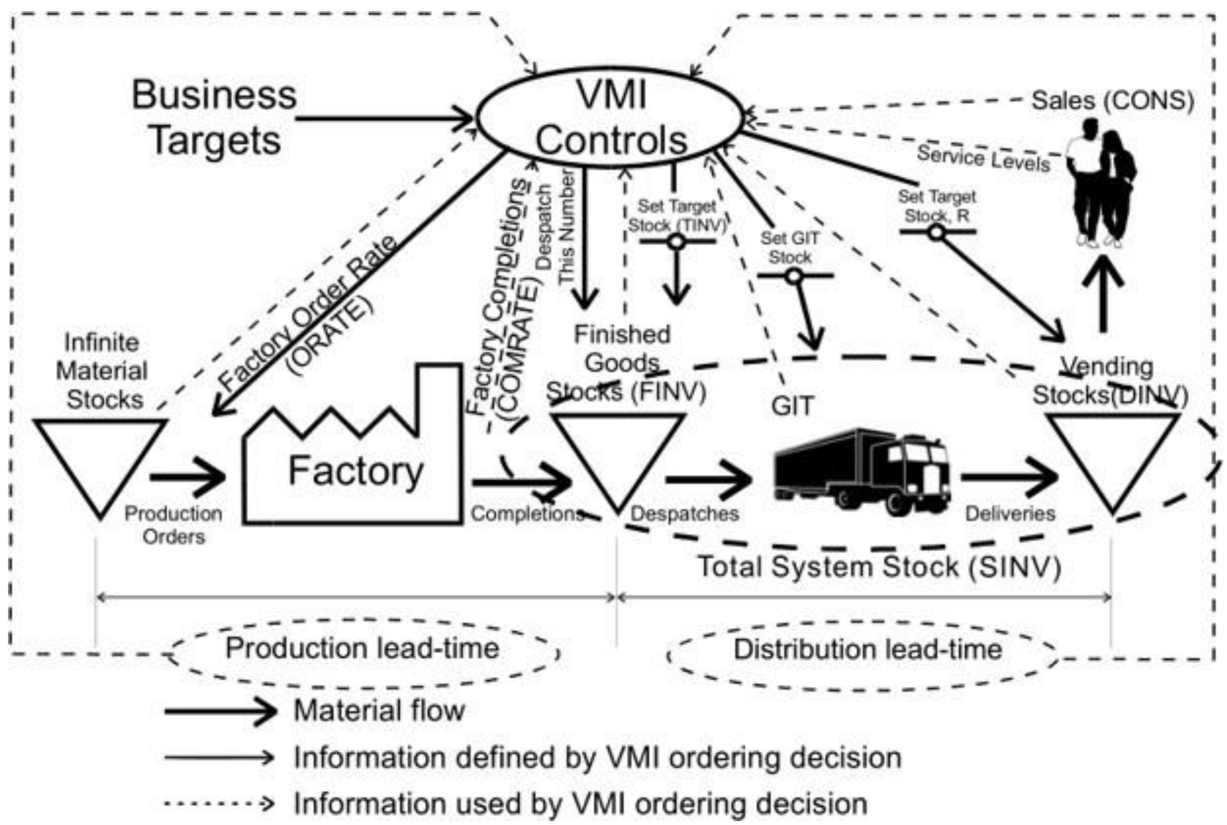

Figure 7: A full (end-to-end VMI framework **[**28] [29]**)**

Static and partial VMI can be very much disadvantageous for the suppliers as the stocks may suddenly increase because of a demand shock but the cooling periods can be much longer than what the customers may experience because of the service level agreements [37]. VMI can actually increase the total system cost if implemented partially with static practices [21]. Several changes in old business processes are needed to achieve a fully dynamic, end-to-end VMI to achieve system-wide cost savings benefitting both the vendor and the manufacturer [21] [37]. A manufacturer views VMI as a trade-off with the lost sales penalty because of inadequate capacity or inadequate capacity utilisation or both [38]. Hence, the key performance delivery of a vendor in a VMI setting is to optimise order processing by reducing lost sales penalty. A vendor can deliver it through four key strategies, as shown in Figure 8: accelerating the supply chain (quick response), reducing the bullwhip effect (discussed earlier in this section), and controlling costs of inventory and transportation through collaborative forecasting and replenishment [39]. In operations terms, these strategies result in acceleration of order cycles (reduced cycle times), faster refill (replenishment) rates, and enhanced service levels to the customers [40] [41] [12]. In practice, these variables may have to be modelled separately for vendor-managed raw materials inventory, work in progress inventory, and finished goods inventory [12]. These benefits combined with the suppliers' ability to recognise false demand surges and resulting amplification of false demand waves (bullwhip) form the fundamental framework of VMI for any manufacturing business.

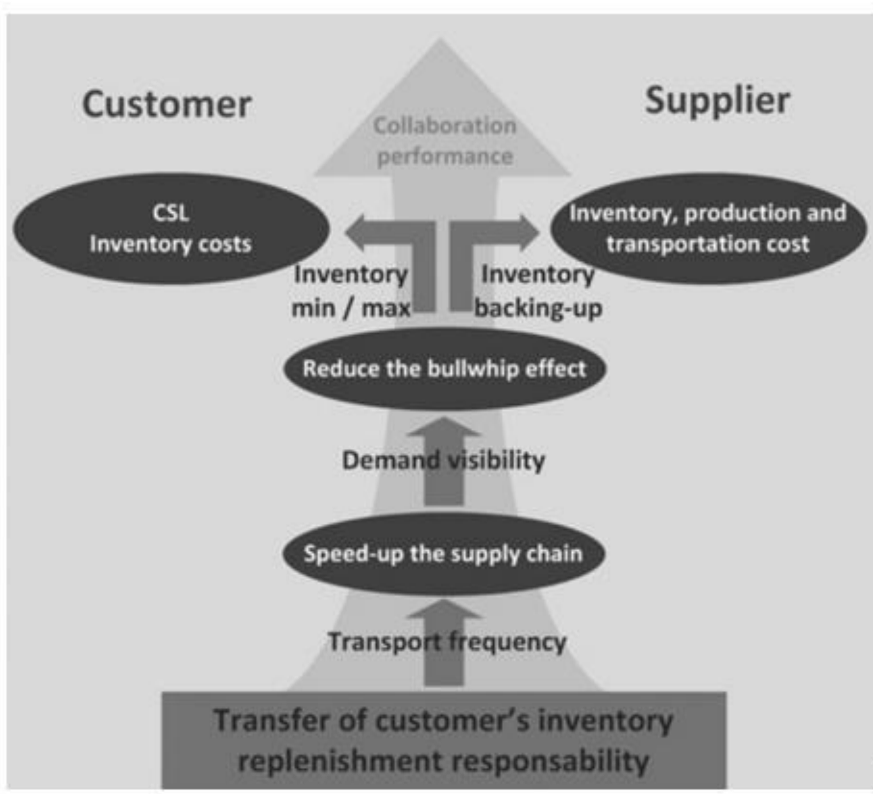

Figure 8: A strategic framework of VMI [39]

For activating these strategies, the operating framework of VMI is as presented in Figure 9 [17]. The vendor collects data about the structural parameters of the demands and creates a reference knowledge base of the demand structure of a manufacturing setting [17]. This reference knowledge is used to generate the demand flows to be fulfilled by the inventory capacity to be maintained by the vendor. The actual demand flows are projected through a forecasting application collecting data from the points of sales.

Analytics software estimates the order-up-to level based on the demand reference knowledge and the forecasting data.

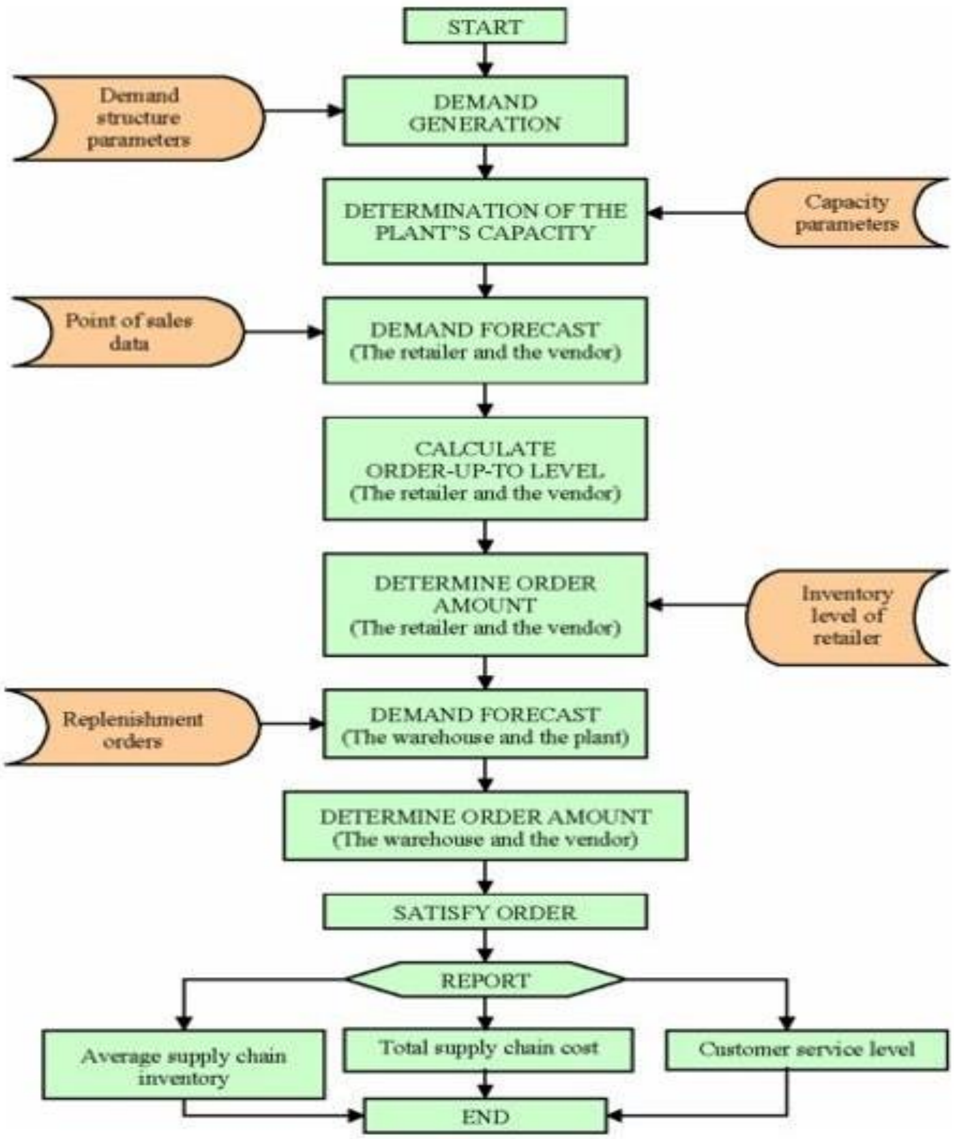

Figure 9: An operating framework of VMI [17]

The ordering amount is defined by the inventory level maintained at the point of sales (retailers) and the demand forecasting between the manufacturing plant and the warehouses [17]. The replenishment points are estimated by the information on the previous replenishment orders between the warehouses and the vendor. The final order flows (transportation) are executed between the customer's warehouses to the retailers and the reports on average inventory maintained, total supply chain costs, and customer service levels (order fulfilment) achieved. In a basic setting, a centralised warehouse can be used as the order coupling point between multiple manufacturing plants and multiple goods exchange facilities, which are directly coupled with the points of sales [19]. In complex settings, the goods exchange facilities may be transformed into stock keeping units when the ordering frequency and quantities are stochastic.

Before ending this section, a brief insight into the transportation part of this system is essential. The transportation costs represent quite a significant portion of the VMI costs on the vendor [42] [43]. It also influences the other logistics-related costs (like packaging, loading, and unloading) of a VMI setting. Optimum scheduling of transportation is a critical component of VMI. A vendor can reduce transportation costs and its indirect influences on the other logistics costs by undertaking channel coordination objectives as a part of the VMI agreements. The transportation costs of the VMI are influenced by multiple variables: size of transportation vehicles, extent of loading on the vehicles (full or partial), and frequency of transport runs. In highly complex and dynamic scenarios, a freight payment schedule may be formed to assess a trade-off between transportation costs and inventory holding costs at the points of sales. In many cases, the amounts of inventories held may be increased at the points of sales to reduce transportation costs but also showcased as a premium service to the manufacturers and the retailers. There is a possibility to arrive at a model with optimum win-win scenario for the manufacturer and the vendor as this arrangement can help in optimum order fulfilment while the cost of holding extra inventories is effectively traded off with the cost of transportation and its indirect influences on other logistics costing.

This section presented a review of the fundamental design attributes of VMI. As this research is focussed on developing an optimal model of factors influencing success of VMI, this knowledge is not expanded to delve deeper into the key factors that influence effectiveness of VMI.

2.4 FACTORS INFLUENCING SUCCESS OF VENDOR MANAGED INVENTORY

VMI is highly dependent upon information technology and the resulting efficiencies achieved in the processes [44]. Initial technology implementation challenges faced by the vendors and manufacturers results in parallel runs of manual and automated systems resulting in delayed abandonment of the traditional purchase ordering system.

Further, it takes time to provide full information visibility to the vendors fearing misuse and opportunistic behaviours. Every manufacturer realises the utmost dependence on the vendors in a VMI setting, the level of trust needed on the vendor, and the extremely high costs involved in switching to a new vendor. Hence, VMI is never implemented in a short time span. Full realisation of the VMI system takes a long time. In addition, VMI is considered only when a manufacturer feels its utmost need (like, facing dysfunctional impacts because of bullwhip effect). The legal, ethical, and behavioural aspects are documented in the VMI contracts in significant detailing.

Hence, the most fundamental factor enabling success of VMI is willingness of the customer to share information [40] [44] [18]. However, in many settings it may not be a variable measurable directly. To measure it, another variable is needed that indirectly reflects customer's willingness to share information. One such variable is the extent to which, information flow has been allowed by the customer. The curbs applied on information disclosure directly reflect the reluctance of customer in sharing information and indirectly reflects the trust on the vendor.

The third enabler is the characteristics of the demands of the products and the criticality of products [18]. The key aspect is whether the vendor has been trusted to handle deterministic demands or the stochastic demands. In critical applications (like healthcare), the vendors may not be trusted for VMI of products having stochastic demands because stock outs may result in significant impacts. The fourth enabler is the characteristics of the supply chain itself, which may include level of supply chain integration, mode of operandi for management of flows of products, funds, and information, and collaborative approaches and trust relationships between the suppliers and the customers. In addition, the capability of a supply chain to absorb demand elasticity and optimise the total distribution time, increase in products range, and increase in market scale affects VMI performance [16].

The VMI performance may be more sensitive to demand elasticity instead of increase in market scale and products range. Further, the VMI performance is sensitive to the stock boundaries established by the vendors [45]. Storage space capacity committed by the vendor under a VMI agreement should be sufficient to absorb the demand surges, surges in replenishment frequencies, and the same in shipment frequencies. If the vendors want to establish boundaries on the level of surges they want to absorb, then alternate arrangements to VMI should be explored (like, integration of supply chains of multiple manufacturers handling similar demand parameters in a marketplace). Perhaps, a multi-vendor setting may also face multiple constraints in VMI if only a single warehouse capacity is used [46]. The manufacturers should select the VMI vendors capable of resolving their capacity constraints, especially the bottlenecks causing constraints in utilisation of the optimum manufacturing capacity [47]. The total inventory capacity and cost implied on a manufacturer, and the order fulfilment levels should be justified to a manufacturer for full scale utilisation of the manufacturing capacity.

An optimum VMI design of a manufacturer capable of serving the stocks of a large number of retailers was presented by Arora, Chan, & Tiwari (2010: 40) [48]. Figure 10 presents the VMI design in which, a large number of retailers is served by four distributed locked with the manufacturer in a VMI arrangement. Through simulations, it was found that success of VMI was governed by varying capacity of delivery vehicles, optimised routing and scheduling of the delivery vehicles keeping in mind maximum capacity loading on them, the demand thresholds handled by each distributor, and the maximum inventory thresholds of each of the distributors. The total cost of inventories and extent of customer satisfaction through demand fulfilment can be optimised by varying these thresholds. If the upper limits are reached, then additional strategies need to be incorporated, like using multi-layered distribution centres.

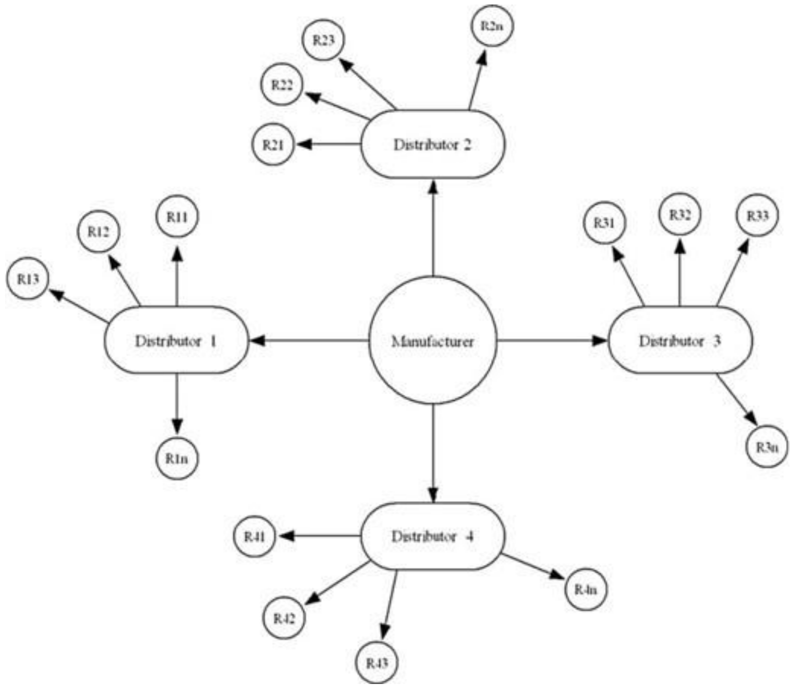

Figure 10: VMI model for a manufacturer capable of massive-scale production feeding the stocks of a large number of retailers [48]

Another characteristic of the supply chain crucial for VMI performance is deployment and operations of distribution centres, which may also be viewed as additional levels in a warehouse network (Shu *et al.*, 2012; Yang, Ng, & Cheng, 2010). Ryu *et al.* (2013: 319) [49] [50] [51] presented this concept as a fractal system in VMI-enabled distribution. Many other studies have defined this characteristic in strategic deployment and operations of urban consolidation centres used as strategic last mile infrastructures for unloading large trucks, and consolidating and reloading on small trucks carrying loads for targeted retail centres [52] [53] [54]. In this characteristic, VMI will be affected positively if the additional distribution centres are also used for improving lead time efficiencies and not only as capacity enhancement centres. This means that the locations of the distribution centres are crucial to improve VMI performance. The VMI performance shall also be enhanced by applying economies of scale in transportation if the distribution centres are located closer to the retail centres. This setting requires few large trucks to transport large inventories from warehouses to distribution centres whereas the deliveries to the customer locations can be managed by small vehicles with varying loading capacities. The locations and interconnection of the distribution centres are crucial in optimising transportation and lead time efficiencies. The additional capacity developed can be plugged into an active flow of materials such that the risk of inventory overruns in non-optimally located distribution centres can be mitigated. In a fractal system, a distribution centre may be made self-sufficient by creating localised information hubs instead of waiting for feeds from the main warehouse [51]. In this setting, each distribution centre is sufficiently equipped to handle its coupled retail centres independently. Except for receiving the large consignments from the warehouses, all other facilities are built within the distribution centres enabling them to operate independently. For example, each distribution centre can make their own scheduling and routing decisions for serving the directly coupled retail centres.

The first factor discussed in this section was willingness of the customers to share information openly with the vendors. Assuming that the customers are ready to transparently share information with the vendors selected for VMI services, the factors related to information systems also need to be taken into account. Bullwhip effect causes sudden changes in demand waves in both positive and negative directions [30]. If companies follow the demand waves as-is, they can face hefty losses in either unconsumed inventory piling up or missing orders because of frequent stock out situations. The role of information systems is to curb the ripple effect of the demand waves by smoothing of the input variations to streamline the fulfilment process.

The process of curbing ripple effects of the bullwhip phenomenon requires end-to-end visibility into the events of the supply chain and reducing certain dysfunctional activities carried out by agents out of fear of uncertainties [25] [27]. Some examples are: forward buying, beer gaming, order rationing, aggressive trade promotions and discounts, and large lots sizing [30]. A business needs to explore technology-enabled VMI and invest in infrastructures capable of feeding control data to a system capable of enhanced visibility into the supply chain events [55]. A coordination mechanism riding on technology-enabled VMI needs to be activated ensuring that its strategy is carefully planned, it is balanced as per the VMI budgeting, and it is effective and efficient [56]. This can be achieved through effective IT systems, quality of information, quality and standardised information sharing protocols and processes, quality and trustworthiness of relationships driving the information sharing protocols and standards, and a supportive multi-party organisational structure [57] [40] [58].

The modern developments in Industry 4.0 reflects realisation of these information systems capabilities [59]. The concept of cyber-physical systems employing Industrial Internet of Things and manufacturing cloud systems are evolving technologies for end-to-end information integration in industries [59] [60]. The cyber-physical systems in manufacturing and supply chains are autonomous electronic units capable of collaborating with other units and centralised sensing and actuation control software over Internet Protocol version 6 (IPv6). They can collaborate autonomously to execute automation algorithms, feed information to artificial intelligence decision makers, feed spatial and location-based information to real three-dimensional visualisation software systems, and facilitate integration of multiple manufacturing plants over a manufacturing cloud system comprising of shared IT systems used by multiple member organisations.
The knowledge of inventory management challenges, VMI, and the factors enabling success of VMI has been formed in this and previous two sections. The next section presents an initial structural construct that guided the primary research of this study.

2.5 INITIAL STRUCTURAL CONSTRUCT

The initial structural construct formed based on the detailed literature review on VMI in this chapter is presented in Figure 11 below. The key factors influencing VMI performance and the variables influencing these key factors are presented in this construct. The influencing variables were divided into three categories: information systems and sharing, demand characteristics, and supply chain characteristics. This categorisation, however, are indicative based on theoretical review only. The actual categorisation was evolved through interpretive structural modelling (ISM) in Chapter 4, and the quantification of variables was evolved through graph theory in Chapter 5. The predictive modelling of VMI was conducted in Chapter 6 using Markov chain analysis with Monte Carlo approximation using Gibbs sampling.

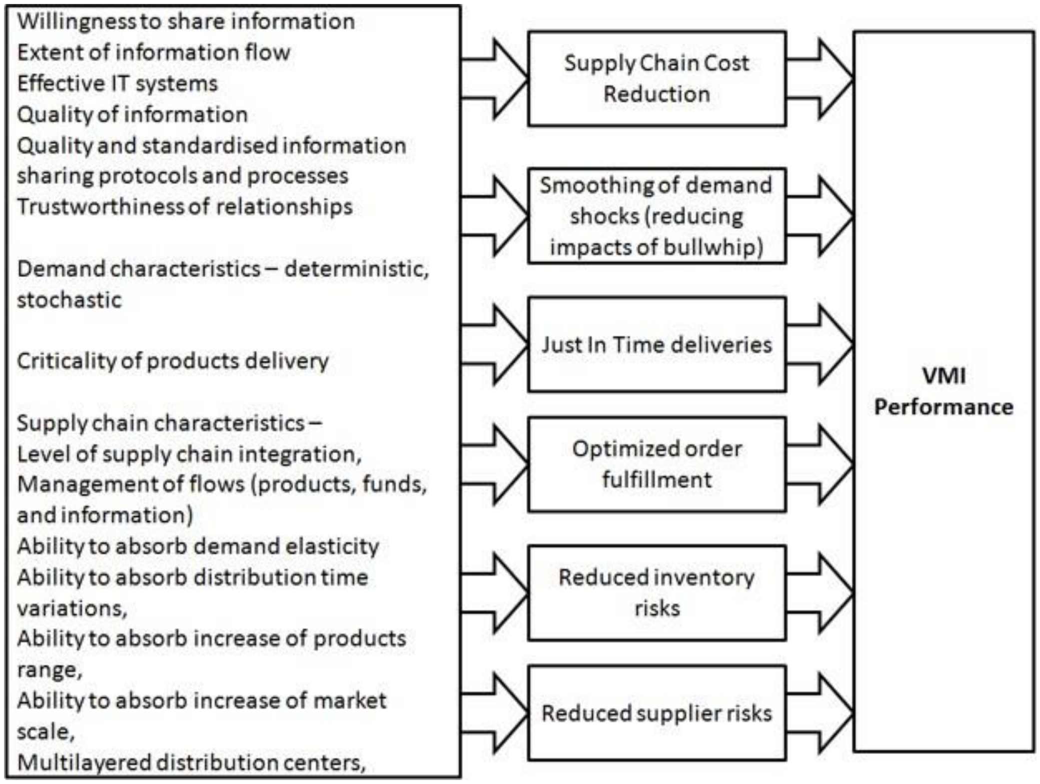

Figure 11: Initial Structural Construct

2.6 RESEARCH DESIGN:

Research design is basically the methods used and processes that are helpful in collecting and analysing the different variables in research. It is a systematic way to find answers of the research questions that arise. There are various kinds of research designs:

1. Descriptive: In descriptive research the various forms of research used are Case study, observation, survey and natural observation. Natural observation is used in wildlife studies where you can't disturb the habitat of object under observation. Case study is used in social sciences, industrial studies and in the field of medicine where changes are observed for a particular time period. Observation is used in behavioural studies, psychological studies where you can't change anything about the subject.
2. Correlational: It is used in the form of observational study in the field of medicine, psychology and statistics.

3. Semi experimental: It is like conducting experiments in order to check out the claims of various treatments etc., It is called field experiment and there is experimentation known as empirical study, researcher has control upon testing population like minimum marks criteria for students.
4. Experimental research: For validating a proposed hypothesis, various factors are tested to get the results and calculate the outcomes. Review: This is used in historical studies and social sciences. The most abundantly used and trusted research design is literature review where you can analyse and get insight into various study methods adopted. It can be literature review and systematic review.
5. Meta analytics: This method comprises of various scientific studies. The results are the relationships that come into picture after conducting multiple studies.

In our research, we are using the descriptive form of research as we will study the case of small auto-parts manufacturer.

2.6.1 PHILOSOPHY AND LEARNING THEORIES

During the research, a researcher tries to find out the research objectives from his understanding of the literature. He tries to interpret the problem or gaps in literature for finding out the research results a directed research approach is required. The approach that is generally adopted can be written as: Positivism and Interpretivism.

Positivist approach begins with a clear explanation of the topic of research and then applying a suitable method of research [61]. The researchers are not related to or attached to the persons participating in the research findings, this ensures that the research remains free from any emotional influence and stays neutral [61] [62]. The research methods are generally statistical and mathematical techniques.

In Interpretivism, the researcher believes that the result or the answers to the research questions can change depending upon the situations. The results are obtained from the open analysis of information from the sample. It is generally used to gain information about time based knowledge of realities of society [61].

For our research, we use the positivist approach so that we obtain reliable knowledge and focus our research on a consistent and logical approach. We go for building up a structural framework to achieve maximum benefits of Vendor Managed Inventory. Further we use mathematical techniques for justification of results.

Inductive and deductive learning approach: Every scientific method taken up by a researcher needs a reasoning approach. The most common approaches used in this process are Inductive and Deductive learning approach. Scientists consider that deductive reasoning is standard for any kind of scientific research [61] [62]. The research starts from a general level and then works on to become more specific and strong at the end. The study begins with a specific hypothesis and inputs from various resources help us to reach the conclusion.

Inductive reasoning is like going from specific phenomena to generalised phenomena. It is used in research frequently but it has its own weaknesses. It is an open-ended research and the conclusions derived are not right or wrong.

Out of the two, one approach is chosen depending upon whether the research requires testing of a hypothesis or finding out a new area in the existing disciplinary study. If the study requires answers to a particular set of questions, deductive approach is better. For quantitative data, it's better to use deductive approach whereas for qualitative data, it's good to use interpretive approach.

For our research, we conclude on using positivism approach with deductive learning as our research requires us to go from general to specific and we wish to use mathematical techniques for further quantification.

2.6.2 RESEARCH APPROACHES

There are two types of research approaches that are used generally for research purposes, these are quantitative and qualitative approaches.

Qualitative methods: The qualitative methods are generally easy during the planning phase but involve a lot of skill and hard work in the analysis phase, it depends upon the skill of the researcher. It involves in depth information on few cases. It is used for getting information from the sample who is actually involved. It constitutes of review of papers and in depth interviews of very experienced people.

Quantitative methods: This method is used when the sample size chosen is large. It involves a lot of hard work in the planning period and the analysis is much easier. The reliability of results depends upon the tools used for collecting information. It includes review of research articles, structured interviews and surveys etc. The results are more generalised in this method. [61] [62].

2.6.3 POPULATION AND SAMPLING

Population: It is defined as a collection of persons or elements that have some common characteristics. The size of population is equal to the number of elements involved. It is basically the set on which your research results will be applied. In our research, the population is small scale manufacturers who intend to apply Vendor Managed Inventory and desire to proceed in the right way so that they can avail maximum benefits. Though our study is specific for small scale auto parts manufacturer and our sample relates to auto parts sector but the results obtained are beneficial for any small-scale manufacturer.

Sample: It is the small portion of the large population chosen by the researcher for analysis. There are various methods for choosing different samples from the population. The various sampling techniques are Probability Sampling and Non-Probability Sampling. Probability sampling involves random picking up of samples from the population: Systematic sampling to ensure that information is obtained from every corner and perspective. Cluster Sampling for getting unbiased results by picking up a random cluster. Multi stage sampling where randomly picked clusters are further separated into groups of various types.

Non-probability Sampling: This is a method where researchers does not rely on random samples. It is more effective technique. The sample chosen is generally purposeful. The sampling methods used in this type of sampling are:

(a) Convenience sampling: If sample is not easily available and getting information is costly, this method is adopted for sampling.

(b) Purposive sampling: In this we use sample depending on purpose of research.

(c) Quota Sampling: The sample chosen in this method depends on a pre- fixed standard.
(d) Snowball sampling: When the population set is not known to the researcher, we take help from the initial set of elements to recommend the elements for further data collection. So, it keeps on increasing in size like a snow ball. [61] [62].

In our case, as we have followed interview method for research so the sample chosen by us is purposive and snowball. We chose few persons who are related to or deal with many small auto parts manufacturer and understand that what challenges and what outcomes they expect from Vendor Managed inventory. Our respondents are Managers in Industries who know the details of this technique and small auto parts manufacturers in NCR region.

(a) The respondent has been convinced about the aim and objectives of the research and agreed to contribute to this study
(b) The respondent is an auto parts manufacturer or official of repute in the field of Supply Chain Management in National Capital Region of North India.
(c) The respondent has knowledge and experience in inventory management or other functions influencing it (like, supplier relationship, procurement, and materials requirements planning)
(d) The respondent has good English, Hindi, or Punjabi language skills
(e) The respondent does not violate any ethical or company policies in providing responses for this research.

2.6.4 DATA COLLECTION

In any research, the method of data collection is extremely important. Inaccurate data collection leads to inaccurate results. For quantitative data, there are various instruments for data collection that are easy to analyse. In general, the techniques that deal with both the qualitative and quantitative part will give more detailed and accurate results [61] [62]. Some of the data collection techniques are:

1. Observation: These techniques are used wherein the researcher records all the data for later use. It is used in study related to checking safety measures, assessment of damage or bad effects on health etc. It is very effective method if data collector is experienced and skilful.
2. Survey or Questionnaire: Questionnaires are best for collection of data as it can be filled by mail, telephone or through internet. When we require information from a large group of people we use questionnaires or survey. The questions included in these methods can be multiple choice, open ended and true/false etc. In surveys, main advantage is that the respondents take time to answer the survey questions. The responses cannot be biased by the collector. The main challenge in survey is the low response rate and delay in receiving responses. Generally, researcher tries to keep the survey short and in a logical sequence. The language used in questions is also very simple.
3. Interviews: Interview method is a focussed and planned interaction between two or more people regarding desired information. The interview method is the most reliable method for getting information as the respondent in every research may not be very aware or literate person. As interviews can be face to face and telephonic, so the respondent feels free to express his thoughts and perceptions in a refined way. Depending upon the topic of research, the interview methods can be listed as:
    a. Telephonic interview: These are generally cost effective and shorter than face to face interviews. In this interview, tone of the respondent gives you a better judgement of responses. This method is used when respondents are far or the respondent has time constraints. It is generally shorter than face to face interview.
    b. Video interviews: In this method as you are able to notice the expressions as well as voice tone of the respondent, the method is more useful due to clarity of responses. The only drawback can be a poor connection or interruption in internet signal.
    c. Face to face interviews: These interviews are expensive to arrange and sometimes it is difficult to schedule due to time constraints. Sometimes

respondents are not available. This is very effective if respondent is a knowledgeable person in his field.

4. Experimental: This data collection technique is used when we have to study materials, chemical changes of an element etc. Such studies do not require any other source of data collection. The whole analysis is done based on the experimental findings. It is generally used in environment related research, material science, research related to chemistry. Its reliability depends upon the sample used and quality of instrument.
5. Quasi experimental method: This is generally used to calculate the effect of change in variable on a focussed group. This is generally used in social researches. It is used to compare pre-test and post test results. Pre- test is done to find out whether there are certain tendencies in the participants. Generally, naturally occurring variables like age, height etc. are studied by this technique.
6. Simulation techniques: Simulation techniques are related to producing a replica of the process or system under study. It is used in training, computer experiments, safety engineering, robotics, satellite navigation. The researchers use simulators that create same conditions or objects. There are various simulation techniques available which are used depending upon the research area. [61] [62].

In this research, we used the interview method for data collection in our research as it is more reliable and cost effective. We gathered responses through telephonic interviews; the research requires quantitative data about the factors included in the initial structural construct.

2.7 SUMMARY OF CHAPTER 2

This chapter forms the basis of our research, this is the literature review chapter. It can be broadly classified into two parts, first one dealing with VMI and the second one as review of research methods, research approaches and research analysis techniques. It begins with analyzing the loopholes of inventory optimization and then a thorough review of literature on VMI. The knowledge of inventory management challenges, VMI, and the factors enabling success of VMI has been formed in two sections. The next section presents an initial structural construct that guided the primary research of this study. Though the initial structural construct was further improved in chapter 4 after interview of experts in chapter 3. The last part of the chapter relates to review of the research methodology, philosophy and approach adopted in further chapters. The various methods and approaches are briefly explained and then the research method, approach is chosen that is appropriate for our research. This chapter provides us with a well- defined path for further research.

3. INTERVIEWS WITH SUPPLY CHAIN AND LOGISTICS PROFESSIONALS IN THE MANUFACTURING COMPANY SELECTED FOR PILOT STUDY

3.1 INTRODUCTION

An organised in-depth interview process was conducted with 30 supply chain professionals in the auto parts manufacturing organisation selected for the pilot study. The interviews were conducted to collect data about the current VMI/non-VMI practices followed by the organisation. The interviews helped in developing a strategy for pilot study of VMI, and developing a strategy for measuring the value of VMI as compared with pre-VMI inventory management practices. The interviews were conducted as a cross-sectional study (data collected in 15 days only) whereas the pilot was conducted as a longitudinal study (data collected over a period of 18 months). The interview data was analysed after reducing and categorising the data as per the variables studied in the literature review.

3.2 INTERVIEW DATA OUTCOMES

The interview questions were organised in a semi-structured fashion. The design of the questionnaire was based on the initial structural construct presented in Section 2.5. For each variable influencing VMI performance, a question was framed. The idea was to collect data on the factors related with the variable and compare with the input factors discovered from the detailed literature review conducted in Chapter2. The questionnaire presented used in the interviews is the following:

Q1: In your experience, which factors contribute to increase in supply chain costs?

Q2: In your experience, which factors help in smoothing of sudden demand shocks?

Q3: In your experience, which factors contribute to just in time deliveries?

Q4: In your experience, which factors contribute to optimum order fulfilment?

Q5: In your experience, which factors help in reducing inventory management risks?

Q6: In your experience, which factors help in reducing suppliers-related risks?

The in-depth interviews method largely generates qualitative data; unless the respondents share some quantitative reports during the interview process. The respondents were requested to provide detailed descriptions and examples related to the questions. The free text answers and examples were recorded for transcribing them. The transcribed textual data was analysed deeply and multiple definitive facts were derived through an iterative reading process. After collecting all the definitive facts, the duplicate statements stating the same fact were identified (by interpreting their languages carefully) and combined. Finally, the definitive facts were placed under the respective themes of Questions 1 to 6. This was necessary because the respondents were not necessarily providing only the information tied to the context of the question asked. Some of the information provided in response to a question was better related to another question. To create a clean model of facts, the definitive facts had to be grouped together under a variable carefully.

Table 2: Definitive facts derived from the detailed free text responses provided by the supply chain experts interviewed.

S. No.	**Variable**	**Definitive Facts**
1.	Increase in supply chain costs	Lack of integration in organisational structures, processes, and tasks allocated to people; Lack of strategic partnerships with suppliers; Non-optimal utilisation of supply chain capacities (example: partially loaded trucks, lack of internal storage planning, unplanned internal movements of

S. No.	**Variable**	**Definitive Facts**
		materials, etc.); Delays in approvals and fund allocation; Lack of cross-functional training of workers; Idle times of people and machines; Lead time delays in replenishments of input buffer stocks; Machine-level or whole factory breakdowns; Partial or full strikes; Too many rejections during audits (lack of quality assurance during process execution); Too much wastage of materials; Overstocking of products in inventory; Poor visibility into demands and supplies; Lack of appropriate costing mechanisms, budgeting, and tracking and measurements of expenses;
2.	Smoothing of sudden demand	Demand visibility;

S. No.	Variable	Definitive Facts
	shocks	Accurate demands forecasting; Strategic safety inventories based on close analysis of the demands flows; Strategic partnerships with customers to share demands and consumption data; Strategic partnerships with suppliers to gain visibility into the supply processes and channels, and the suppliers in progress for current order fulfilment; Information quality and trustworthiness of intelligence gathered;
3.	Just in time deliveries	Strategic partnerships with suppliers to gain visibility into the supply processes and channels, and the supplies in progress for current order fulfilment; Integrated information systems shared with suppliers and customers; Timely and accurate visibility into demand flows; Advance planning of materials through strategic demand intelligence; Elimination of unnecessary processes

S. No.	Variable	Definitive Facts
		causing delays in supply chain flows;
4.	Optimum order fulfilment	Strategic partnerships with customers to share demands and consumption data; Capturing seasonal fluctuations in demand accurately and timely; Timely stocking of additional materials whenever seasonal fluctuations are predicted; Strategic partnerships with the suppliers; Strategic partnerships with suppliers to gain visibility into the supply processes and channels, and the supplies in progress for current order fulfilment; Integrated information systems shared with suppliers and customers; Timely and accurate tracking of demand patterns and fluctuations;
5.	Reducing inventory management risks	Adopting and implementing a strategic risks assessment, mitigation, and management strategy; Timely visibility into the supply chain

S. No.	Variable	Definitive Facts
		events; Estimation of normal to adverse impacts of supply chain events and proactive planning of mitigation actions; Continuous tracking of inventory consumptions and matching them with changing demand patterns; Contiguous tracking of demand fluctuations and continuous readjustments in replenishment levels and timings; Near real time sharing of data and information with suppliers; Continuous auditing of inventory quality assurance to predict chances of large scale rejections when critical production tasks are in progress;
6.	Reducing suppliers-related risks	Adopting and implementing a strategic risks assessment, mitigation, and management strategy; Timely visibility into the supply chain events; Estimation of normal to adverse impacts of supply chain events and proactive

S. No.	Variable	Definitive Facts
		planning of mitigation actions; Maintaining close collaboration and communications with the suppliers; Maintaining multiple suppliers; Building capabilities jointly with suppliers to handle demand shocks;

The definitive facts collected have been tied closely with the variables influencing VMI performance, as presented in the initial structural construct in Section 2.5. The responses are discussed and analysed in the next section keeping the initial structural construct engaged with the context of analysis.

3.3 DISCUSSIONS AND ANALYSIS

The initial structural construct presented in Section 2.5 reveals the key variables influencing the factor variables associated with VMI performance. The discussions and analysis presented in this section are in the context of matching or any possible contrast with those key variables discovered from the literature review. Hence, the discussions and analysis is conducted by first revisiting the initial structural construct and then mapping it with the findings captured from the in-depth interviews.

The results revealed an in-depth view into the variables affecting the factors influencing VMI performance as derived in the Section 2.5. It should be noted that these respondents were not practicing VMI at the time of the interviews. However, they were very much aware of the factors influencing the VMI performance and the variables affecting the factors, as revealed in the literature review. This means that they were clear about the measures that make VMI successful in an organisation.

The keywords coming out of the interview data are trustworthiness, collaboration, willingness, quality, and dynamic abilities. Trustworthiness, collaboration, and willingness are variables related to good and fruitful relationships with both suppliers and customers. Such relationships can be formed through transparency, honest and trustworthy partnerships, sharing of risks and gains, sharing of resources, facilities, and working capital funds, sharing of information and information processing, storage, and transmission facilities, and sharing of intellectual property rights, patents, secret technical knowhow, secret production methods, design, and other attributes. The value of sharing, collaboration, and communications is very well established. [44] [18]. Timely, accurate, and adequate sharing of information is the most crucial aspect of trustworthiness, collaboration, and willingness. Such arrangements require strategic agreements, partnerships, technical and procedural integration, and integration of organisation structures and power systems.

The initial structural construct in Section 2.5 presented the perspective of dynamic abilities derived from literature review. The perspective incorporates ability to absorb critical supply chain dynamics, like change of product types and range, changes in market and consumer expectations, change in demand elasticity, change in distribution lead times, and change in the scale of markets (market expansion). In the modern supply chains, the change in market structures should also be absorbed. For example, the market may introduce an exchange-based or forum-based system, or usage of Internet for order booking and delivery scheduling may be introduced.

An individual manufacturing company with traditional agreements signed with suppliers and customers, following traditional hierarchy and boundary-driven processes, and maintaining a strategy of keeping a distance and disconnected approach of handling suppliers and customer orders cannot build dynamic capabilities. Dynamic capabilities need to be developed industry-wide and cannot be confined within an organisation. This philosophy has come out clearly in the interview outcomes. However, the advanced dynamic capabilities have not come out clearly, because the professionals interviewed are very much focussed at ground-level gaps and challenges of supplier-buyer relationships instead of collective handling of demands and order bookings. Aspects like continuous visibility, continuous tracking, and continuous readjustments have been emphasised. While the respondents have clearly emphasised the value of demand-driven organisation of processes and systems, they have not expressed the need for the suppliers to visualise end-customer demand patterns. Perhaps, the business model involving manufacturer requires visibility into inter-echelon demands instead of end-customer demands. Although, this variation is apparent the respondents do not appear to be suggesting anything against the philosophy of demand visualisation and collaborative efforts to meet the demands with all their dynamics they offer to a manufacturing company.

Olufemi *et al.* (2016), and Sanchez-Ramirez *et al.* (2014) [10] [32] discussed that multi-party collaborative strategies like just in time, collaborating forecasting and replenishment, vendor-managed inventory, third and fourth party logistics (3PL and 4PL), and quick response are needed to implement dynamic capabilities, and derive full benefits from them. This research study derived VMI as the strategy suitable for the pilot study presented in Chapter 6. This is because the test organisation is a manufacturer of auto parts and works more with manufacturer than procuring readymade raw parts from the market. The market is faced primarily by the main manufacturer and hence other strategies are not applicable. However, collaborative forecasting is very much needed to get the best services from the manufacturer, with or without VMI.

Post completing the interviews with every respondent, a discussion on the benefits of VMI was initiated with every respondent. Although, not every respondent could provide answers majority of them could enumerate at least couple of benefits of VMI. Some of these benefits were suggested by Olufemi *et al.* (2016), and Sanchez-Ramirez *et al.* (2014) [10] [32]. With the knowledge of variables influencing the factors affecting VMI performance, and the key benefits of VMI evolving from the perspectives of experiences supply chain professionals and supported by literature, the next step conducted in this research was evolving an interpretive structural modelling. It may be viewed as the next step after the initial structural construct but is based on data and a systematic quantitative methodology. A detailed report on studying VMI through interpretive structural modelling is presented in Chapter 4.

Chapter 5 presents the next step of this research: graph theory analysis. Graph theory was used to organise the construct by categorising the VMI benefits under three categories: decisive variables, operative variables, and budgeting variables. It helped in representing VMI effects on three categories of factors and in representing the interdependencies using definitive measures of factors and values assigned to them. The method helped in deriving diagraphs representing the interdependencies, and finally deriving the scope of improvements in each of the permanent functions evaluated using the diagraphs.

Finally, in Chapter 6 presents the report on the pilot setting, testing, and outcomes in an auto parts manufacturing company in India.

3.4 SUMMARY OF CHAPTER 3

The primary research for this thesis was planned in the form of a pilot VMI project at an auto parts manufacturer in NCR (North India). Before setting up the pilot project and running the testing, in-depth interviews were planned with the supply chain professionals in the organisation. The questionnaire for the interviews was designed as per the initial structural construct presented in Section 2.5. The interviews revealed the key variables affecting the six factor variables affecting VMI performance as discovered from literature review in Chapter 2. These key variables were similar to the findings in the literature review except that the respondents did not consider those variables requiring joint interfacing with the market because their suppliers were manufacturer instead of demand fulfilment partners. The next chapter presents the ISM outcomes.

4. VARIABLES INVOLVED IN SUCCESSFUL IMPLEMENTATION OF VENDOR MANAGED INVENTORY AND THEIR STRUCTURAL MODEL

4.1 INTRODUCTION

The importance of delivering products on right time can be well understood by the number of trucks we see while travelling on the highways. Any interruption in regular flow of products can result in disruption of business. The entire process that is behind this system includes transportation, storage, supplier coordination, logistics coordination, communication, data collection and analysis, and many more. Supply chain management is governed by the philosophy of collaboration with the external organizations to achieve common benefits for all stakeholders.

4.2 ROLE OF MANAGED INVENTORY

As the process of production and distribution involves a good amount of time, so the companies strive to make the products available within a reasonable time. Inventory decisions are vital decisions and are required to take in consideration multiple variables to achieve certain goals. Optimised inventory levels help organizations sustain or reduce the costs while maintaining a higher customer service level.

4.3 VENDOR MANAGED INVENTORY

As reviewed, Vendor Managed Inventory is an inventory control technique that allows companies to respond quickly to customer demands. As nowadays, businesses are spread across many countries so management of supply chain becomes the main concern. Similar to JIT Inventory management between OEMs (Carmakers) and Tier 1 (Component) suppliers, Retailers and suppliers are now shifting to Vendor Managed Inventory. In VMI process, inventory at retailer is directly monitored and managed by supplier. Supplier send out a shipping notification to retailer as a communication to what products are dispatched. This concept is already adopted by large organizations, like Wal-Mart, and Procter and Gamble. These are big fishes in the market and spend any amount of money to maintain a smooth functioning of supply chain, whereas for the middle level and smaller supply chains it is not easy to invest in any new process. There are certain variables, which we target to achieve through Vendor Managed inventory. The variables are very crucial in applying the VMI process.

The concept of VMI can be applied in any industry. In Automotive industry, 3PL (third party logistics) concept is adopted by large manufacturers in which, a third partner is responsible for maintaining the inventory at warehouse near to the customer which is mutual economic benefit to both customer and supplier. The concept of 4PL (fourth party logistics) has also matured in many parts of the world in which, a large sophisticated and IT-savvy organisation integrates multiple 3PL providers of a manufacturing company. However, in this research the 3PL model will be studied as Indian auto parts manufacturers are not yet introduced to the 4PL model.

4.4 LITERATURE REVIEW

The Literature review done till date reveals that there are various factors that are achieved if VMI is applied. The studies done so far have revealed the factors. Some researchers have tried to bring up some benefits of VMI adoption [28] [29], they have discussed ordering costs, inventory related costs, transportation costs in VMI, service levels targeted etc.

Cachon [24] [26] insisted on a fixed payment transfer method in VMI, He says, "VMI alone cannot assure a supply chain solution, both supplier and retailer must agree on fixed payment transfer methods". Dong and Xu (2007) [31] analyzed the effect of VMI on costs involved in the entire chain, they focused upon an integrated supply chain. A.Taleizadeh et.al. (2015) [12] defined, "VMI is a collaborative strategy between customer and vendor". The supplier is responsible for managing inventory at customer's end. The performance targets are mutually decided and are changed as per the requirement. All these studies focus on benefits of VMI but present a one-sided approach without taking care of the whole supply chain. Most of the studies on VMI focus upon changes introduced by one or two important factors responsible for inventory management.

An early study shows that the order release policy in use with VMI influences the level of inventory required at the vendor which directly affects the supplier's inventory cost. Vigtil (2007) [23] in another study on JIT (Just in Time) practices showed that the benefits of these inventory control methods flow to the buyer rather than supplier. Yao et al (2007) [36] argued that many researchers have tried to bring out the complexities in the supply chain [8] [36].

4.4.1 Literature on Interpretive Structural Model: ISM is used in various aspects of supply chain management. It is used in automobile industry for green supply chain [63], as the industries nowadays want to adopt green supply chain methods due to the rising environmental concerns. ISM is used by researchers for finding out third party reverse logistics provider from the third-party logistics providers available, as the technique holds the potential of giving structural approach to any critical problem. [64] [65] [66], ISM is used [67] for designing a business process orientation model, some used it to analyze the structural form of factors involved in Emergency support system [68], Chidambaranathan [69] used it for finding out the structure of critical factors in the function of supplier development. Supplier development involves a lot of time, planning and involves a huge capital, moreover the market value of product should not exceed the planned commercial value. All these things are taken into consideration during supplier development.

In our present work, we tried to find out all the factors/outcomes that we target after VMI implementation. We have explained various factors and applied ISM technique to give a hierarchy to each factor followed by application of Mic-Mac techniques to analyze driving and dependent factors. First section deals with these factors that we have listed after interviewing some experts in the field of supply chain management and some industry owners, managers etc., second section deals with these factors and a structural model is obtained after iterations, third section uses the MICMAC analysis, driving factors and dependent factors are identified ,finally a conclusion is drawn .This research will give a proper direction to the VMI partners and they can focus on the factors obtained at end to obtain their desired results.

4.5 OUTCOMES TARGETED IN IMPLEMENTATION OF VMI

The desired outcomes of applying Vendor Managed Inventory are discussed. These outcomes are developed as per the literature review and post interview discussions with the supply chain professionals.

- Better customer service/satisfaction
- Better management of goods
- Planned production
- Decreased Inventory holding costs
- Decreased storage area
- Increased reliability on supplier
- Timely delivery of goods/production
- Better documentation
- Decreased cost of products
- Better prediction of sales
- Better coordination / communication between supplier and retailer
- Improved trust between supplier and retailer.
- Efficiently managed supply chain

Better customer service/ satisfaction:

A goods manufacturing company cannot survive in today's competitive environment if the end customer is not satisfied. Therefore, this variable is one of the biggest determinants of success of VMI.

Better management of goods:

One of the major variables that encourage adoption of VMI process is the improved management of goods manufactured. As supplier gets hold of inventory management, it helps supplier align his production process in line with customer's requirements and to overcome the inconsistent demand patterns from customers. This gives supplier better control on manufacturing processes and planning. Hence, products are delivered in efficient manner and always on time.

Planned Production:

A quick and easy access to Retailer's inventory levels shall always help the manufacturer in laying a good plan for production of goods. At the same time, it helps suppliers schedule optimal lot size and plan work force and other resources. Planning is always the first step for achievement of results in any of the inventory models and in VMI too.

Reduced inventory-holding costs:

In traditional set-up, inventory is stored in larges batch sizes in big stores. Storage for long periods always cost companies lot of money and in addition to that loss due to damage or expired shelf life period. Use of VMI leads to reduced inventory holding costs and optimised inventory levels at storage area.

Reduced storage area:

Inventory is maintained in big stores, which consumes lot of space causing additional costs. Use of VMI leads to optimised inventory levels further reducing the costs related to space for storage as big warehouses.

Increased reliability on suppliers:

VMI model works on collaboration between manufacturers and retailers wherein manufacturers have complete access to inventory levels and have authority to deal with inventory levels to avoid any stock-out situations. This leads to increased reliable relationship between the two parties.

Timely delivery of goods/products:

Better management at vendor's end will ensure quick and efficient delivery of products. As soon as the inventory is about to reach the lowest mark, vendor makes sure that the product reaches the retailer's end

Improved Documentation:

More managed production and product delivery can be ensured if proper documentation is done at all levels. So post VMI, this will definitely be an additional benefit.

Reduced product costs:

VMI leads to effective inventory management, which helps in reducing inventory-carrying cost. Hence, cost of goods/products is reduced as well.

Better prediction of sales numbers:

Since the supplier is owner of inventory management process, the demand patterns can be analysed in a better manner over a period. This helps in prediction of sales in a better way.

Improved communication:

Coordination amongst supplier and retailer is prerequisite for successful implementation of VMI process. It helps in achieving common goals.

Improved trust among vendor/retailer:

Lack of trust in supply chain can lead to failure of a collaboration approach. VMI process brings in more trust and visibility leading to effective management of inventory.

After understanding all these variables, discussions with interviewees helped in thorough analysis of factors. The firms generally have profit goals and they do not move in a planned way i.e. giving more importance to crucial factors that later on help in achieving higher profits. We have tried to use ISM technique so that the variables are analysed and assigned a priority level.

4.6 UNDERSTANDING ISM

ISM is a systematic approach for formation of processes. It clears up the path and forms a linkage towards achievement of company's strategy, goals. Sometimes in the implementation of any new process, the focus on models, processes take away the attention on linkages between various variables. Concentrating on the right process can bring the desired result. [65] [67]

“ISM gives a structured approach to any complex system. ISM is a comprehensive systematic model to portray the structure of a problem in a carefully designed pattern”

“ISM is a result of years of practical and theoretical development. It analysis the various needs very quickly and efficiently and leads to structural improvement in service delivery”

4.7 THE ISM APPROACH

Once we have enlisted the various variables from our sources, the steps involved in applying ISM are as follows:

Step I: Finding the distinctive relationships between variables:

In the wake of the list of variables that are finalised after discussions with professionals and the input received from various experts in supply chain. The correlation between the various variables and their corresponding direction is decided. Symbols are used for denoting the relationship between two variables (‘a’ and ‘b’). The matrix that is formed is called the Structural Self Interaction Matrix. The symbol is decided according to the given relationship between ‘a’ and ‘b’ in the following ways:

i. If the variable ‘a’ is directly related to ‘b’, then ‘V’ can be used to denote the relationship;
ii. If variable ‘b’ influences ‘a’, then ‘A’ is used to denote the relationship;
iii. If both ‘a’ and ‘b’ are related to each other i.e. increase in a will ensure increase in ‘b’ and vice-versa. The relationship will be denoted by ‘X’;
iv. If both the variables ‘a’ and ‘b’ are not related to each other, then ‘O’ is used to denote the relationship.

Step II: Setting up the reachability matrix (RM):

In this reachability concept, the distinctive variables that are identified by the experts/researchers are correlated to each other and a relationship is represented in the form of a matrix. If a influences b, then the entry in the matrix is 1, if a doesn't influences b, then the entry is 0. This binary matrix will be called the IRM i.e. the initial reachability matrix.

Step III: Setting up FRM (Final Reachability Matrix):

The next level of RM will use the concept of transitivity. Transitivity will mean, if a influences b, b influences c, then a also influences c i.e. (a, b) =1, (b, c) =1 implies that (a, c) =1. These transitive relationships are denoted by 1* in the subsequent iterations. So, the final matrix is achieved.

Step IV: The RM so obtained is subdivided into different levels.

Step V: The RM is then converted into canonical form i.e. with most zeros in upper half of the matrix and unitary elements in lower half.

Step VI: Now according to the levels achieved, we can give a hierarchy to the various variables and a digraph is drawn.

Step VII: The final ISM model is presented with the relationship between them.

The SSIM that we get for the variegated variables is presented in Table 2.

Table 3: SSIM

	13	12	11	10	9	8	7	6	5	4	3	2
1	A	A	X	A	A	O	A	A	O	O	A	A
2	X	A	A	A	V	V	V	A	V	V	A	
3	X	A	A	A	V	V	A	A	V	V		
4	A	O	A	A	V	O	A	A	A			
5	A	A	O	A	V	O	A	A				
6	V	A	A	O	O	A	A					
7	V	V	A	A	O	A						
8	X	V	A	V	O							
9	A	O	A	O								
10	A	V	A									
11	V	X										
12	V											

Initial Reachability Matrix is formed based on the SSIM, and the values are assigned as discussed in step II (Table 3).

Table 4: Initial Reachability Matrix

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	1	0	0	0	0	0	0	0	0	0	1	0	0
2	1	1	0	1	1	0	1	1	1	0	0	0	1
3	1	1	1	1	1	0	0	1	1	0	0	0	1
4	0	0	0	1	0	0	0	0	1	0	0	0	1
5	0	0	0	1	1	0	0	0	1	0	0	0	0
6	1	1	1	1	1	1	0	0	0	0	0	0	1
7	1	0	1	1	1	1	1	0	0	0	0	1	1
8	0	0	0	0	0	1	1	1	0	1	0	1	1
9	1	0	0	0	0	0	0	0	1	0	0	0	0
10	1	1	1	1	1	0	1	0	0	1	0	1	0
11	1	1	1	1	0	1	1	1	1	1	1	1	1
12	1	1	1	0	1	1	0	0	0	0	1	1	1
13	1	1	1	1	1	0	0	1	1	1	0	0	1

The final reachability matrix is formed by applying transitivity as presented in Table 4.

Table 5: Transitivity application

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	1*	1*	1*	0	1*	1*	1	1*	1*	1*	1*	1*
2	1	1	0	1	1	1*	1	1	1	1*	0	1*	1
3	1	1	1	1	1	1*	1*	1	1	1*	0	1*	1
4	1*	0	0	1	0	0	0	0	1	0	0	0	0
5	1*	0	0	1	1	0	0	0	1	0	0	0	0
6	1	1	1	1	1	1	0	1*	1*	0	0	0	1
7	1	1*	1	1	1	1	1	1*	1*	1*	1*	1*	1
8	1	0	1*	1*	1*	1	1	1	1*	1	1*	1	1
9	1	0	0	0	0	0	0	1*	1	0	0	0	0
10	1	1	1	1	1*	1*	1	1*	1*	1	1	1	1*
11	1	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1*	1	1	0	1*	1*	1*	1*	1*	1
13	1	1	1	0	1	1	1*	1*	1	1	1	1	1

FOR LEVEL I: In this first level of selection, the variables that have same R.S. and I.S. are placed at the top level in digraph. In this first table the variable number 1, 9 are marked as the variables at Level I (Table 5).

Table 6: First Iteration

	R.S.	A.S.	I.S.
1	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	1, 2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13
2	1, 2, 4, 5, 6, 7, 8, 9, 10, 12, 13	1, 2, 3, 6, 7, 10, 11, 12, 13	1, 2, 6, 7, 10, 12, 13
3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13	1, 3, 6, 7, 8, 10, 11, 12, 13	1, 3, 6, 7, 8, 10, 12, 13
4	1, 4, 9	1, 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13	1, 4
5	1, 4, 5, 9	2, 3, 5, 6, 7, 8, 10, 11, 12, 13	5
6	1, 2, 3, 4, 5, 6, 8, 9	1, 2, 3, 6, 7, 8, 10, 11, 12, 13	1, 2, 3, 6, 8
7	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	1, 2, 3, 7, 8, 10, 11, 13	1, 2, 3, 7, 8, 10, 11, 13
8	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
9	1, 8, 9	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	1, 8, 9
10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	1, 2, 3, 7, 8, 11, 13	1, 2, 3, 7, 8, 11, 13
11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13	1, 7, 8, 10, 12	1, 7, 8, 10, 12
12	1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 13	1, 2, 3, 7, 8, 10, 11, 12, 13	1, 2, 3, 8, 10, 11, 12, 13
13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13	1, 2, 3, 6, 7, 8, 10, 11, 12, 13	1, 2, 3, 6, 7, 8, 10, 12, 13

FOR LEVEL II: In the second round of levels, Variable at number 4 qualifies for level II in the digraph (Table 6).

Table 7: Second Iteration

	R. S	A.S.	I.S.
2	2, 4, 5, 6, 7, 8, 10, 12, 13	2, 3, 6, 7, 10, 11, 12, 13	2, 6, 7, 10, 12, 13
3	2, 3, 4, 5, 6, 7, 8, 10, 12, 13	3, 6, 7, 8, 10, 11, 12, 13	3, 7, 8, 10, 12, 13
4	4	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13	4
5	4, 5	2, 3, 5, 6, 7, 8, 10, 11, 12, 13	5
6	2, 3, 4, 5, 6, 8	2, 3, 6, 7, 8, 10, 11, 12, 13	2, 3, 6, 8
7	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13	2, 3, 7, 8, 10, 11, 13	2, 3, 7, 8, 10, 11, 13
8	3, 4, 5, 6, 7, 8, 10, 11, 12, 13	2, 3, 6, 7, 8, 10, 11, 12, 13	3, 6, 7, 8, 10, 11, 12, 13
10	2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13	2, 3, 7, 8, 11, 13	2, 3, 7, 8, 11, 13
11	2, 3, 4, 5, 6, 7, 8, 10, 12, 13	7, 8, 10, 12	7, 8, 10, 12
12	2, 3, 4, 5, 6, 8, 10, 11, 12, 13	2, 3, 7, 8, 10, 11, 12, 13	2, 3, 8, 10, 11, 12, 13
13	2, 3, 4, 5, 6, 7, 8, 10, 12, 13	2, 3, 6, 7, 8, 10, 11, 12, 13	2, 3, 6, 7, 8, 10, 12, 13

LEVEL III: In the third round, variable 5 comes at the third level (Table 7)

Table 8: Third Iteration

	R.S.	A.S.	I.S.
2	2, 5, 6, 7, 8, 10, 12, 13	2, 3, 6, 7, 10, 11, 12, 13	2, 6, 7, 10, 12, 13
3	2, 3, 5, 6, 7, 8, 10, 12, 13	3, 6, 7, 8, 10, 11, 12, 13	3, 6, 7, 8, 10, 12, 13
5	5	2, 3, 5, 6, 7, 8, 10, 11, 12, 13	5
6	2, 3, 5, 6, 8	2, 3, 6, 7, 8, 10, 11, 12, 13	2, 3, 6, 8
7	2, 3, 5, 6, 7, 8, 10, 11, 12, 13	2, 3, 7, 8, 10, 11, 13	2, 3, 7, 8, 11, 13
8	3, 5, 6, 7, 8, 10, 11, 12, 13	2, 3, 6, 7, 8, 10, 11, 12, 13	3, 6, 7, 8, 10, 11, 12, 13
10	2, 3, 5, 6, 7, 8, 10, 11, 12, 13	2, 3, 7, 8, 11, 13	2, 3, 7, 8, 11, 13
11	2, 3, 5, 6, 7, 8, 10, 12, 13	7, 8, 10, 12	7, 8, 10, 12
12	2, 3, 5, 6, 8, 10, 11, 12, 13	2, 3, 7, 8, 10, 11, 12, 13	2, 3, 8, 10, 11, 12, 13
13	2, 3, 5, 6, 7, 8, 10, 12, 13	2, 3, 6, 7, 8, 10, 11, 12, 13	2, 3, 6, 7, 8, 10, 12, 13

LEVEL IV: At the fourth level of selection variables 6, 8, and 13 are selected as R.S. and I.S. is the same (Table 8).

Table 9: Fourth Iteration

	R.S.	A.S.	I.S.
2	2, 6, 7, 8, 10, 12, 13	2, 3, 6, 7, 10, 11, 12, 13	2, 6, 7, 10, 12, 13
3	2, 3, 6, 7, 8, 10, 12, 13	3, 6, 7, 8, 10, 11, 12, 13	3, 6, 7, 8, 10, 12, 13
6	2, 3, 6, 8	2, 3, 6, 7, 8, 10, 11, 12, 13	2, 3, 6, 8
7	2, 3, 6, 7, 8, 10, 11, 12, 13	2, 3, 7, 8, 10, 11, 12, 13	2, 3, 7, 8, 10, 11, 12, 13
8	3, 6, 7, 8, 10, 11, 12, 13	2, 3, 6, 7, 8, 10, 11, 12, 13	3, 6, 7, 8, 10, 11, 12, 13
10	2, 3 ,6, 7, 8, 10, 11, 12, 13	2, 3, 7, 8, 11, 13	2, 3, 7, 8, 11, 13
11	2, 3, 6, 7, 8, 10, 12, 13	7, 8, 10, 12	7, 8, 10, 12
12	2, 3, 6, 8, 10, 11, 12, 13	2, 3, 7, 8, 10, 11, 12, 13	2, 3, 8, 10, 11, 12, 13
13	2, 3, 6, 7, 8, 10, 12, 13	2, 3, 6, 7, 8, 10, 11, 12, 13	2, 3, 6, 7, 8, 10, 12, 13

LEVEL V: At the fifth level variable number 2 and 12 are selected (Table 9).

Table 10: Fifth Iteration

	R.S.	A.S.	I.S.
2	2, 7, 10, 12	2, 3, 7, 10, 11, 12	2, 7, 10, 12
3	2, 3, 7, 10, 12	3, 7, 10, 11, 12	3, 7, 10, 12
7	2, 3, 7, 10, 11, 12	2, 3, 7, 10, 11	2, 3, 7, 10, 11
10	2, 3, 7, 10, 11, 12	2, 3, 7, 11	2, 3, 7, 11
11	2, 3, 7, 10, 12	7, 10, 12	7, 10, 12
12	2, 3, 10, 11, 12	2, 3, 7, 10, 11, 12	2, 3, 10, 11, 12

Level VI: The variables 3 and 7 are selected at level VI (Table 10).

Table 11: Sixth Iteration

	R.S.	A.S.	I.S.
3	3, 7, 10	3, 7, 10, 11	3, 7, 10
7	3, 7, 10, 11	3, 7, 10, 11	3, 7, 10, 11
10	3, 7, 10, 11	3, 7, 11	3, 7, 11
11	3, 7, 10	7, 10	7, 10

LEVEL VII: At the seventh level, variable number 3 is selected (Table 11).

Table 12: Seventh Iteration

	R.S.	A.S.	I.S.
3	3, 10	3, 10, 11	3, 10
10	3, 10, 11	3, 11	3, 11
11	3, 10	10	10

LEVEL VIII: This final level is achieved by variable 11 and the variable ten attains the ninth level. This gives us the hierarchy of variables which are basically the best possible outcomes of VMI application (Table 12).

Table 13: Eighth Iteration

	R. S	A.S.	I.S.
10	10, 11	11	11
11	10	10	10

Finally, the iterations resulted in the variable outcomes presented in Table 13.

Table 14: Results obtained by ISM

ITERATION NUMBER	VARIABLES/ OUTCOMES THAT ARE SELECTED	LEVEL ASSIGNED FOR DIGRAPH
1	**1,9**	**I**
2	**4**	**II**
3	**5**	**III**
4	**6,8,13**	**IV**
5	**2,12**	**V**
6	**7**	**VI**
7	**3**	**VII**
8	**11**	**VIII**
9	**10**	**IX**

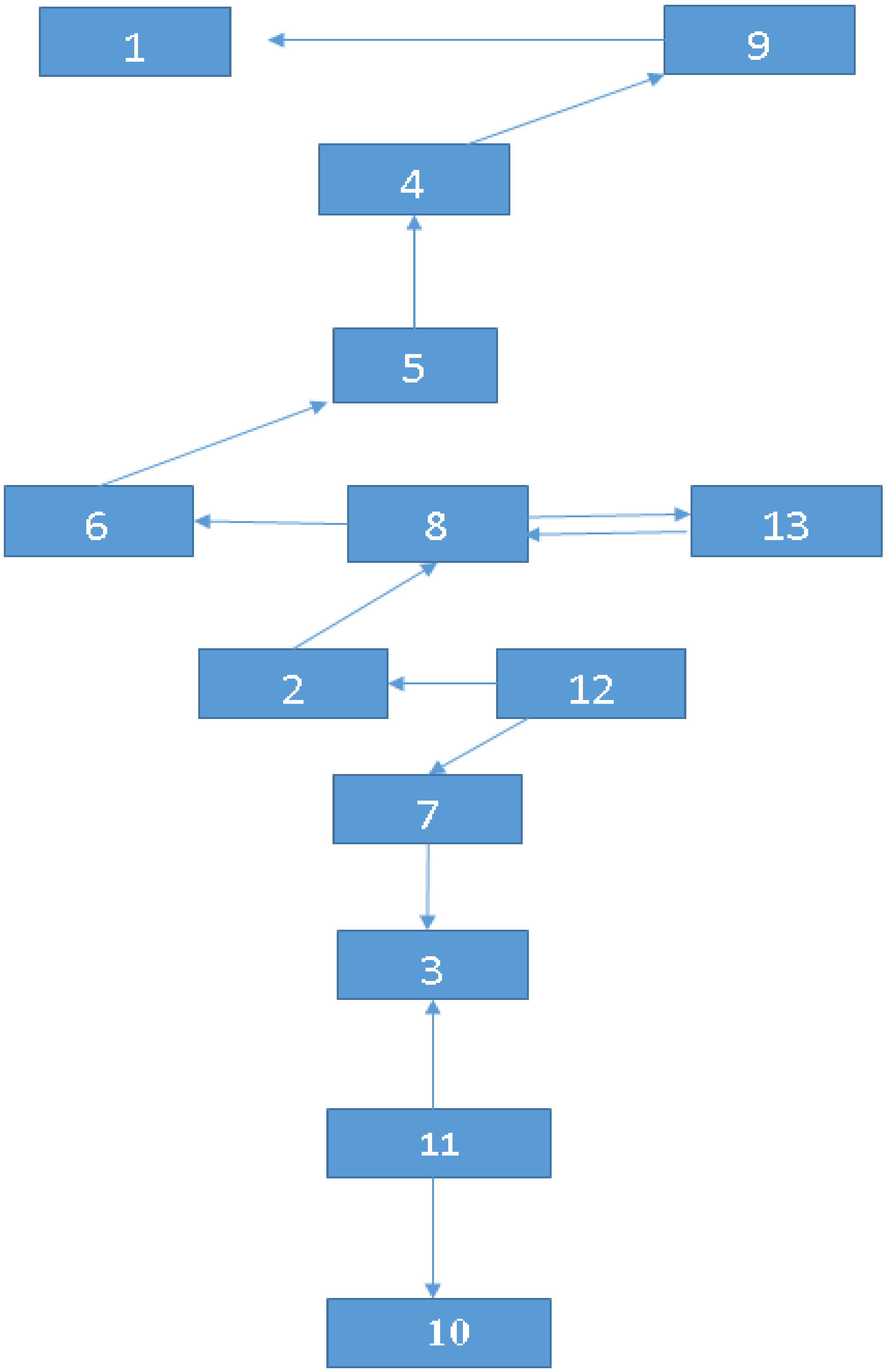

Figure 12: Diagraph obtained by ISM

The final diagraph obtained by ISM is presented in Figure 12. Figure 13 presents the variables represented by the numbers in the diagraph of Figure 13.

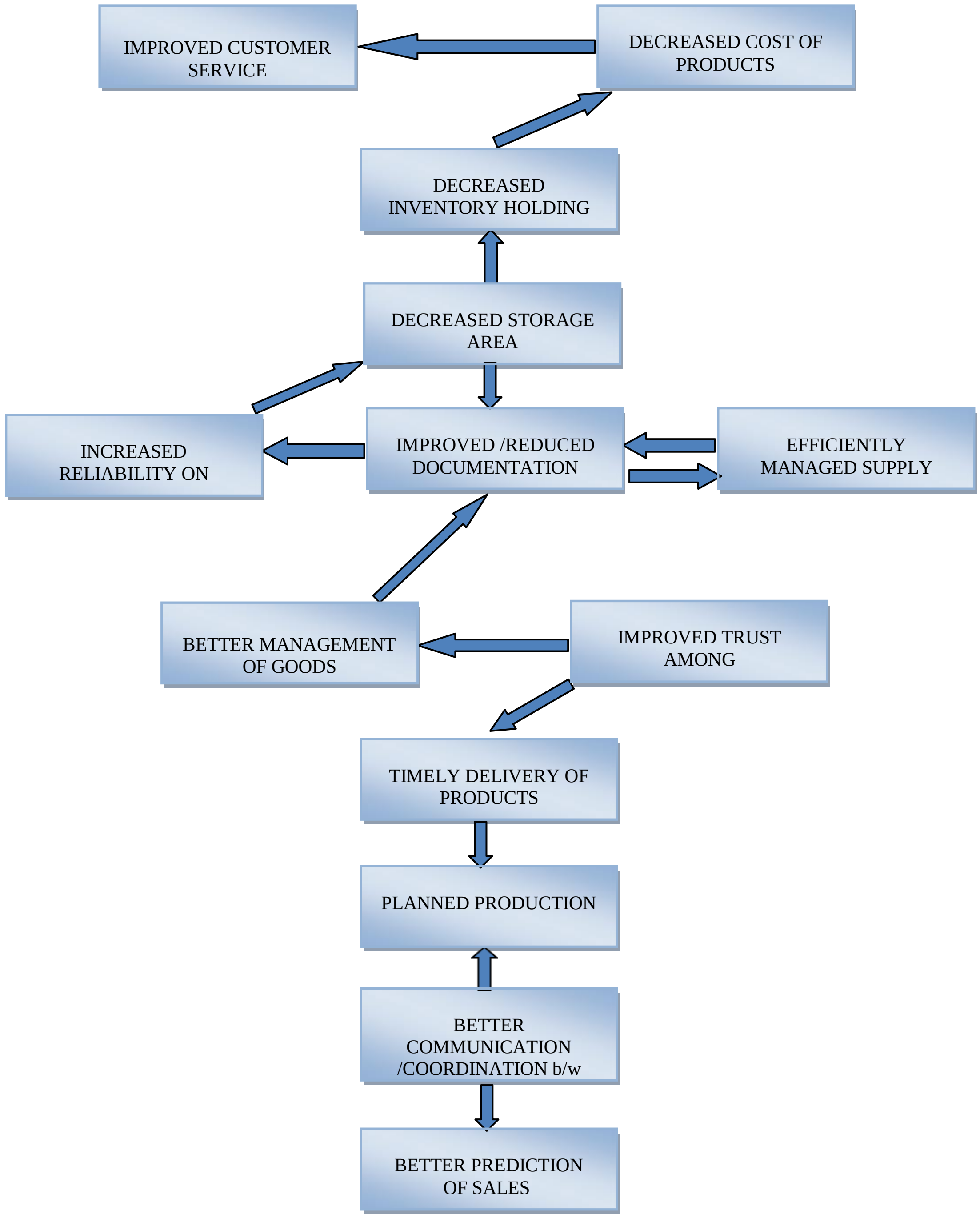

Figure 13: Actual variables obtained by ISM

4.8 THE MICMAC ANALYSIS

MICMAC analysis is done to calculate the driving power and dependence power of the variables listed as the desired outcomes of VMI process. It is a cross-impact matrix multiplication applied to classification also called Matrice d'Impact croises-multiplication applique and classment. Through MICMAC analysis, we can classify the variables that actually drive or impact other variables.

The variables are classified as:

(a) Autonomous variables: These variables have a weak driving power and weak dependence power as listed in this category. It occupies first quadrant. The variables listed in this quadrant are the least important variables.

(b) Linkage variables: These variables have strong drive power and strong dependence power. They lie in the third quadrant of the figure. These are strong variables and cannot be missed out.

(c) Dependent variables: These variables have a weak drive power and strong dependence. These variables lie in the second quadrant. They are dependent upon some other variables but are not able to drive the process.

(d) Independent variables: These are the variables, which have strong drive power, and weak dependence power. It is very influential variable in the process analysed by ISM.

The variables that fall in the independent or linkage variables are the key variables.

Through the MICMAC analysis, we can categorize the various variables as:

(a) The autonomous variable is improved documentation, which means it does not play any significant role in VMI implementation, as outcomes are not driven by this.

(b) The dependent variables are decreased inventory holding costs, decreased storage area, decreased costs of products, and better customer satisfaction.

(c) The linkage variables are better management of goods, planned production, and efficient management of supply chain.

(d) The Independent variables are reliability on supplier, better communication /coordination among vendor and retailer, improved trust relation between supplier and vendor and retailer, better prediction of sales and timely delivery of products.

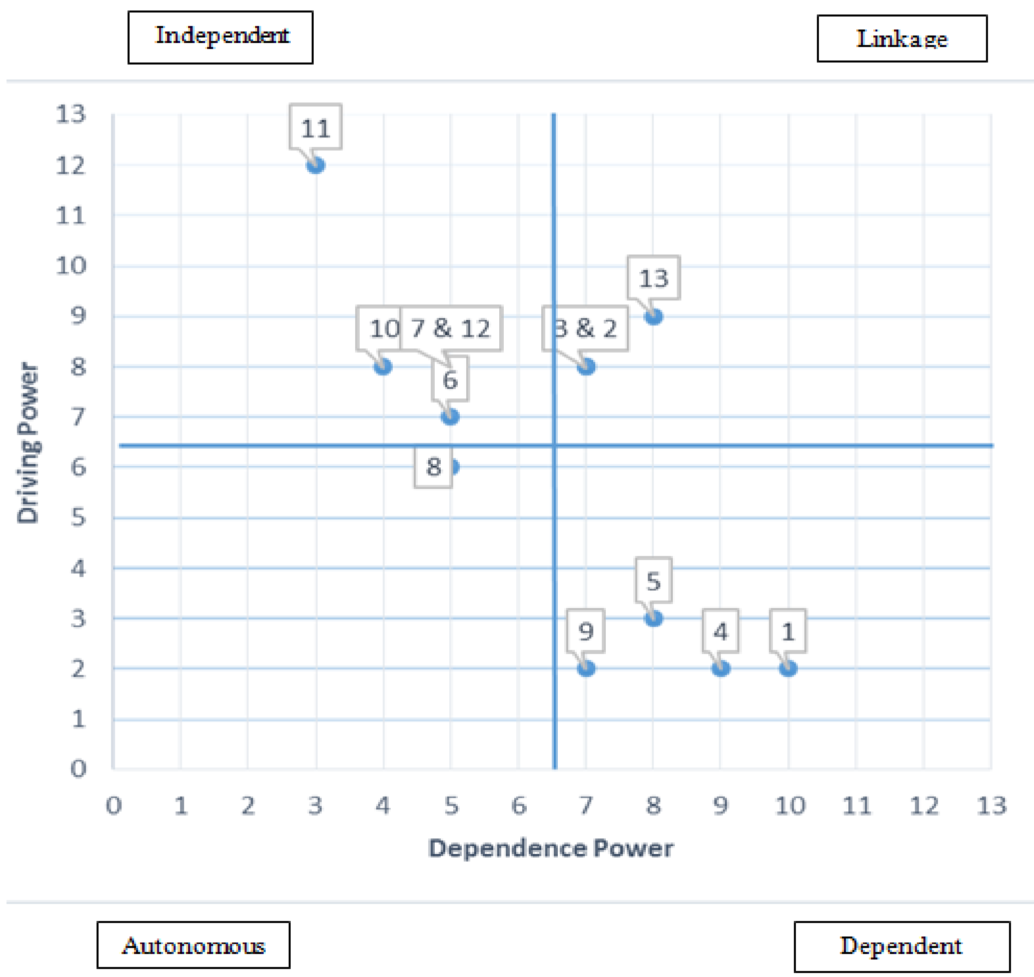

Figure 14: Classification of variables through MICMAC analysis

The MICMAC analysis confirms the key factor (independent) variables influencing VMI performance as reviewed in Chapter 2 and presented in the initial structural construct.

Reduced inventory holding costs (costs incurred in managing internal inventory) is the most significant dependent variable from the perspective of the supply chain professionals interviewed. Decreased storage area may be viewed as an enabler of decreased inventory holding costs, and decreased cost of products is an overall effect visible as inventory costs contribute significantly to the products cost.

4.9 CONCLUSION

In this work, we have shortlisted the various variables/ expected outcomes of applying Vendor Managed Inventory in any small-scale industry. Generally, the researchers have discussed the various models or they have done empirical study of this inventory management process. As a researcher, we have tried to do a complete analysis of all these variables by very successful ISM technique followed by MICMAC analysis. The results obtained are quite convincing; they show that the driving force behind the whole VMI process is reliability on supplier, better communication and coordination among vendor and retailer, improved trust relationship among supplier, vendor, and retailer, better prediction of sales, and timely delivery of products. These are the strongest variables, which will help any industry to apply VMI. The industry should keep its focus on these variables and the results will follow via the linkage variables i.e. better management of goods, planned production and efficient management of supply chain. The results achieved will be decreased inventory holding costs, decreased storage area, and decreased costs of products and better customer satisfaction. Moreover, VMI is not adopted in small-scale industries or middle level firms with small supply chain, where funds are limited. This analysis can be very beneficial for small supply chains that are planning to adopt VMI.

4.10 SUMMARY OF CHAPTER 4

ISM and MICMAC analysis are organised mathematical methods for studying the factors and their associated variables related to VMI performance. The initial structural construct evolved in Chapter 2 through literature review gets a more refined, focussed, and narrowed view as applicable to the auto parts manufacturer studied in this research. This approach may result in different constructs for other countries and their industries. It may be used as a generalised and useful technique to determine VMI performance before implementing it as the preferred technique for inventory management. However, it may also be kept in mind that this method does not provide the quantified values of the factors and associated variables. It only helps in deriving a categorisation as applicable in a specific industrial setting. The next two sections deal with techniques of quantification of the factors and variables related to VMI performance assessment in an industrial setting. Again, the techniques require specific data collection from the industrial setting under study and hence, results may vary by country, industry, business models, and many such specific attributes of the industrial research setting.

5. QUANTIFICATION OF THE BENEFITS OF APPLYING VENDOR MANAGED INVENTORY ON AN INDUSTRY USING GRAPH THEORETIC APPROACH

5.1 INTRODUCTION

The current competition in the market and complex supply chains led to use of many policies and management-systems. VMI (vendor-managed inventory) is also such a tool. It can also be referred as inventory management system controlled by supplier. The entire responsibility of managing inventory at the customer's end is taken by the vendor/supplier. By using any of the data interchange method, the supplier gets all information about the limits within which the inventory should be maintained. It also improved the efficiency of flow of materials in a supplier and retailer partnership. This collaborative approach ensures management, continuous replenishment and process coordination.

5.2 BACKGROUND

Vendor Managed Inventory has proved its success for big supply chains. Vendor Managed Inventory and Consignment Inventory gained popularity in India in the last decade; many big entrepreneurs adopted it in their business houses also. The studies still say that generally businesses derive 30-40% of the benefits. The small business houses in India still struggle to know the actual benefits they can obtain from Vendor Managed Inventory. The small-scale manufacturers do not know the benefits they should target and achieve long-term benefits. Our study relates more with the benefits of Vendor Managed Inventory for those who are in the process of adopting VMI. We analysed the various variable involved in VMI and through interviews with professionals and entrepreneurs, we listed the variables and categorized them in three headings that play the most important role in achieving all the benefits of VMI. In this work, we tried to quantify the benefits of these thoroughly researched variables.

5.3 LITERATURE REVIEWED

Faisal et al. [70] calculated the quantification of risk factors of supply chain using the digraph and matrix method. It also provides opportunity to integrate new variables that impact the risk mitigation environment of overall supply chain. Singh and Agrawal (2008) [71] identified the various structural patterns for manufacturing system. It served as a framework to develop various dimensions of performance i.e. maintaining flexibility, increased responsiveness etc. Many structures can be ranked and compared and the selection can be made for system wise optimization. S. Grover et al. [72] [73] used Graph theoretic approach to calculate the quality dimension of web 2.0. The purpose of the paper is to present the single numerical value for, “website quality dimension in 2.0 environment”. Jangra et al. (2011) [74] [75] used this graph theory approach for calculating performance of compacting die manufactured by wire EDM. They considered the “surface characteristics and dimensional accuracy” as an important attribute for judging the performance of a compacting die. The performance indexes were under combination of various factors/ sub-factors that evaluate the influence of factors considered. They also used GTA to evaluate the machinability of tungsten carbide composite with wire EDM. Material removal rate is considered important here. Researchers have used graph theoretic approach to analyze system and structure of an automobile vehicle [76], to study the causes of failures of the machine tools [77] [78] and to select machine group in a flexible manufacturing cell.

Table 15: Variables considered for applying VMI

S. No.	Categories	Sub variables
I	Decisive variables	• Better customer service • Efficiently managed supply chain • Timely delivery of products • Improved sale • Increased trust among supplier/customer
II	Operative variables	• Planned production • Better management of goods • Decreased storage area • Increased reliability on supplier • Better documentation • Better prediction of sales
III	Budgeting variables	• Decreased transportation cost • Decreased inventory holding costs • Reduced product cost

5.4 DECISIVE VARIABLES

These deciding variables will decide the overall impact of benefits of VMI on the industry that we have chosen. These are categorized as per discussions with experts. The variables included in this subhead are:

(i) Better customer service: Customer satisfaction is the most important determinant of success of Vendor Managed Inventory. It is therefore topmost in decisive variables.

(ii) Efficiently managed supply chain: The success of any of the inventory management methods is best measured by the efficiency of its supply chain. Therefore, this helps in determining the success of the process.

(iii) Timely delivery of products: Customer satisfaction is very much dependent on timely delivery of products. It actually proves that the supply chain is in proper coordination.

(iv) Improved Sales: One of the important variables that determine the success of VMI process is the increase in sales. Increased sales prove that the whole process is going in right direction.

(v) Increased trust among supplier/customer: Winning trust of customers is more difficult than increasing sales of the industry. Sustainable growth of any industry can be achieved only when trust relationship is there.

5.5 OPERATING VARIABLES

These are significant variables in the whole VMI process. This category is formed of those variables that play an important role in success of VMI.

1. Planned production: It is the process of production planning, and is highly organized in the supply chain network. Without production planning, the supply chain will result in overstocking only.

2. Better management of goods: Goods manufactured and their handling is again a key variable for deriving benefits of VMI for an industry.

3. Decreased storage area: One of the most significant variables for VMI. This variable yields to decreased inventory holding costs. Storage area and its rent etc. constitute a major component of inventory costs.

4. Increased reliability on suppliers: Without sharing a reliable relationship, neither the supplier nor the retailer can achieve success in this information sharing process.

5. Better Documentation: Better Management and Documentation are interrelated to each other. They show interdependence too. This variable resolves all the financial issues between the supplier and retailer.

6. Better prediction of sales: It is a detrimental variable for achieving timely production and delivery of products at the customer's end. This variable cannot be ignored in the list of significant variables.

5.6 BUDGETING VARIABLES

These variables are directly related to the money matters. The major sub-variables in this category are:

1. Decreased transportation cost: The cost of transportation can be reduced significantly by choosing a suitable VMI process. In some of the VMI agreements, this cost is shared between suppliers and retailers. Both parties receive the benefits in due course of time.
2. Decreased inventory holding costs: It is one of the major components of inventory costs involved in holding and maintaining the right amount of inventory. This variable plays an important role in budgeting variables.
3. Reduced product cost: This reduction in cost is very much related to implementation of operative variables. This again contributes towards the financial matters of a company.

5.7 GRAPH THEORY

Graph theory has proved itself in many fields of science and technology like mathematics, chemistry, physics, economics, operation research, linguistics etc. it has played an important role in network analysis, diagnosis, functional representation etc. It is closely related to various branches of Mathematics including matrix theory, group theory, probability, topology, and combinatory analytics. [79] [80]

Graph theoretic approach has the following advantages:

(a) It gives a simple numeric value to all the variables.
(b) It cares for the directional relationship and interdependence among the variables and its various sub variables.
(c) It is a very systematic approach for converting qualitative variables in to quantitative values.
(d) GTA allows computer processing as well as visual analysis of variables involved.
(e) It allows comparison between different organizations and also self-analysis.

Using these features of GTA, authors have tried to quantify the benefits of VMI on an industry and provided a platform for self-analysis. The benefits of VMI depend upon the inheritance of different variables that influence the VMI Process. These are modelled by a network of variables and interactions between them. These are represented in the form of a diagraph. The variables are classified in to three categories and the benefits of VMI are found in "BOV", measuring how much benefits are obtained by the use of VMI.

Main objective is correlation between the three categories of variables and their quantification. For this the quantification is done based on their sub-variables and interdependent relationships that they share through graph theoretic approach.

The main components are:

(a) Directed graph
(b) Representation in matrix form
(c) Representation of permanent function

The directed graph [79] helps us to look at the interdependencies between the variables. The matrix converts these interdependencies in mathematical form and helps us to calculate the 'BOV' value. A methodology for evaluation of BOV for an Industry is proposed through the basis of GTA.

Main Steps involved in this process are the following:

(a) The variables that help a company gain from VMI in terms of list of management benefits are listed. These are obtained after interviews with experts and researchers in this field.
(b) Based on these, a diagraph is formed which considers all the variables and their interdependence. The three major heads identified will become the nodes, and the direction of the edges gives their interdependence.
(c) A diagraph is developing b/w the sub variables depending on the linkage among them.
(d) From this, a matrix is developed. It is an m*m matrix, where the diagonal element represents sub-variables and off diagonal elements represent the interactions b/w them.
(e) Finally, calculation of 'permanent function' is done.

Develop the BOV matrix calculating the benefits from the diagraph. Value of permanent function at each sub-variable level provides inheritance for each variable; it is again decided after discussions with experts.

Now calculate the permanent function 'BOV', which quantities all the VMI benefits.

5.8 FORMATION OF DIGRAPH

A directed graph or diagraph is used for representing the variegated variables and their mutual interdependence. It consists of set of nodes B= $\{B_i\}$ with i=1,2,3……, M and a set of edges B= $\{b_{ij}\}$. Node B_i will represent the i th variables and its edges will represent interdependencies between the variables. The number of nodes will be equal to the number of variables considered. If the node i has some connection with the node j, an arrow is directed form i towards j. if node j has some connection with node i i.e. they have an interrelationship, an arrow is directed form j to i. According to interdependencies of these variables, the directed edges are shown (b/w B_1, B_2, B_3). The digraph is formed as shown and this will help the decision makers and experts to see the analysis of VMI implementation and the interrelationship they have. If they increase beyond a certain limit, complexity of representation is solved by use of matrix form.

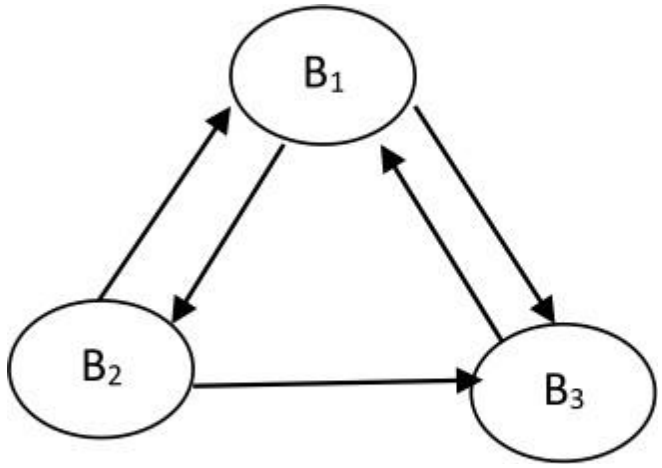

Figure 15: A diagraph

5.9 THE MATRIX REPRESENTATION

A matrix is easy and informative way of representing a digraph for further computer calculation. The matrix representation of benefit-calculated variables in VMI is represented in form of binary matrix b_{ij}:

$$B^* = \begin{array}{c} \\ B_1 \\ B_2 \\ B_3 \end{array} \begin{array}{c} \begin{array}{ccc} B_1 & B_2 & B_3 \end{array} \\ \begin{bmatrix} B_1 & b_{12} & b_{13} \\ b_{21} & B_2 & b_{23} \\ b_{31} & b_{32} & B_3 \end{bmatrix} \end{array} \qquad \text{Equation (1)}$$

B_1, B_2, and B_3 represent the VMI effects on three categories of variables and bij represents interdependencies between ‘i’ and ‘j’.

5.10 DECIDING THE INHERITANCE AND INTERDEPENDENCE OF VARIABLES

The inheritance of variables is decided as per the following values:

Table 16: Inheritance of variables

Measure of variable	**Value assigned**
Extremely insignificant	1
Very insignificant	2
Moderately insignificant	3
Slightly insignificant	4
Medium value	5
Slightly significant	6
Moderately significant	7
Very significant	8
Extremely significant	9

Interdependence of variables in VMI is decided as per the following values:

Table 17: Interdependence of variables

Quantitative Measure of variable	Value assigned
Very Low	1
Low	2

Medium Level	3
High	4
Very High	5

Quantification of the benefits of applying VMI on Industry using graph theory:

$$B^* = \begin{array}{c} \\ B_1 \\ B_2 \\ B_3 \end{array} \begin{array}{c} \begin{array}{ccc} B_1 & B_2 & B_3 \end{array} \\ \begin{bmatrix} 7 & 4 & 2 \\ 1 & 8 & 2 \\ 2 & 4 & 9 \end{bmatrix} \end{array}$$ Equation (2)

5.11 PERMANENT REPRESENTATION

Using the distinct representation of diagraph and matrix, permanent function of productivity matrix is calculated B*, the permanent function is a standard matrix function, used in combinatorial mathematics. A quantitative value of benefits obtained on applying VMI is calculated using this permanent function. The equation obtained contains 31 terms and these are arranged in n+1 groupings, where n is the number of variables.

Here n= 3.

'BOV'=Per B= $B_1B_2B_3 + (b_{12}b_{21}) B_3 + (b_{13}b_{31}) B_2 +(b_{23}b_{32}) B_1 +(b_{12} b_{23}b_{31} +b_{13}b_{32}b_{21}) B_3$

The first classification of variables is represented in the form of digraph as presented in the figure below:

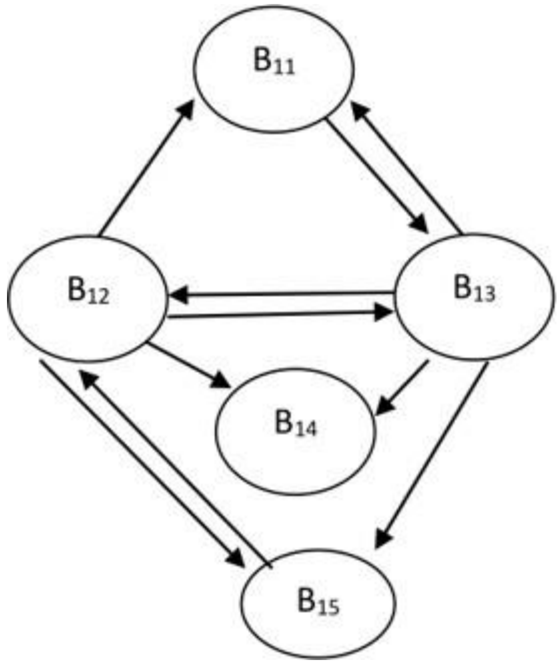

Figure 16: Formation of digraph of decisive variables

The corresponding matrix formed is given as the following:

$$
\begin{array}{c} \\ B_{11} \\ B_{12} \\ B_{13} \\ B_{14} \\ B_{15} \end{array}
\begin{array}{c} \begin{array}{ccccc} B_{11} & B_{12} & B_{13} & B_{14} & B_{15} \end{array} \\
\begin{bmatrix} 8 & 3 & 3 & 5 & 2 \\ 4 & 8 & 3 & 4 & 3 \\ 4 & 4 & 7 & 4 & 2 \\ 2 & 4 & 3 & 7 & 3 \\ 3 & 4 & 2 & 3 & 6 \end{bmatrix} \end{array} = B_1^*
$$

Equation (3)

The digraph formed for the operative variables is given as in the following Figure:

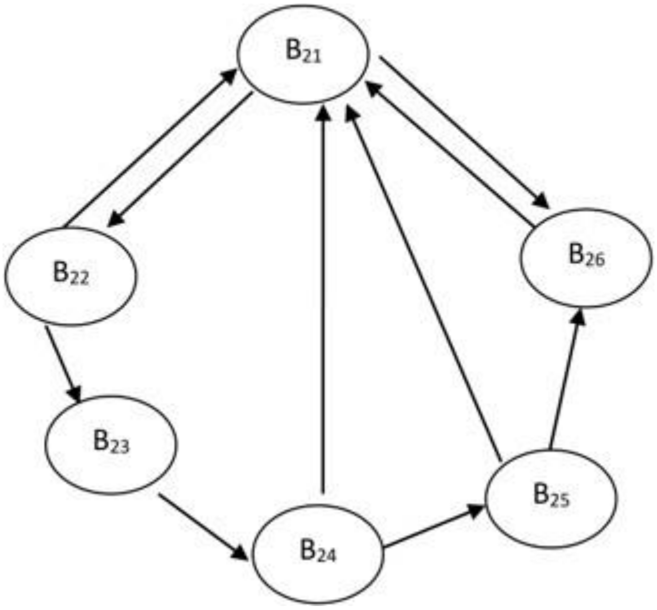

Figure 17: Digraph formed for the operative variables

The corresponding matrix formed is given as the following:

$$
\begin{array}{c} \\ B_{21} \\ B_{22} \\ B_{23} \\ B_{24} \\ B_{25} \\ B_{26} \end{array}
\begin{array}{c} \begin{array}{cccccc} B_{21} & B_{22} & B_{23} & B_{24} & B_{25} & B_{26} \end{array} \\
\begin{bmatrix} 8 & 4 & 2 & 3 & 4 & 4 \\ 3 & 7 & 1 & 1 & 3 & 3 \\ 1 & 2 & 4 & 1 & 1 & 2 \\ 1 & 2 & 1 & 3 & 1 & 3 \\ 4 & 4 & 2 & 2 & 6 & 3 \\ 4 & 4 & 3 & 2 & 4 & 8 \end{bmatrix} \end{array} = B_2^*
$$

Equation (4)

For budgeting variables, the digraph is given as in the figure below:

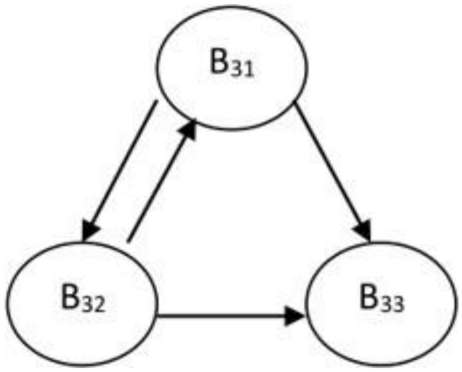

Figure 18: Diagraph for budgeting variables

The matrix that corresponds to this is given by the following:

$$B_3^* = \begin{matrix} & B_{31} & B_{32} & B_{33} \\ B_{31} & 7 & 2 & 4 \\ B_{32} & 3 & 9 & 5 \\ B_{33} & 4 & 4 & 8 \end{matrix}$$

Equation (5)

5.12 THE APPLICATION

In this application part, researchers tried to access benefits of VMI on small-scale industry using VMI for resolving inventory issues. We followed the following steps:

(a) We identified the major variables and used the table I for values.
(b) The various sub-variables listed under the major variable were assigned values from table I.
(c) Directed graph is developed showing the linkage b/w them.
(d) The numerical inheritance values are assigned and the interdependent values are assigned (using the tables II and III).
(e) The matrix and diagraph are formed for all three categories of variables.
(f) The values are calculated for B_1*, B_2*, B_3* and B* using GRAPHER tool.

(g) These values are than compared with the hypothetical maxima that can be obtained in each category and analyzed for further scope of improvement in each of the variables.

5.13 RESULTS CALCULATED USING GRAPHER

‘GRAPHER’ is a tool specifically designed to calculate the permanent function of interdependent variables. This tool is used to calculate result from the matrix obtained using digraph. The numeric value obtained in our case shows the benefits derived by the industry from that particular category of variables.

Value obtained for $\square^*_1$, $\square^*_2$, $\square^*_3$ and B* respectively are:

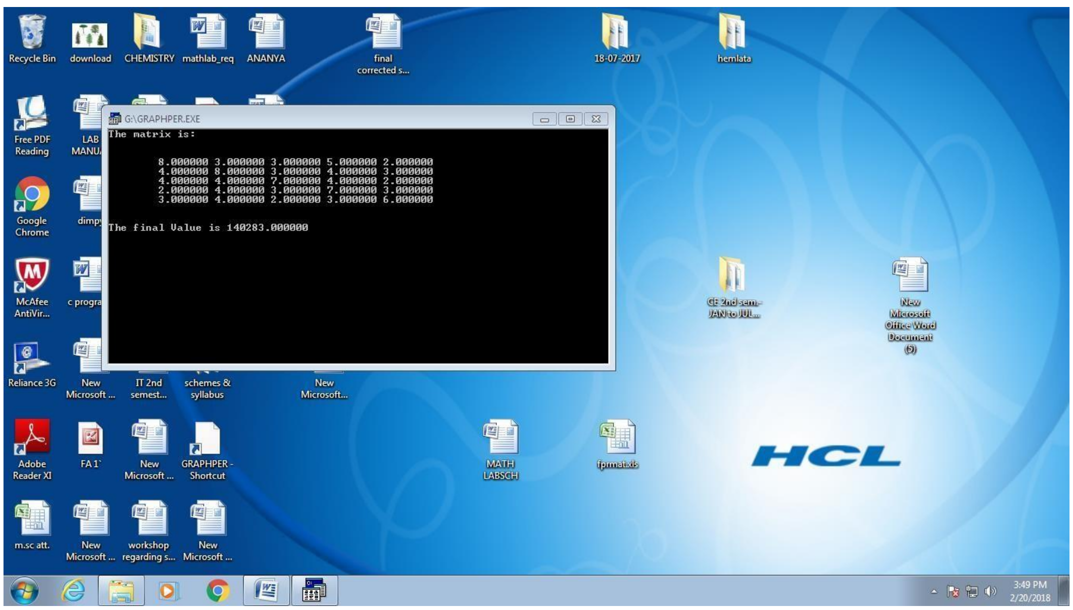

Figure 19: Estimating quantitative values – Step 1

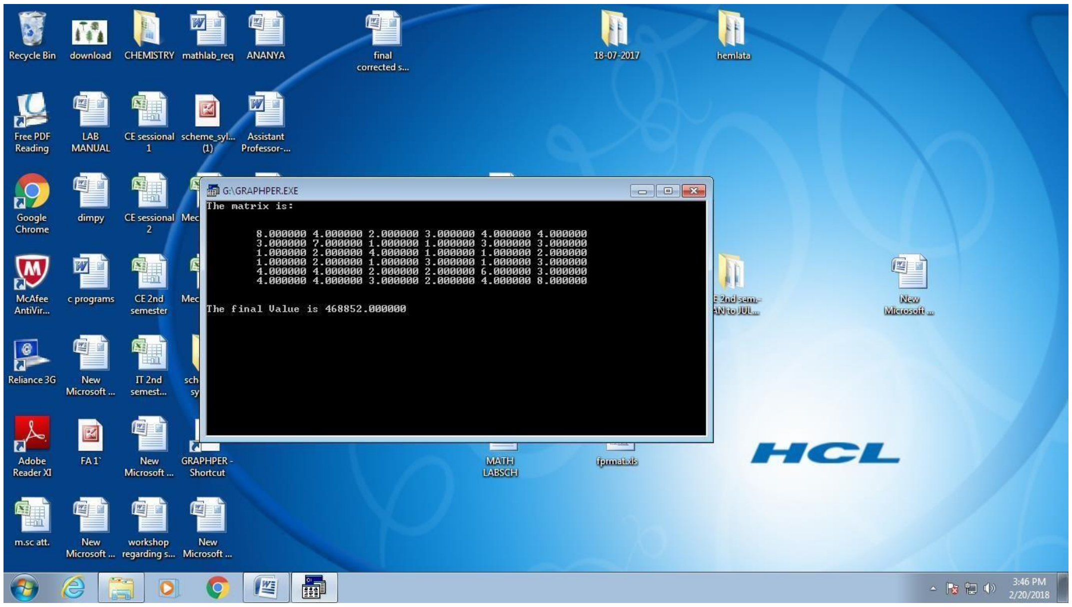

Figure 20:   Estimating quantitative values – Step 2

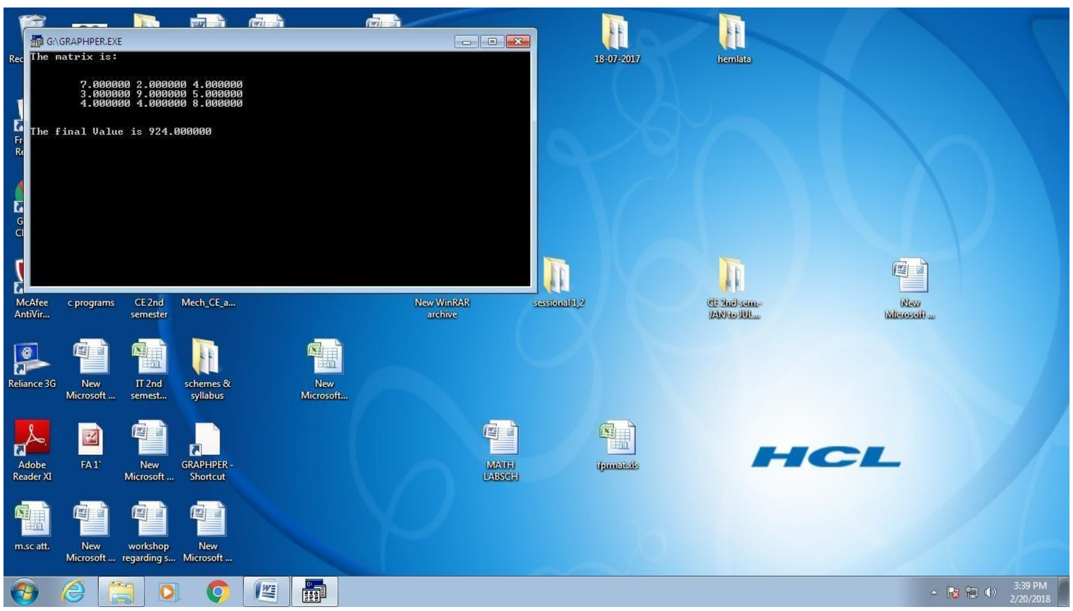

Figure 201: Estimating quantitative values – Step 3

The values that we got, do not give us any direction about the further possibilities of improvement in the existing weighting that we have assigned to the benefits. Therefore, we considered some hypothetical maximum values of these interdependent variables.

The result obtained for attained and maximum values (using Grapher) is compared in the following table:

Table 18: Interdependence of variables

Permanent function	Attained value	Maximum value
B*	652	897
$\square_3^*$	140283	250260
$\square_2^*$	468852	1768857
$\square_1^*$	924	1195

Table 18 gives a clear view of gaps in achieving the benefits attained values are the achieved values out of the interdependent values discussed with the manufacturer and experts and Maximum values are the hypothetical maximum values which are decided after discussions with the researchers and supply chain managers who are actually involved in these processes.

Table 19: Interdependence of variables

Permanent function	Scope of improvement
B*	27.31%
$\square_1^*$	43.94%
$\square_2^*$	73.49%
$\square_3^*$	22.67%

Table 19 shows that the global benefits out of Vendor Managed inventory can be improved significantly by 27.31%, whereas individually the decisive factors show an improvement level of 43.94%, the operative factors that are in fact responsible for carrying out the whole management process bring up to growth of around 73.49%, which means substantial scope of improvement in whole process. The third category of factors is the budgeting factors which shows that the financial benefits can be improved further by about 22.67%. These resulted values give us the exact quantitative data required for further improvement of process.

5.14 CONCLUSION

This Chapter is regarding the quantification of benefits of applying Vendor Managed Inventory on an auto parts manufacturer in North India. The extensive classification of benefits and the factors that are convoluted are done in three groups. The aftermaths so obtained gives us a quick assessment of the benefits that are obtained by the specific industry and using the hypothetical maxima, the supplementary scope of improvement in each classification of factors is also analysed. Thus, the global scope for improving the" BOV" value is about 27% which means with slight change in the interdependencies, the maximum values can be achieved. The maximum scope of improvement lies in the operative factors which principally includes a better management of the entire process. So, more is the improvement in management and forecasting market trends implies a better profit and more benefits of Vendor Managed Inventory. This entire study is very advantageous as this analysis will be very beneficial for those manufacturers who are preparing themselves for implementing the process of Vendor Managed Inventory.

5.15 SUMMARY OF CHAPTER 5

This chapter is about quantification of the benefits that can be achieved by applying vendor managed inventory in a small industrial set up, followed by literature review on graph theory literature and its use in quantification of various parameters. The step by step process of using this technique is also explained.

Second part of research paper is related to deriving the, 'Benefits of Vendor Managed Inventory" for small scale manufacturer. The three categories of factors that are quantified are: **decisive factors, operative factors and budgeting factors**. The interrelation between the various sub factors under each main category is shown by digraphs and then the quantified values in matrix are obtained after discussions with experts and researchers, results are obtained using the tool GRAPHER.

In the last section, the obtained quantified values are compared to the theoretical maximum that can be achieved in all three categories. This chapter gave us the direction for focusing on operative factors which includes a better management of the whole process. Thus, more is the improvement in management and forecasting, better is the cost benefit of Vendor Managed Inventory. This study gave us valuable inputs and encouraged us to go for pilot testing of Vendor Managed Inventory in industrial set up.

6. PILOT STUDY IN AN INDUSTRY IN INDIA MANUFACTURING AUTO PARTS

6.1 INTRODUCTION

In this chapter, the report of a pilot project conducted in an auto parts manufacturing company in India is presented. The pilot was conducted by introducing a VMI agreement with one of the manufacturer producing six spares for the manufacturing company through an old outsourcing contract. The contract was modified to enable the manufacturer manage the local inventory of the six components in an old warehouse of the manufacturing company. This chapter presents details of the pilot setting, the longitudinal test design, the data set collected, test results, and the final discussions and conclusions on the pilot study.

6.2 THE PILOT SETTING

An auto parts manufacturer in North India was selected for the pilot testing of VMI. The manufacturer had old contracts with multiple manufacturer for producing components for their auto parts. One of the manufacturer was selected for this pilot. The purchase ordering process between the manufacturer and the manufacturer was suspended and the manufacturer was allowed to manage the onsite inventory of their components directly. For this purpose, the manufacturer assigned an onsite coordinator who was trained on a module of the materials requirements planning (MRP) version II on SAP software for tracking the production usage and buffer stocks of their components only. Based on the requirements generated, the onsite coordinator generated weekly consignment requests to the manufacturer to ship the components as per the requirement specifications. This process replaced the earlier monthly purchase ordering system managed by an employee of the customer (the auto parts manufacturer).

This process retained the delivery challans being issued to claim the payments. The inspection process was shifted upstream from the delivery stage to the buffer feed stage. All delivery inspection processes were suspended for this pilot. The inspections were carried out by the manufacturer, and no separate bills were raised to the customer. Instead, the scope of inspections at the buffer feeding was increased.

As the consignments were shipped weekly instead of monthly, the manufacturer started using small SUV-like vehicles and mini trucks instead of large trucks. The packaging was also changed from large metallic containers to small wooden/ply-board boxes fit for handling smaller consignments. The docking and unloading, unpacking, internal movement, and storing processes were managed by the manufacturer onsite with the help of workers on their payrolls. Earlier, these tasks were handled by contract workers hired by the customers; those were replaced by the workers hired by the manufacturer. In the new VMI arrangement, the manufacturer billed for these services to the customer. The inventory codes used by the customers in the MRP II were used by the manufacturer although they were not delivered against a purchase orders. The payment cycles shifted from on-delivery (based on delivery challans) to on-buffer-feed (based on pre-feed inspection clearances). However, transportation costs were billed by the manufacturer on delivery challans as per the older agreement because they did not agree to eliminate it in the new arrangement. The earlier arrangement of taking back unused materials applied to this pilot, as well.

6.3 THE TEST DESIGN

The test design comprised of collection of financial and performance data related to the following heads:

(a) Transportation cost (actual costs billed to the customer)
(b) Material handling cost (sum total of actual services costs billed to customer for docking and unloading, unpacking, internal movements within the warehouse, and storing)
(c) Cost of the components (actual costs billed to the customer after the materials were passed by inspection officer at the buffer entry point of the machine where the six components were consumed)

(d) Lead times (time difference between the requirement generation timestamp in MRP II and the inspection approval timestamp at the buffer entry point of the machine)

The miscellaneous costs, like electricity, general warehouse maintenance costs, cleaning and housekeeping costs, etc. were kept out of this test design as they were not billed by the manufacturer and were presumed to remain unchanged in the VMI arrangement. A fifth metric was captured from SAP application used by the manufacturing company to run the MRP II. SAP generates an internal inventory performance index (IPI) for each item code stored in the inventory, which is based on more than 50 variables captured internally within SAP and indicates a value in the scale 1 to 10 (higher is better). For example, a value at 7.3 indicates that the IPI score is at 73% of an internally estimated SAP benchmark for inventory performance, and there is a 27% scope of improvement. Although, there is no document on how SAP estimates this index (perhaps it is their confidential intellectual property), the IT manager in the company confirmed that all the variables included in the MICMAC analysis in the interpretive structural modelling presented in Chapter 4 are included in SAP's IPI calculation. The owner of the manufacturing company insisted to capture this metric in this test as an indicator of VMI performance. They have been dependent upon this metric in the past to know about their inventory management performance.

The data sets for the pilot after introducing the VMI were collected for three quarters (9 months), and integrated with three quarters of data collected prior to introducing the VMI on a time series. The overall data table included data collected from April 2017 to September 2018. The first analysis conducted was a basic time series plotting of the data sets and observing the probability relationships between the variables. The second analysis was done using the Markov chain analysis by assuming correlation coefficients as transition probabilities. Correlation coefficients were used for estimating the initial reachability matrix and evolving the final reachability matrix by considering transitive relationships. By completing the iterative steps, the most relevant variables influencing VMI were obtained in the eighth iteration: reduced costs and improved services. This method, however, was not having any prediction ability. This is because the transitive relationships do not indicate any predictive probability of the VMI performance in MICMAC analysis.

Markov chain analysis was chosen for the pilot study because:

(a) Its approach is similar to the graph theoretic approach used in Chapter 5;
(b) It has an ability of predictive analytics based on transition probabilities;
(c) It does not require direct application of historical data as long as there is a method followed to estimate the transition probabilities between the current state to the next state in the graph; that is, Markov chain does not require a memory of transition probabilities such that the next state transition can be estimated based on the conditions at the current state only;

A review of Markov chain analysis is presented as the following:

Markov chain analysis is used for a variable that is not influenced by its past values [81] [82]. It works by forming a state space 0 to S over a time domain that is finite and in which, there are discrete jumps from one state to another represented by the Markov probability matrix presented below [81]:

$$P = \begin{bmatrix} P_{00} & P_{01} & P_{02} & P_{0S} \\ P_{10} & P_{11} & P_{12} & P_{1S} \\ P_{20} & P_{21} & P_{22} & P_{2S} \\ P_{S0} & P_{S1} & P_{S2} & P_{SS} \end{bmatrix} \quad \text{Equation (6)}$$

The Markov probability matrix is always M X M and the sum of probabilities in either a row or a column is always unity [81]. In a simple experimentation, the values of P_{00} to P_{SS} can be estimated by running multiple trials and carefully examining the change of state of a variable and noting the different states of the variable. Then, the transition probability between any two states is the ratio of number of times the state transition between these two states was observed to the total number of trials conducted.

When a variable is complex (that is, influenced by many other factor variables) then the simple experimentation setting will not be helpful [81]. To study the Markov chain of a complex variable, a controlled experimentation setup needs to be formed in which, probabilities of occurrence of each factor variable needs to be taken into the sample. Sampling of multiple random variables in a controlled experimentation setting for Markov chain analysis of a complex variable was discussed by Walsh (2004) [83]. The sampling equation for “m” events realisations is presented as the following:

$$\square[\square(\square)]_{\square} = \frac{1}{\square}\sum_{\square=1}^{\square}\square(\square_{\square}) \qquad \text{Equation (7)}$$

If the factor variables and the influenced variable are all occurring on a common time series (that is, they are overlapping), then the next state probability of the influenced variable can be estimated by its correlation with other overlapping variables on the time series. The correlation may be estimated using auto or cross correlation, or Pearson correlation. This is not a pure Markov Chain albeit uses some historical knowledge based on Gibbs sampling [83]. It works for sufficiently long chain length. If the chain length tends to infinity, the above equation becomes a Monte Carlo estimate using Gibbs sampling space.

The individual transition probabilities of the influencing variables shall be between 0 and 1, and their sum shall be unity. One more aspect to be kept in mind is about the direction of transition of the influenced variable. For example, if X is a variable influencing Y, then if Y increases based on a transition probability “p” of X, it will decrease based on a transition probability “(1 – p)” of X. If there is a chance that Y may increase without any change in X, then the probability “p” needs to be split into two transition probabilities. Similarly, if there is chance that Y may reduce without any change in X, then the probability “(1 – p)” needs to be split into two transition probabilities.

In this research, the Pearson correlation coefficients between the four state variables and the IPI variable are taken as transition probabilities. An increase or decrease of IPI is investigated based on increase or decrease of the state variables. Total 16 scenarios are possible as there are four state variables. The test results are presented in Section 6.5. The next section presents the test data.

6.4 DATA SET

The data set comprised of monthly values recorded of transportation cost, material handling cost, cost of the components, lead times, and internal inventory performance index (IPI) of SAP from April 2017 to September 2018. The VMI agreement was signed on 14 December 2017 with its commencement date as 1st January 2018. The Table 17 presents month wise data collected from the manufacturer. Prior to VMI introduction in January 2018, the data was collected from internal costing journals maintained by the cost accountant (that were later fed to the internal financial application formed by a module in SAP). From January 2018 onwards, the data was collected from the bills raised by the manufacturer assigned the VMI contract.

Table 20: Data collected from the pilot implementation and testing of VMI

Month	Transportation cost (TC) (INR; inclusive of all taxes)	Material handling cost (MHC) (INR; inclusive of all taxes)	Cost of the components (COTC) (INR; inclusive of all taxes)	Lead Times (LDT) (Hours)	Inventory performance index (IPI) (captured from SAP) (higher is better)
Sept 2018	1,50,305	1,91,570	74,98,990	74	8.3
Aug 2018	1,46,764	1,94,478	75,99,978	73	8.4
July 2018	1,48,115	1,95,395	75,78,745	78	8.3
June 2018	1,51,980	1,97,899	77,67,448	81	8.3
May 2018	1,53,450	1,97,576	79,76,939	83	8.1

Month	Transportation cost (TC) (INR; inclusive of all taxes)	Material handling cost (MHC) (INR; inclusive of all taxes)	Cost of the components (COTC) (INR; inclusive of all taxes)	Lead Times (LDT) (Hours)	Inventory performance index (IPI) (captured from SAP) (higher is better)
Apr 2018	1,44,676	1,99,879	81,37,494	84	8.0
Mar 2018	1,57,358	2,08,056	85,49,224	89	8.0
Feb 2018	1,61,000	2,29,787	87,48,492	86	7.6
Jan 2018	1,67,455	2,34,445	87,48,944	84	7.5
Dec 2017	1,78,760	1,97,643	87,67,658	82	7.8
Nov 2017	1,74,285	1,96,381	87,33,483	83	7.6
Oct 2017	1,75, 976	1,97,948	89,63,743	83	7.9
Sept 2017	1,74,008	1,98,983	88,75,491	80	7.5
Aug 2017	1,76,280	1,95,294	88,93,284	79	7.8
July 2017	1,77,224	1,94,209	89,56,923	77	7.7
June 2017	1,79,512	1,93,492	89,46,385	83	7.9
May 2017	1,78,330	1,95,836	88,24,953	79	7.7
Apr 2017	1,74,560	1,97,653	87,50,591	78	7.8

The data set was entered into SPSS for further testing and analysis in three steps: times series analysis, Pearson correlation analysis, and Markov chain predictive modelling. The time series analysis was conducted to study the variations in discrete values of the variables over the experimentation period longitudinally (for eighteen months). The Pearson correlation coefficients were obtained at p = 0.01 (99% confidence interval). The correlation coefficient reflects the extent to which, two different variables transition together. For example, a Pearson correlation coefficient of 0.5 indicates that two variables are transitioning together 50% of the time. Hence, the Pearson correlation can be used as the transition probability between two variables. When multiple variables are influencing the variable under study, and their events are sampled separately, then the following equation can be used to calculate the combined transition probabilities of the variables influencing the main variable using Gibbs sampling [83]; this may lead to Monte Carlo approximation when the time series chain of the overlapping stochastic variables is infinite:

$$\square(\square)_{\square} = \frac{1}{\square}\sum_{\square=1}^{\square} \square(\square_{\square}) \qquad \text{Equation (8)}$$

Where, m = number of samples; $\square(\square)_{\square}$ = transition probability of the variable studied;

$\square(\square_{\square})$ = transition probability of each influencing variable

The Markov chains are analysed accordingly to predict the variables causing the IPI to increase or reduce. The test results and analysis are discussed in the next section.

6.5 TEST RESULTS

To evaluate the test results, the month of January 2018 should be remembered as the month of change as the inventory management system was switched from internally managed to VMI in this month. In all the time series charts the change occurring in and after January 2018 needs to be studied carefully.

The first variable studied on the time series is transportation cost (TC). TC exhibited a reducing trend from the first month of VMI itself. The per-kilometre costs of smaller vehicles are lower than large trucks. The manufacturer used smaller vehicles as the materials were shipped on weekly internal demands raised instead of monthly orders. This also reduced road taxes and tollgate expenses as per the government slabs. In April 2018, the transportation costs dipped significantly, and then exhibited an increasing trend thereafter. Although, one may safely assume that the transportation cost during VMI will be lower than that when inventories were managed internally, the actual picture will be clearer after collecting data for a longer period. An increasing trend was evident after a sudden dip in April 2018 but remained lower than the pre-VMI TC.

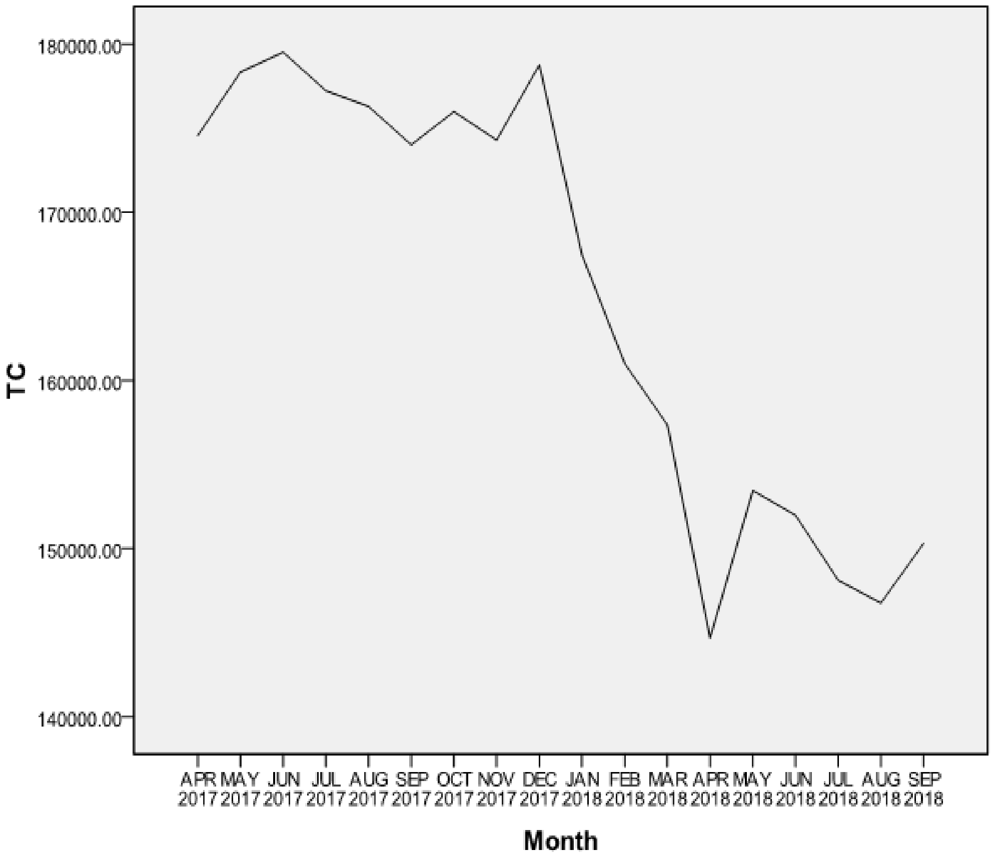

Figure 212: Time series plotting of the transportation costs (TC)

The materials handling cost (MHC) shot up significantly in the first month of the VMI. Thereafter, MHC exhibited a sharp declining trend to costs close to pre-VMI period. The MHC reduced below pre-VMI levels only in the month of September 2018, which is the last month of this pilot test study. In January 2018, the manufacturer had to deploy more resources during the takeover process, and later the resources were withdrawn when the internal processes streamlined. Given that the manufacturer decided to follow a weekly replenishment schedule, new internal storage bays were constructed for stocking smaller wooden packs instead of the large metallic containers used earlier. In addition, new machines for unpacking from wooden boxes and internal movement of smaller packages were acquired. This may explain the sudden rise of MHC in January and February 2018.

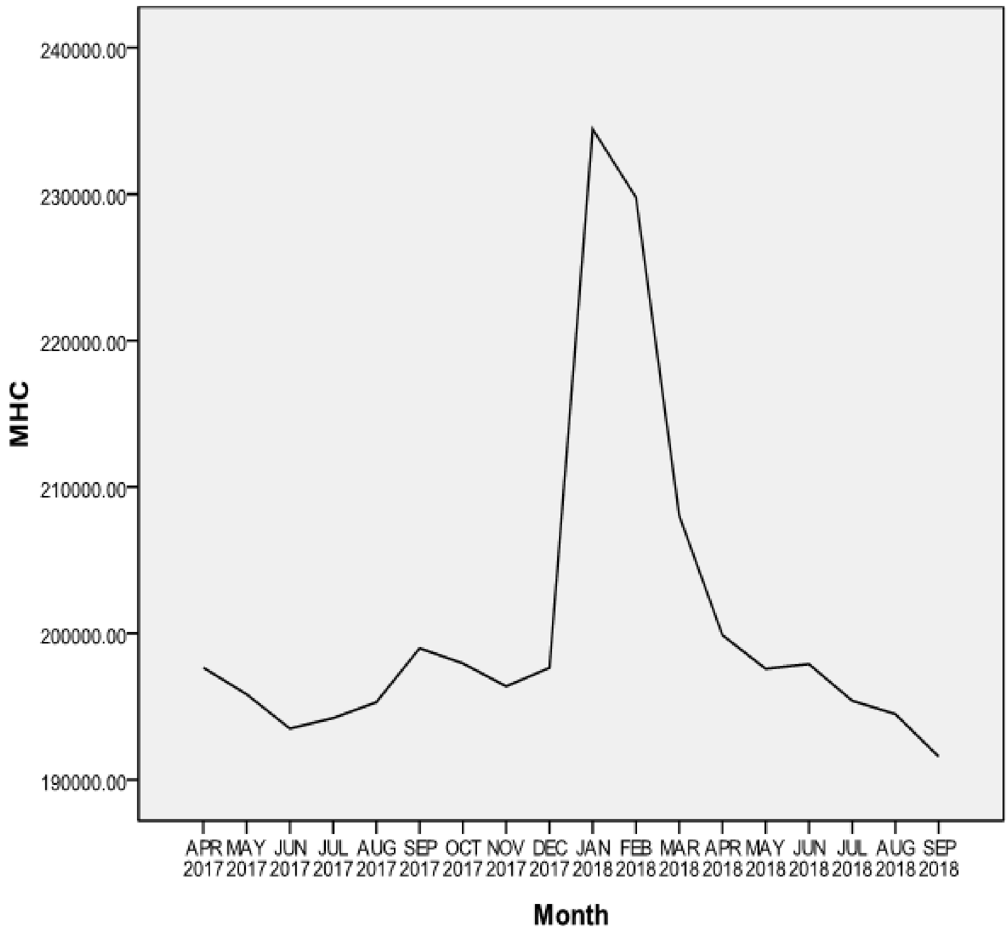

Figure 223: Time series plotting of the materials handling costs (MHC)

The cost of the components (COTC) comprises of the six components supplied by the manufacturer for the assembly line selected by the manufacturer to test VMI. The COTC showed clear reducing trend after introduction of VMI (Figure 24). The manufacturer reported reduced wastage of materials because of using smaller and easy to open packages, shorter storage inventory holding, and lighter internal movement in small volumes. Further, the manufacturer also reduced over ordering to some extent by carefully analysing the materials consumption in MRP II and switching to a weekly replenishment schedule. These adjustments helped in achieving a reducing trend of COTC. During the pilot test period, the reducing trend has not stopped. Hence, further observations will be needed.

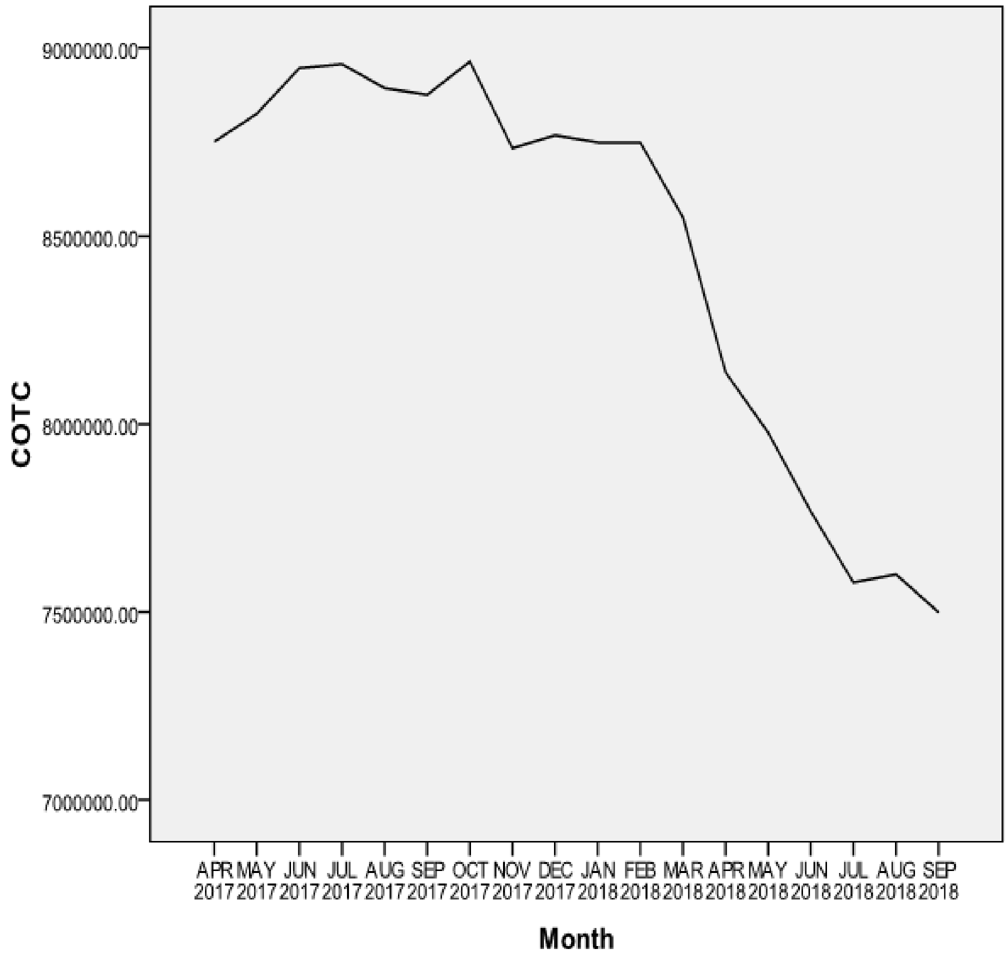

Figure 234: Time series plotting of the costs of the components (COTC)

The lead-time (LDT) increased sharply in the months of January and February 2018. The manufacturer reported some initial delays when the switchover to VMI was in progress. The delays were primarily because of the time taken in delivery of the new materials-handling equipment to manage the weekly replenishment schedule (instead of monthly schedule) and to handle smaller consignments coming in wooden or ply wood boxes instead of metal containers. Thereafter, LDT exhibited a sharp decline to levels lower than the pre-VMI period. At the end of the pilot period, LDT exhibited an increasing trend again. Further sampling is needed to study if the trend has increased further or has stabilised after some time to values lower than the pre-VMI period.

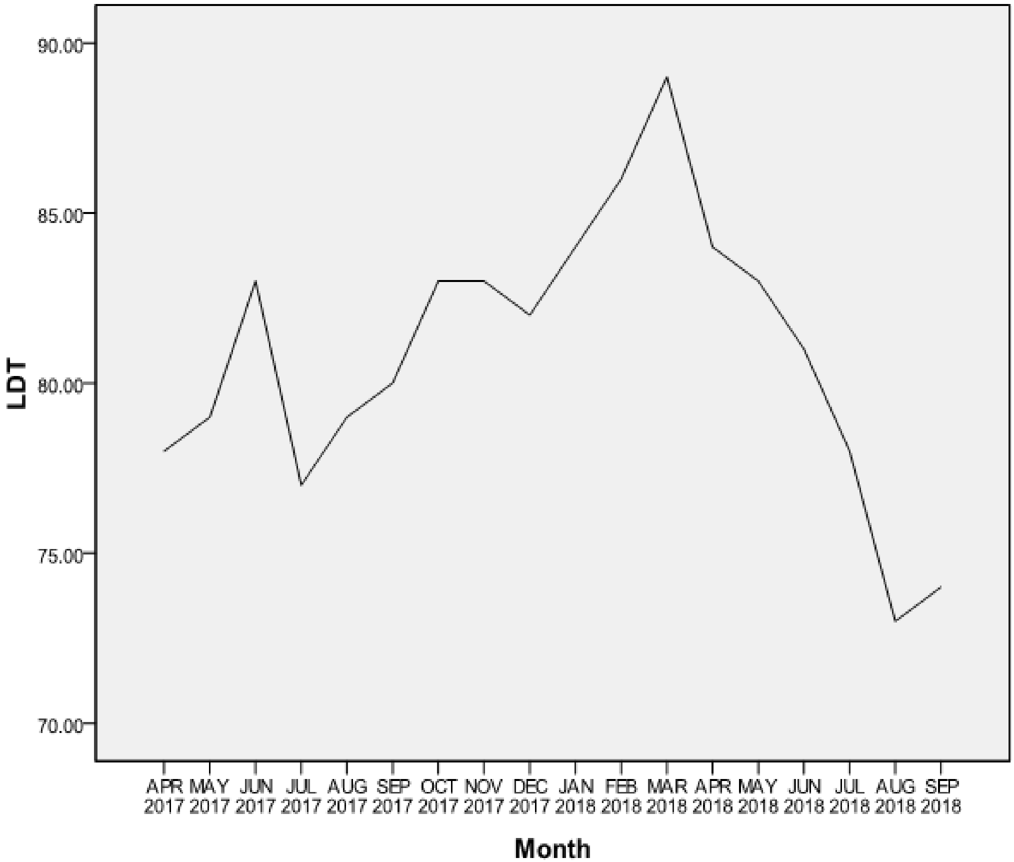

Figure 245: Time series plotting of the Lead Times (LDT)

The inventory performance index (IPI) reduced to a low value in January 2018 as presented in Figure 26 (higher values of IPI reflect better inventory management performance). The IPI gained slightly in the month of February 2018. Thereafter, it increased sharply and maintained an increasing trend until August 2018. After August 2018, a declining trend had started. Further sampling is needed to observe if the declining trend proceeds or IPI stabilizes at values lower than the pre-VMI period. The IPI clearly reflects a good initial performance of the manufacturer in managing the VMI. Much longer trends will reflect if the performance sustained. As described by Walsh (2004) [47], an infinite time series comprising of multiple stochastic variables (number of events tending to infinity) follows Monte Carlo approximation of Gibbs sampling (Equation- 7) and may exhibit a cooling period before stabilising. Because of stochastic nature of the variables, it is difficult to estimate how long the cooling period would continue. In this pilot testing period, it is difficult to estimate if the cooling period is over or will continue. Initial shocks were evident in MHC, LDT, and IPI. However, it is very difficult to ascertain if the VMI system has cooled down after the initial shocks.

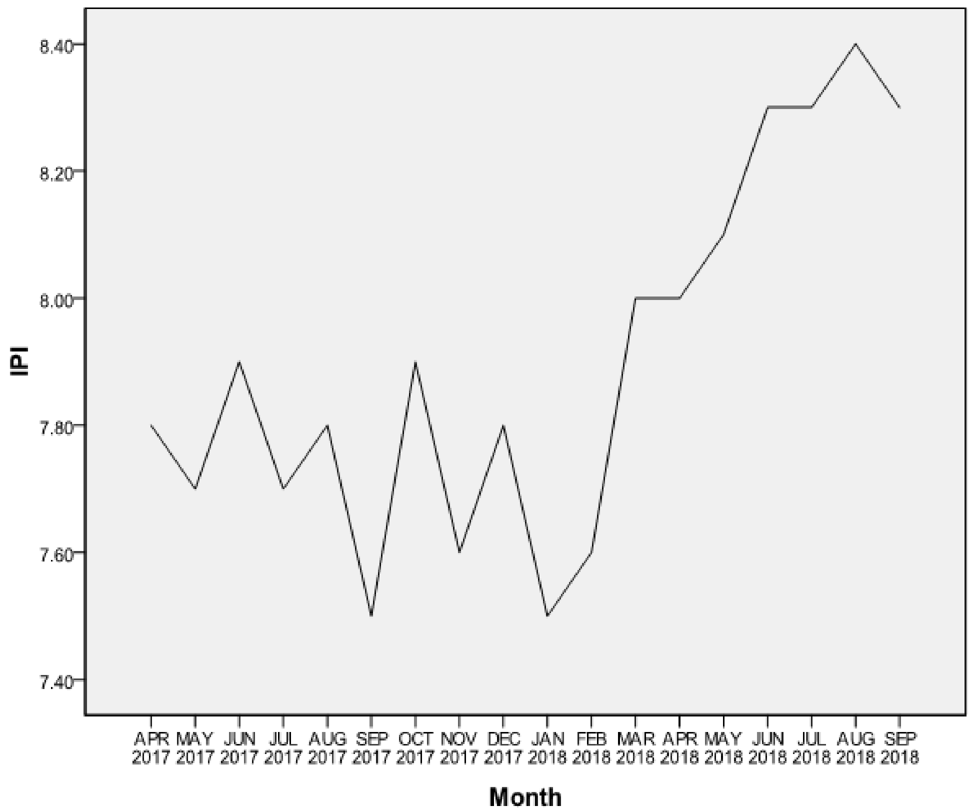

Figure 256: Time series plotting of the Inventory Performance Index (IPI)

Hence, a more realistic approach to evaluate the performance of VMI is to study Markov chains with Monte Carlo approximation of Gibbs sampling (Equation 7). As studied earlier in this chapter, Markov chains only require the observations at the current state to predict the future state (that is, Markov chains have no memory). However, Monte Carlo approximation of Gibbs sampling helps in deriving the transition probabilities from the historical sampling of the time series having overlapping variables.

The IPI is used as the reference variable because it reflects inventory management performance and is estimated internally in the SAP application based on more than 50 variables. The correlations between IPI and the rest of the variables (TC, MHC, COTC, and LDT) are presented in Table 21. Although multiple correlation coefficients can be calculated using SPSS, the Pearson correlation coefficient has been chosen as it was earlier used in the interpretive structural modelling presented in Chapter 5.

Table 21: Correlations' Table

Correlations						
		TC	MHC	COTC	LDT	IPI
TC	Pearson Correlation	1	-.050	.897**	.100	-.739**
	Sig. (2-tailed)		.845	.000	.694	.000
	N	18	18	18	18	18
MHC	Pearson Correlation	-.050	1	.233	.552*	-.462
	Sig. (2-tailed)	.845		.352	.017	.053
	N	18	18	18	18	18
COTC	Pearson Correlation	.897**	.233	1	.413	-.873**
	Sig. (2-tailed)	.000	.352		.089	.000
	N	18	18	18	18	18
LDT	Pearson Correlation	.100	.552*	.413	1	-.394
	Sig. (2-tailed)	.694	.017	.089		.106
	N	18	18	18	18	18
IPI	Pearson Correlation	-.739**	-.462	-.873**	-.394	1
	Sig. (2-tailed)	.000	.053	.000	.106	
	N	18	18	18	18	18
**. Correlation is significant at the 0.01 level (2-tailed).						
*. Correlation is significant at the 0.05 level (2-tailed).						

The correlations are captured at 0.01 level for ensuring 99% confidence interval of the sampled events. The correlation coefficients are negative because reduction in TC, MHC, COTC, and LDT causes increase of IPI.

The Markov chain is formed to predict three states of IPI: IPI remains the same, IPI shall increase, and IPI shall decrease. Taking the Pearson correlation coefficients as transition probabilities, the following transition probabilities of IPI are estimated:

(a) IPI shall increase with reduction in TC (or IPI shall reduce with increase in TC) at a probability $\square_{\square\square\square/\square\square} = 0.739$.
(b) IPI shall reduce with reduction in TC (or IPI shall increase with increase in TC) at a probability closer to $(1 - \square_{\square\square\square/\square\square}) - 0.01 = 0.251$ (although it might appear unlikely, a small probability of 0.01 should be assumed that IPI will not change with either increase or decrease of the influential variables).
(c) IPI shall remain unchanged with either reduction or increase of TC = 0.01
(d) IPI shall increase with reduction in MHC (or IPI shall reduce with increase in MHC) at a probability $\square_{\square\square\square/\square\square\square} = 0.462$.
(e) IPI shall reduce with reduction in MHC (or IPI shall increase with increase in MHC) at a probability closer to $(1 - \square_{\square\square\square/\square\square\square}) - 0.01 = 0.528$.
(f) IPI shall remain unchanged with either reduction or increase of MHC = 0.01
(g) IPI shall increase with reduction in COTC (or IPI shall reduce with increase in COTC) at a probability $\square_{\square\square\square/\square\square\square\square} = 0.873$.
(h) IPI shall reduce with reduction in COTC (or IPI shall increase with increase in COTC) at a probability closer to $(1 - \square_{\square\square\square/\square\square\square\square}) - 0.01 = 0.117$.
(i) IPI shall remain unchanged with either reduction or increase of COTC = 0.01
(j) IPI shall increase with reduction in LDT (or IPI shall reduce with increase in LDT) at a probability $\square_{\square\square\square/\square\square\square} = 0.394$.
(k) IPI shall reduce with reduction in LDT (or IPI shall increase with increase in LDT) at a probability closer to $(1 - \square_{\square\square\square/\square\square\square}) - 0.01 = 0.596$.
(l) IPI shall remain unchanged with either reduction or increase of LDT = 0.01

With an estimate of all the individual transition probabilities accounted, the Markov chains can be used to predict the change of state of IPI by assessing all possible scenarios of states of the four influencing variables: TC, MHC, COTC, and LDT. The scenarios are presented in the Table 19 with the transition probabilities of IPI estimated in each scenario as presented in the last column. With four variables evaluated, there are $2^4 = 16$ scenarios possible. Each scenario can result in a three state Markov Chain:

State A = Current state of IPI;

State B = Next state of IPI witnessing an increase in its value;

State C = Next state of IPI witnessing a reduction in its value;

Given that there are three states, the Equation 6 for Markov chain shall reduce to the following:

□□□ □□ □□□

□

□ = [□□ □□ □□□ Equation (9)

The probabilities indicated in the matrix are the following:

□□□ = Probability of IPI to remain in current state A;

□□□ = Probability of IPI to transition from current state A to the state B resulting in an increase in its value;

□□□ = Probability of IPI to transition from current state A to the state C resulting in a reduction in its value;

□□□ = Probability of IPI to remain in current state B;

□□□ = Probability of IPI to transition from current state B to the state A resulting in a reduction in its value;

□□□ = Probability of IPI to transition from current state B to the state C resulting in an increase in its value;

□□□ = Probability of IPI to remain in the state B;

□□□ = Probability of IPI to transition from current state B to the state A resulting in a reduction in its value;

□□□ = Probability of IPI to transition from current state B to the state C resulting in a reduction in its value;

□□□ = Probability of IPI to remain in the state C;

□□□ = Probability of IPI to transition from current state B to the state A resulting in an increase in its value;

□□□ = Probability of IPI to transition from current state B to the state C resulting in an increase in its value;

Table 22: Scenarios of Markov chain predictions for implementation and testing of VMI in the pilot setting

Scenario No.	**State of TC**	**State of MHC**	**State of COTC**	**State of LDT**	**Probability estimates for IPI (using Equation 8)**
1	Reduces	Reduces	Reduces	Reduces	IPI remains unchanged = 0.01; IPI increases = 0.617; IPI reduces = 0.373;
2	Reduces	Reduces	Reduces	Increases	IPI remains unchanged = 0.01; IPI increases = 0.6675; IPI reduces = 0.3225;
3	Reduces	Reduces	Increases	Reduces	IPI remains unchanged = 0.01; IPI increases = 0.428; IPI reduces = 0.562;
4	Reduces	Reduces	Increases	Increases	IPI remains unchanged = 0.01;

Scenario No.	**State of TC**	**State of MHC**	**State of COTC**	**State of LDT**	**Probability estimates for IPI (using Equation 8)**
					IPI increases = 0.4785; IPI reduces = 0.5115;
5	Reduces	Increases	Reduces	Reduces	IPI remains unchanged = 0.01; IPI increases = 0.6335; IPI reduces = 0.3565;
6	Reduces	Increases	Reduces	Increases	IPI remains unchanged = 0.01; IPI increases = 0.684; IPI reduces = 0.306;
7	Reduces	Increases	Increases	Reduces	IPI remains unchanged = 0.01; IPI increases = 0.4445; IPI reduces = 0.5455;
8	Reduces	Increases	Increases	Increases	IPI remains unchanged = 0.01; IPI increases = 0.495; IPI reduces = 0.495;
9	Increases	Reduces	Reduces	Reduces	IPI remains unchanged = 0.01; IPI increases = 0.495; IPI reduces = 0.495;
10	Increases	Reduces	Reduces	Increases	IPI remains unchanged = 0.01;

Scenario No.	State of TC	State of MHC	State of COTC	State of LDT	Probability estimates for IPI (using Equation 8)
					IPI increases = 0.5455; IPI reduces = 0.4445;
11	Increases	Reduces	Increases	Reduces	IPI remains unchanged = 0.01; IPI increases = 0.306; IPI reduces = 0.684;
12	Increases	Reduces	Increases	Increases	IPI remains unchanged = 0.01; IPI increases = 0.3565; IPI reduces = 0.6335;
13	Increases	Increases	Reduces	Reduces	IPI remains unchanged = 0.01; IPI increases = 0.5115; IPI reduces = 0.4785;
14	Increases	Increases	Reduces	Increases	IPI remains unchanged = 0.01; IPI increases = 0.562; IPI reduces = 0.428;
15	Increases	Increases	Increases	Reduces	IPI remains unchanged = 0.01; IPI increases = 0.3225; IPI reduces = 0.6675;
16	Increases	Increases	Increases	Increases	IPI remains unchanged = 0.01;

Scenario No.	State of TC	State of MHC	State of COTC	State of LDT	Probability estimates for IPI (using Equation 8)
					IPI increases = 0.373; IPI reduces = 0.617;

The above table is valid as in September 2018. It may be noted that all these probability estimates are dynamic and stochastic. These values will change continuously as the time series progresses carrying forward these overlapping variables. However, Markov chain can provide a prediction of improvement or reduction of inventory performance in any month based on the current state of scenarios in that month. To illustrate some scenarios, the scenario nos. 5 and 12 in Table 22 are analysed using Markov chain.

The Equation 9 for scenario 12 shall be as presented below taking the probability values estimated in Table 19:

$$\square = \begin{bmatrix} \square_{\square\square} & \square_{\square} & \square_{\square\square} \\ \square_{\square\square} & \square_{\square} & \square_{\square\square} \end{bmatrix} = \begin{bmatrix} 0.01 & 0.6335 & 0.3565 \\ 0.3565 & 0.01 & 0.3565 \end{bmatrix}$$

Equation (10)

Based on this Markov matrix, the Markov chain for predictions can be plotted as presented in Figure 27.

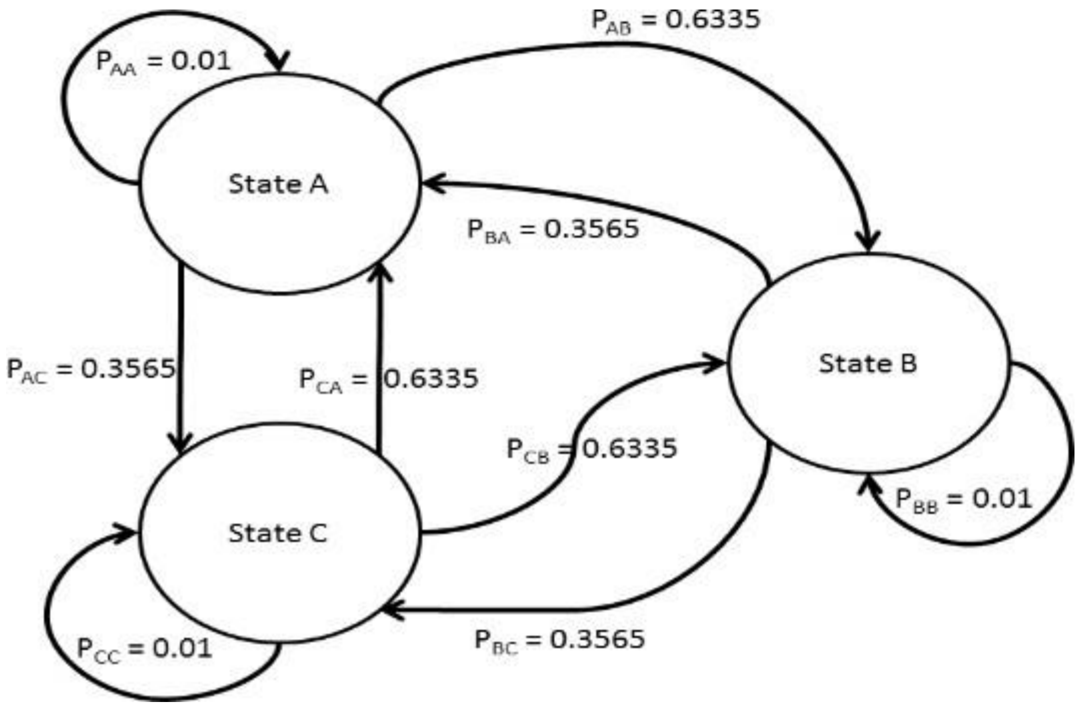

Figure 267: Markov chain plotting for Scenario 5 of Table 19

This Markov chain presents a plot of state transitions if there are chances of reduction of TC, increase of MHC, reduction in COTC, and reduction in LDT. Similarly, the Markov chain for Scenario 15 in Table 19 can be plotted as shown in Figure 28. In this scenario, there are chances of increase of TC, increase of MHC, increase in COTC, and reduction in LDT. The state transition probabilities are based on the current state of the variables that are derived from correlation analysis of the overlapping variables on the time series prior to the current state. A small finite probability of 0.01 is assumed that the current state in the Markov chain will be retained. This means that the exact values of TC, MHC, COTC, LDT, and IPI in the current state will be replicated in the next state. Although, such a scenario may not happen at all, Markov chain allows keeping a small finite probability that it may occur. As stated above, the probabilities will keep changing as the time series progresses. January 2018 was the month of introduction of VMI for six components manufactured by a manufacturer. The sample of nine months after the introduction does not reveal whether the system has stabilised or the cooling period is still progressing. However, Markov chain presents a definitive answer about the next state if the current state can be modelled as per probabilities based on the time series before and after introduction of VMI. It also provides a view into the probabilities that the current state will be retained again after the next state. To get more accurate results, the sampling period prior to VMI introduction was kept equal to the sampling period after VMI was introduced.

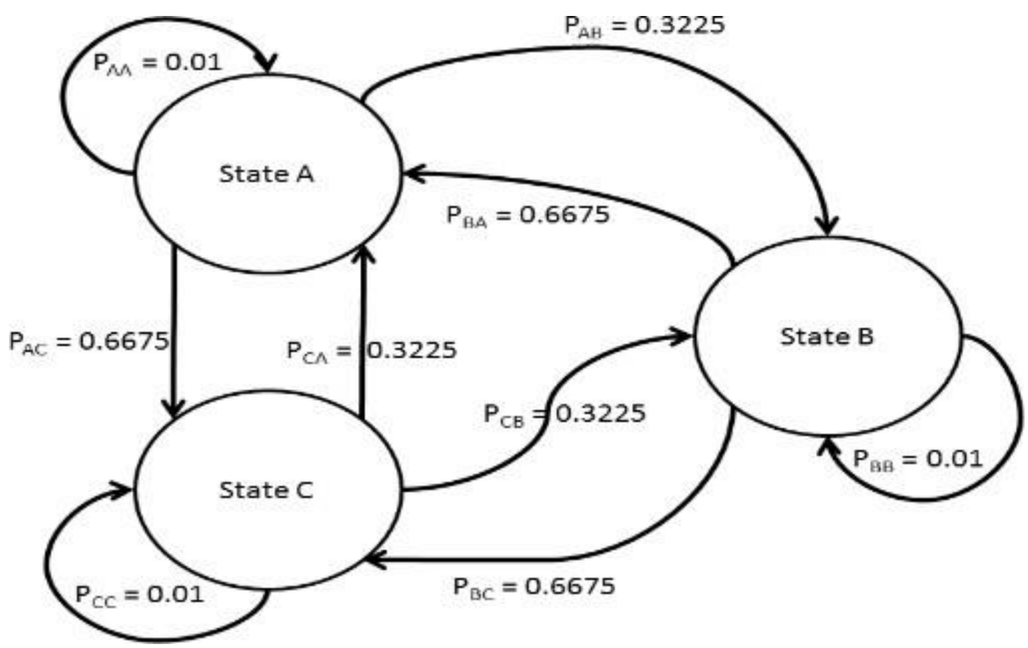

Figure 278: Markov chain plotting for Scenario 15 of Table 19

With all these analyses, the question on effectiveness of VMI for improving inventory management performance in the pilot setting can now be answered. The next section presents a detailed discussion and key conclusions about this question.

6.6 DISCUSSION AND CONCLUSIONS

From the findings of the pilot study, the time series analysis, and estimation of transition probabilities for Markov chain plotting, it is clear that VMI is not an achievement albeit is a journey. VMI should not be considered as a failure-proof strategy returning definitive benefits. VMI is highly complex with multiple overlapping variables on a time series playing their respective roles. To demonstrate the VMI phenomena, four critical variables were studied during the pilot study and their impact on the inventory performance index generated in SAP was assessed. While IPI is a complex metric influenced by more than 50 variables in the SAP system, the correlations of TC, MHC, COTC, and LDT with IPI were found to be significant at 99% confidence interval. A model of transition probabilities comprising $2^4 = 16$ scenarios was formed. There can be more scenarios when the number of stochastic variables is increased. For N no. of variables, the number of scenarios will be 2^N. TC, MHC, COTC, and LDT were chosen by the logistics head of the auto parts manufacturer as they are most critical for them, they vary stochastically, and they influence their key variable IPI significantly.

Now the question is whether VMI was beneficial for the manufacturing organisation. From the time series analysis of nine months, VMI appears to be returning positive results. However, Walsh (2004) warned that it is risky to trust a time series system of overlapping stochastic variables if the sample is not long enough. Surely, 18 months is not a long enough time series. If all the observations are merely part of a cooling period, then anything can happen beyond this period. The best approach is to revisit VMI every month and evolve an empirical model only when it has existed for a sufficiently long period (like, five years). Markov chain is a powerful empirical method to revisit the performance of VMI every month. The probabilities will change every month with the change in correlation coefficients (as new data shall be added every month). Hence, Markov chain predictions will change every month and Table 19 will be updated.

The manufacturer may follow the steps listed below to build and operate an inventory performance monitoring and control system using VMI:

(a) Define a period sufficiently long enough before introduction of VMI;
(b) Define a cut-off date when the inventory management system shall fully switch to VMI; preferably, this date should be the first day of a month;
(c) The month of transition from internal inventory management system may be ignored in the time series as the shocks in this month may affect the accuracy of the analysis;

(d) The inventory manager may wait for a few months more allowing the VMI to cool down;

(e) The month of introduction (the month full of shocks) and the months of stabilising period (also facing some shocks) may be eliminated from the analysis framework to get better results;

(f) In the month after the stabilising period, the correlation coefficients of all the key inventory performance variables with the inventory performance index should be calculated using SPSS or any statistical tool. The VMI introduction and stabilising months may be excluded from this calculation.

(g) The top four variables influencing the inventory performance index significantly may be selected;

(h) The transition probabilities between the four influencing variables and the inventory performance index may be estimated using the correlation coefficients;

(i) The scenario table comprising of 16 different scenarios of the four variables (similar to Table 19) may be formed; the transition probabilities for each scenario may be entered in the last column;

(j) Now the inventory manager is ready for testing VMI performance; the switch between the previous and current states of the four variables may be noted (excluding the VMI introduction and stabilising months). It should be noted that VMI may have stabilised bit the cooling period may be still in progress;

(k) The Markov chain-switching plot may be constructed based on the scenario of the four variables and the state switching probabilities of IPI taken from the table of all scenarios.

(l) The Markov chain analysis needs to be conducted every month based on the switching states of the four variables recorded between the previous and current states. The state switching probabilities of IPI will also be updated every month, as the correlation coefficients will change with progress of the time series and addition of monthly data.

If monitored closely following this process, VMI can result in better performance than internal inventory management. The state changes of variables in the Markov switching chain should be favourable for positive VMI performance (that is, the inventory performance index should be contained within pre-defined bounds). The time series analysis in this chapter provides this confidence. However, VMI can cause losses if not monitored closely and corrective actions causing unfavourable state changes of the variables are not taken every month.

There was a limitation in this analysis. The manufacturing company where the pilot study settings were made does not face seasonal fluctuation for these six components, as the orders are stable throughout the year. If there are seasonal fluctuations, they need to be monitored separately by segregating them as shock time zones. The future researchers may like to test Markov chain analysis in a setting having seasonal fluctuations and shocks caused by them. The shocks will be reflected in the state changes of the four variables. It is suggested that the shock zones are plotted on a separate time series to keep the usual time series clean and stable.

6.7 SUMMARY OF CHAPTER 6

This chapter presented a report on the pilot setting and it is testing for VMI in an auto parts manufacturing company in North India. The pilot was conducted by switching supplies of six components by a manufacturer to VMI mode. The switching was carried out in January 2018 and a time series plotting of five variables nine months prior to and nine months after the switching was done and analysed. Further, transition probabilities of inventory performance index were estimated based on correlations with four most influencing variables. Sixteen state switching scenarios were modelled and Markov chain analysis of IPI for two of them was carried out to test the VMI performance.

7. CONCLUSIONS, RECOMMENDATIONS AND GENERALISATIONS

7.1 A SUMMARY OF THE ENTIRE RESEARCH

This research was conceptualised to investigate the various inventory optimization techniques in Supply Chain Management and explore the VMI model for an auto parts manufacturing company in North India. In Chapter 1, a review of multiple inventory optimisation techniques was conducted and the value of VMI was highlighted. To explore VMI more in detail, it was reviewed extensively in Chapter 2 such that the key factors influencing VMI performance were identified and the variables influencing the key factors were identified. These findings were compiled in the form of an initial structural construct guiding the future course of this research. The next two steps carried out for investigation VMI were interpretive structural modelling and graph theory analysis. Interpretive structural modelling is a qualitative process taking into account correlation between variables based on inputs provided by experts. A matrix called the Structural Self Interaction Matrix is formed based on distinct symbols assigned to the interactions between the variables. The self-interaction matrix is taken through multiple iterations to evolve a final reachability matrix. The interpretive structural modelling helped in categorising the levels and categorisation of the output variables of VMI performance to derive the most critical ones from the perspective of the auto parts manufacturer under research. The final MICMAC analysis was done for estimating the driving power and dependence power of the variables listed as the desired outcomes of VMI process thus categorising them appropriately under four heads: Autonomous variables, Linkage variables, Dependent variables, and Independent variables. The key outcome variables of VMI derived from the MICMAC analysis are improved customer service, decreased cost of products, decreased inventory holding costs, and decreased storage area. The graph theory analysis helped in assigning quantitative values to the factor variables. A diagraph and numerical matrix was evolved by assigning a simple numeric value to all the variables, evolving directional relationship and interdependence among the variables and its various sub variables, conducting computer processing as well as visual analysis of variables involved, and calculating the permanent function.

These efforts provided a view on how the pilot VMI study should be designed. Both interpretive structural modelling and graph theory indicated that the most essential benefits of VMI are reduction of supply chain costs (putting together all the individual cost components), reduction of cost of products for the manufacturer (a reflection of reduced production costs), timely delivery of products (lead times), and better demand predictions through a deeper visibility into the supply chain. The manufacturer being studied worked with manufacturer operating as outsourced manufacturing agencies. The manufacturer manufactured and delivered multiple product codes, which were integrated in the assembly lines of the auto parts manufacturer. By studying the existing supply chain setting of the manufacturer for processing, transportation, and storage of the supplies provided by the manufacturer, it was revealed that supply chain costs can be measured as transportation and materials handling costs, cost of products can be measured directly through the actual billing by the manufacturer, and lead times can be measured as the time spent from order booking to the actual acceptance of the materials after inspections. However, better demand predictions through a deeper visibility into the supply chain can only be studied through a suitable predictive analytics technique. For this purpose, Markov Chain modelling using the Markov Probability Matrix was selected.

Thus, VMI pilot could be designed by converting the agreements of one of the products delivered by one of the manufacturer. The purchase ordering and all other supply chain processes were converted into vendor-handled processes with no interventions by the manufacturer except an inspection at the point of buffer entry of the chosen product into the assembly line. The actual VMI agreement was signed on 14th December 2017 with a commencement date of 1st January 2018. The data was collection from nine months prior to the VMI introduction to nine months after the introduction of VMI. The directly measured variables were transportation cost, materials handling costs, cost of the components (the actual product costs), and lead times. The costing data under all these heads were captured from the bills raised by the manufacturer after introduction of VMI, and from the journal entries in the manufacturer's accounting system (in SAP software) prior to introduction of VMI. The definition of lead times, however, was different prior to introduction of VMI and after introduction of VMI. Prior to introduction of VMI, the time difference between purchase order raised and approval of materials after inspection was recorded as lead time. After introduction of VMI, the time difference between the requirement generation timestamp in MRP II and the inspection approval timestamp at the buffer entry point of the machine was recorded as lead time.

In addition to the directly measurable variables, an indirectly measurable variable was also tracked for these eighteen months. This variable is called Inventory performance index (IPI) that is generated internally in the MRP II module of SAP used by the manufacturer. IPI is calculated by SAP internally based on more than 50 inventory performance variables captured from the quantitative reports of operations and from the accounting statements. The value of IPI varies from 1 to 10. Higher the value of IPI better is the inventory performance achieved by the manufacturer for a particular product code.

After selecting the variables and collecting their longitudinal data for eighteen months, a predictive modelling process using Markov Chain modelling following the Markov Probability Matrix was conducted. Markov Chains do not possess any memory as all the next state transitions of a variable are estimated based on their present states. However, an absolute memory-less modelling was not suitable for this research as the predictive analytics of VMI required a deep view into the time series data of all the variables prior and after introduction of VMI in the supply chain. Given this challenge, the Markov Chain analysis was conducted using Monte Carlo estimation using Gibbs sampling space. In this approach, if the factor (independent) variables and the influenced (dependent) variables are sharing a common time series (by overlapping over each other on a single timeline), then the next state probability of an influenced variable can be estimated by its auto or cross correlation, or Pearson correlation with other overlapping variables on the time series. This approach inducts some historical knowledge in the otherwise memory-less Markov Chain. When the chain length tends to infinity, the Markov Chain gets historical knowledge based on Monte Carlo estimate using Gibbs sampling space. In real world, the VMI implementation is expected to continue for infinity or a very long time period (say, five years). Hence, the predictions are estimated with an assumption that they are made for an infinite time series.

A transition probability table was formed for 16 possible present states of the four variables. For N variables, the number of states possible is 2^N (binary numbers theory). For every state, 12 transition probabilities were found to be possible for IPI. The transition probabilities were numerically assigned based on Pearson correlation coefficient between the influencing and influenced variable. IPI was modelled as the influenced variable whereas other four variables were modelled as influencing variables. The next state of a particular state of the four independent variables was estimated using Markov chain at that particular state. In this way, Markov chain was used as a memory-less chain (as per its fundamental definition) but the transition probabilities were estimated by inducing some historical information using Pearson correlations following the Monte Carlo estimate using Gibbs sampling space (with an assumption that the chain is infinite).

In addition to Markov Chain analysis, the individual time series of the four independent variables and the one dependent variable were also analysed. All these analytics were conducted using SPSS software. The outcomes of these analyses, the concluding points were discussed at the end of Chapter 6. These are summarised with final arguments and a possible mapping with the theoretical framework in the next section.

7.2 CONCLUDING POINTS AND MAPPING WITH THE THEORETICAL FRAMEWORK

The raw time series analysis of the independent and dependent variables (without applying the Markov Chain modelling) revealed very interesting observations. VMI may not appear as fruitful as expected in the initial months of implementation. For few variables, VMI may increase the costs above the regular observed trend. In subsequent months, VMI may exhibit some improving trend but will not be stable. There may be sudden degradation of its performance in a specific month but may bounce back again. This behaviour is expected in Monte Carlo approximations with Gibbs sampling approach when an infinite time series is evaluated. The overlapping variables on the time series need to undergo a cooling period before they exhibit definitive performances to the observer. This means that the benefits of VMI may not be fully realised for a long time although a trend of improvements (with some instability) may be observed in all the performance variables during a prolonged cooling period. If the cooling period is too long, the owners and managers of the manufacturing company may not be satisfied about VMI as the strategic choice for improvements in inventory management. Every manager wants to achieve quick wins to justify the investments made in a new strategy. Hence, simply leaving the supply chain at the mercy of the possible variations during a prolonged cooling period is not a good idea. The inventory managers need to do much more than merely observing the cooling periods of the influencing and influenced variables.

Intermittent actions to ensure that the inventory performance of next month shall be better or at least identical to the inventory performance of the current month can be undertaken using the Markov Chain analytics demonstrated in Chapter 6. The sixteen possible present states of the independent variables and the corresponding 12 transition probabilities of the inventory performance index were tabulated separately. The transition probabilities are correlation coefficients estimated over the overlapping time series. Hence, they will vary every month and needs to be updated in the table. However, on the last day of a month the Markov Chain estimation can be done based the current states of all the variables at that point. This means the Markov Chain can be used with its usual characteristic of a memory-less time series chain. At that point, the Markov chain can be used to estimate the 12 transition probabilities of the inventory performance index as presented at the end of Section 6.5 (Test Results). This analysis can help in predicting if the inventory performance will improve, remain the same, or reduce in the next month. The current states of the influencing variables can be compared with the sixteen possible states to identify which particular state helps in achieving the best inventory performance through VMI. Using the comparisons, the inventory managers can target possible improvements in the influencing variables every month.

If actions undertaken for improvements in the independent variables do not help in achieving the desired VMI performance, a remapping with the initial structural construct and the models of variables derived from the interpretive structural modelling and graph theory needs to be conducted. The remapping may either result in changing some of the variables or adding new variables. As the data for all the variables are being captured in

SAP, it would not be difficult for the inventory manager to reconstruct the overlapping time series for the same historical length. However, all transition probabilities will have to be recalculated. If the number of independent variables increases, the number of possible current states will also increase. For example, if the number of independent variables increases from four to six, the number of current states will increase from $2^4 = 16$ to $2^6 = 64$. By merely adding two independent variables in the model, the analytics will become four times more complex than the original. Updating the transition probability table every month will become more tedious. However, estimating the transition probability matrix (of 12 possible transition probabilities of the inventory performance index) will remain the same. With these concluding points, the key recommendations of this research are presented in the next section.

7.3 KEY RECOMMENDATIONS

VMI strategy is not a fully sufficient solution for improving inventory management performance. It is a complex variable dependent upon multiple influencing variables. The inventory performance index calculated internally in SAP is based on more than 50 influencing variables. This indicates that the variables discovered in Chapter 2 (literature review) and the resulting theoretical framework may be falling short of the actual practical framework monitored in SAP. However, monitoring and continuously improving more than 50 variables is a very difficult and expensive task. The inventory manager needs to identify the topmost influencing variables for the inventory performance index and continuously improve and monitor them. SAP does not report such variables because the breakup of variables influencing inventory performance index is not visible. Further, the algorithm for estimating inventory performance index in SAP's MRP II module is hidden. Hence, the Markov Chain analysis using Monte Carlo approximation and Gibbs sampling can be very useful in identifying the most influencing variables on the inventory performance.

Using the Monte Carlo approximation, the auto, cross, or Pearson correlation can be used to estimate transition probabilities of inventory performance through VMI provided the time series comprises of overlapping influencing variables and is infinite. With this approximation in mind, the data sets of key variables measured under the VMI model should be captured over a sufficiently long period and their correlation coefficients with the inventory performance index should be estimated. Thereafter, the variables having maximum correlation coefficients with the inventory performance index should be shortlisted. For effective inventory control using VMI, not more than four or five variables should be chosen. The cooling period of VMI may be longer than acceptable by the management, hence predictive values of the 12 transition probabilities of the inventory performance index should be estimated on the last date of every month. If the predicted value of the inventory performance index is not satisfactory, the inventory manager should identify the best or optimal states of the current states of the independent variables (from the table of all current states and the transition probabilities of the inventory performance index), and target improvements in selected variables appropriately. This approach may help in controlling the fluctuations of VMI performance during the cooling period.

In Section 6.6, it was suggested that the month of introduction and the cooling period comprising shocks may be eliminated in the longer run from the time series when the VMI performance appears to be stabilising. This step is essential to derive true values of transition probabilities when the VMI has stabilised. This may be viewed as the long-term strategy. In the medium-term, the strategy of assessing the predictive values of the inventory performance index and controlling its variations by making quick improvements needs to be incorporated. The Markov chains may be plotted every month for two different scenarios – the current scenario as well as the targeted scenario quickly achievable through quick wins. When the VMI performance stabilises, only the current Markov chain may be assessed based on the known current states of the variables and strategy enhancements are undertaken for long term and stable VMI performance achievements.

There is a lot of scope for future research based on this study. This research is based on a pilot study of only one product ID supplied by a manufacturer under a VMI agreement. This research does not reveal a multi-product scenario. If inventory management under VMI is designed for a large number of product Ids, this Markov Chain model will become very complex if monitoring and control is done separately for each product. For example, if 25 product Ids are monitored, 50 Markov chains need to be analysed during the cooling period and 25 Markov chains need to be analysed after the cooling period. Further, for each product there will be a specific inventory performance index having correlations with the influencing variables. As the influencing variables will be the same, they might be affecting the inventory performance indices of different products differently. In such a complexity, there will be conflicting strategies evolving from the Markov chains. The mathematical modelling needs to be much more complex to incorporate multiple products and conflicting Markov chain outcomes. Overall, a multi-product strategy needs to be worked out for measuring, monitoring, and controlling VMI performances of all the products included in the scope. The SAP application may report different inventory performance indices for the different products, but a single consolidated value of the inventory performance index needs to be estimated outside the SAP reflecting the overall inventory management performance under VMI achieved by the manufacturing organisation. It is expected to be a complex function but the values should be defined from 1 to 10 to keep it consistent with the individual inventory performance indices reported for every product. In a very simple model, it may be merely an arithmetic average of individual inventory performance indices of all the products. We leave this analysis and decision on the future researchers.

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BRIEF BIODATA OF RESEARCH SCHOLAR

Ms. Jyoti did her M.Sc. (Mathematics) from Himachal Pradesh University, Shimla in 2004.Her teaching career started in year 2006. She has 12 years of teaching experience at YMCA University, starting in 2007. Presently she is working as an Assistant Professor in Department of Mathematics at J.C. Bose University of Science & Technology, YMCA, Faridabad. She has taught students at graduation level and Masters level also. She is pursuing her Ph.D. in Mathematics from J.C. Bose University of Science and Technology, YMCA, Faridabad. She has 8 research papers in International journals and 6 papers in International/National conferences.

LIST OF PUBLICATIONS

Published papers

S. No.	Title of paper along with issue number and year	Name of Journal	Impact factor	Referred or Non-referred
1.	"Development of Markov Chain based tool for studying effectiveness of Vendor Managed Inventory and result analysis from a pilot study", https://doi.org/10.1007/s12046-020-1298-3	Sadhna Springer journal, Official journal of Indian Academy of Sciences, **indexed in Scopus and Science Citation Index Expanded**	0.769	Referred
2.	"The Commercial Impacts of Reverse Logistics in E-commerce in India", Volume 9, Issue-3, February 2020.	International Journal of Engineering and Advanced Technology, ISSN:2249-8958, **Scopus Indexed Journal.**	-	Referred
3.	"Factors involved in successful implementation of Vendor Managed Inventory and its structural model" Volume-4, Issue 11, February 2019	International Journal of Research in Engineering Application & Management, ISSN:2454-9150, UGC Approved Journal.	-	Referred
4.	"Quantification of benefits of Applying Vendor Managed Inventory for a Manufacturer using Graph Theoretic Approach" Volume-5, Issue-2, May 2019	International Journal of Research in Engineering Application & Management, ISSN:2454-9150, UGC Approved Journal	-	Referred
5.	"Analysing the process of Vendor Managed Inventory", published in Volume 5, No.2, February 2018	Journal of Global Research in Mathematical Archives, ISSN 2320-5822, UGC Approved Journal	-	Referred

6.	"Analysing the barriers in Vendor Managed Inventory in medical stores", Issue I, Vol. VII(I), April 2018	Gurukul International Multidisciplinary Research Journal. UGC approved journal Sr. No. 48455, ISSN No. 2394-8426	-	Referred
7.	"Inventory optimization – a necessity for effective SCM" Vol. 1, Issue 2, Dec 2013.	International Journal of Recent Trends in Mathematics & Computing. ISSN: (Online) | 2320-6098	-	Referred
8.	Reverse SCM using Goal Programming,", Volume 4, Issue 10,251-254.	International Journal of Scientific Research, ISSN No. 2277-8179	-	Referred

Presented Papers

S. No.	Title of the paper	International/ National	Held at	Date
1	Vendor Managed Inventory – Cost Analysis	National conference on, "Advances in Mathematics & Computing".	YMCA University of Science & Technology, Faridabad.	1-2 May 2017
2	Study and review of EOQ models in VMI	National Conference on, "Advances in Mathematics & Computing,"	YMCA University of Science & Technology, Faridabad.	1-2 May 2017
3	Vendor Managed Inventory- A Review	National Conference on, "Latest Developments in Civil and Environmental Engineering 2015"	Giani Zail Singh College of Engineering and Technology, Bhatinda.	15-16 October 2015

4	A Goal Programming model for reverse supply chain.	International Conference on recent trends in materials.	Amity University, Noida.	30-31 October,2013
5	Particle Swarm Optimization - A new optimization technique	National Conference on Science in Media (SIM 2012),	YMCA University of Science & Technology, Faridabad.	3-4 December,2012
6	Genetic Algorithm: A Problem-Solving Approach	Technological Advances in Mechanical Engineering (TAME 2012)	YMCA University of Science & Technology, Faridabad.	19-20 October 2012