Few theoretical approaches to the problems of Supply Chain Management based on analytics

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Abstract

The right strategy about supply chain management is one of the key drivers of any successful business in the manufacturing domain and its importance is growing very fast due to latest trends in the analytical tools and services. The most recent research studies says that the global supply chain analytics value in terms of market size is around USD 3.5 K million in 2018 and is expected to grow up to USD 10K million in 2025 at CAGR around 16% forecasted growth. This is achievable only when we can identify the right opportunities and right platforms.

The today's supply chain environment presents lot of challenges to the data scientists in terms of data collection, integration, storing and processing because there are huge and unconnected data sources for each of the processing and the speed at which these data getting generated is also very fast. So, the application of data analytics has very immediate benefit as well as many complexities in the implementation

In the current paper, we want to focus on the key analytical applications in supply chain domain including procurement, manufacturing, replenishment and customer demand. We want to explain the statistical approach for very highly impactful supply chain problems. The analytical applications discussed in this paper starting from procurement and deals up to ware house management and also different internal phases in between them.

Keywords: Inventory Analytics, Consumption forecasting, Supplier Base Optimization, Supplier Reliability Index, Min Stock level, Route Optimization.

Introduction

Supply chain management as concept has quite long history but previously it is focused on only on process improvement initiatives that involves very huge human intervention and very manual in nature. Huge research done around this topic and reached the position where almost all latest SCM initiatives are driven through digitally automated processes and also with very less human intervention.

The current study focuses on identifying right opportunities where we can apply few advanced analytical tools or methodologies that will help to make very clear decisions. Initially we can find many analytical applications around customer insights topic only but later we can observe that the science of data analytics had its applications on end-to-end supply chain management systems as well in the recent times(Anitha,P & Patil,M,2018).The data integration and management skills which consists of ability to use tools and techniques to extract, integrate, store and transform the data from heterogeneous supply chain systems are very key in this area to see some early results(Deepak A, Niraj K et al.).Depending on the level of skills available in this area decides about the successful implementation of supply chain strategy in their organizations.

The Cycle of Supply Chain Management

In the regular manufacturing environment, we consider the following four phases of a supply chain cycle without considering some special scenarios like multi-phase manufacturing where each phase has a separate customer demand etc.

a. **Procurement:** This is the first phase of the supply chain and typically it involves activities like receiving the quotes from suppliers, price negotiations, raising the purchase orders and processing them through some internal systems for creating contracts. Once the supplies are arrived at the facility, then input quality assessment, inventory update etc. might happen within the organization. Here, mostly lead buyers in the purchase department will play a key role along with the purchase head at the level of approval or auditory role.

b. **Manufacturing:** From the supply chain perspective, the manufacturing phase involves consuming the stock from stores, inventory store data updates, return of unused material, complaints about the material quality etc. Here inventory manger or store manager plays a key role along with the store in charges in the plant. Here we can see that different organizations are at different levels of digitization to carry out this phase.

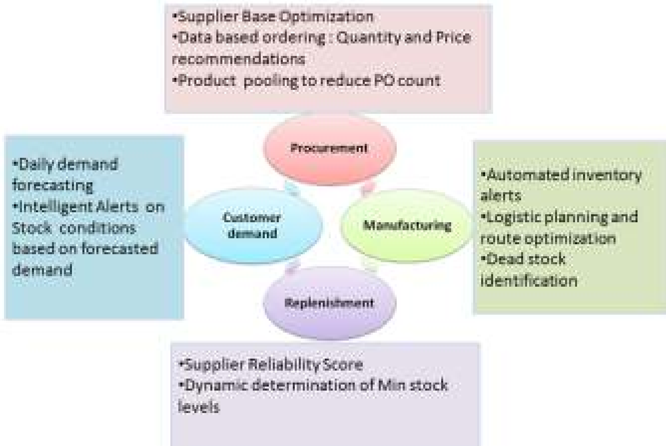
c. **Replenishment:** This is the phase where the items in the store are replenished with new stock and normally it is just extending the purchase orders based previous created contracts etc. It is also done some times automatically through regular supply contracts from vendors. The replenishment happens once the existing stock reaches the minimum stock or safety stock levels.

d. **Customer Demand:** This is the key part for planning and production processes. An efficient forecasting of customer demand might results in right production plan and there by no dead stock or over inventory levels. In practice, the forecasted figures will help the buyers to negotiate more efficiently with suppliers for better discounts and supply plans with right intervals of time. Mostly the historical data of customer demand will give us a starting kick to build the prediction model but along with historical data, we might need to add some other external variables as well to make it more efficient and accurate.

Analytical applications in SCM phases

With the latest development in the data capturing and storing methods, huge amount of datais available in supply chain domain to use them for taking right business decisions. The digital transformation played a key role in implement several tool and technologies and in return, many organizations are able to reduce the cost of total supply chain management

In this section, we tried to describe the analytical / statistical applications in each phase of the supply Chain management with some most popular use cases under each division of SCM. In the later sections we explained them more elaborately with little more technical details.



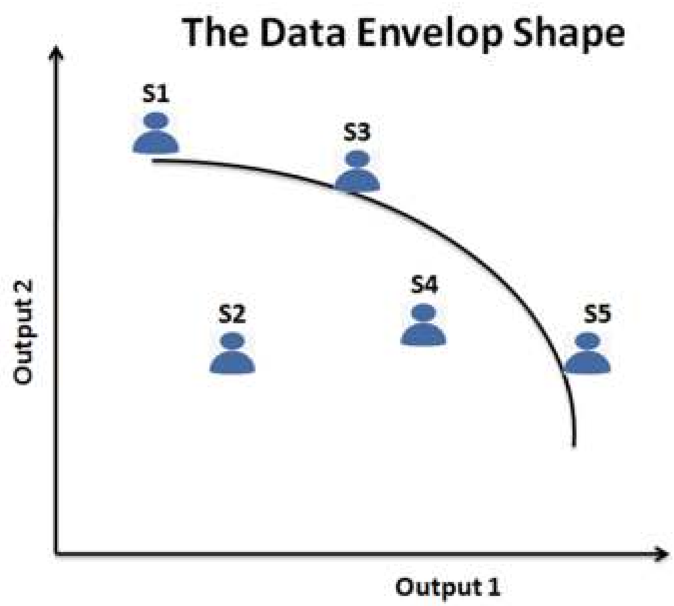
Analytical Applications in Procurement:

The procurement function in any organization ensures that all the goods, materials and services which are essential for manufacturing is made available at right prices and right times. The following are few examples where we can apply statistical methods to arrive at better decisions based on data.

Supplier Base Optimization:

Supplier Base Optimization (SBO) is a strategically very good option for many organizations in the current digital world which can be attained through activities like reducing the suppliers, configuring the entire supplier base etc. (Talluri, Sri & Narasimhan, Ram, 2005). Maintaining the key and only required list of suppliers in the database is always a challenging in this complex supply chain scenario. It is cost to the company if it is maintaining too large and inefficient list of suppliers in the data base and also it causes to buy the items at higher prices than normal because of multiple suppliers for each item. One of the popular analytical methods for supplier base optimization is data envelopment Analysis

Data Envelopment Analysis: Data envelopment analysis is a technique which can be used to measure multiple input dimensions to arrive at single efficiency score or ranking. It allows using multiple inputs and output parameters that enable to compare the suppliers final rank and later the management can optimize the supplier data base depending on its score. It create an envelope like structure or curve where the suppliers who are in the frontier are the best suppliers and suppliers whose presence is below envelop need to improve their performance in terms of selected parameters of quality like delivery time, quality and price.



For example, in the above data envelop, the suppliers S1, S3 and S5 on the frontier of the envelop and hence rendering their optimum efficiency but the suppliers S2 and S4 has still lot of potential to improve their performance.

The usual formation of the liner program might be as follows

$$MAX\ (\varepsilon_{S1}) = \sum I_r Y_{rj_{S1}} / O_i X_{ij_{S1}}$$

Where S_1 is the supplier of our selection

I_r and O_i are Weights of Inputs and outputs respectively

Y_{rj} and X_{ij} are values of inputs and outputs respectively

Following step by step approach can be used to solve the DEA algorithm.

i. List out the key input and out parameters like lead time, discount, size etc.

ii. Collect the numerical data for selected supplier for the above parameters

iii. Calculate the efficiency of the each decision making unit (supplier) by solving the liner program (LINDO API might be useful to solve the Liner program)

Based on the relative efficiencies, we take final call on the optimization of the supplier data base. One should keep in mind that this method is subjected to measurement error since it is data dependent.

Data Based Ordering:

When a procurement request comes to a buyer or lead buyer for an item, the buyer will start identifying and negotiating with the vendor for the request quantity in the procurement list. In this process, the buyer is not necessarily considering two important scenarios like how much frequently this order might repeat in future and what is the consumptions pattern of the item. So, data-based ordering is the process where the buyer is considering the yearly requirement through some prediction models and dynamically verifying the minimum stock to be maintained in the store and this activity will reduce the total inventory in the store as well as procurement cost.

Seasonal Naïve Method: Most of the times, seasonal fluctuations are unavoidable in the data and we can find that using seasonal Naïve Method. This method is very good choice only when seasonal trend is dominating in the data than other trend the components. Here forecast for the coming month is considered from consumption value of the material on the same period before year. Symbolically it is represented as

$$\hat{y}_{T+h/T} = y_{T+h-m(k+1)}$$

Where m is the seasonal period and k is number of completed years before time T+h (i.e., the integral part of (h-1)/m)

Reasonable Price Index: This index is targeted to decide whether the quoted price is in the reasonable limit of difference on both sides or not. For this we need to calculate the estimated unit price which is weighted average of

1. Same item last year price from the same vendor
2. Same item unit price from another vendor for the current year
3. Unit price of the same item from the online vending platforms
4. Commodity Price Index released by Govt of India multiplied by the last year price of the same vendor

The weights are based on user preferences or we can assign equal weight. Now we can calculate the Reasonable Price index as

$$\textit{Reasonable Price Index} = \frac{|\textit{Actual Price} - \textit{Estimated Price}|}{\textit{Actual Price}} \times 100$$

If the index value is more than 40 % (we can set it differently as well) then it may not be reasonable price (on both sides) and buyer can investigate it further.

Product Pooling by Conditional probability score

In the regular practices we can find that many vendors will supply multiple items to the same company where these multiple items might go even up to or more than 100 items. But the buyer community places the orders for each individual item separately in very shorter intervals to the same vendor as per the purchase requests arrives in their table. This actually end-up in lot of administrative costs due to high number of purchase orders and hence we can use the product pooling concept to combine the different items in the same order and hence reduce the count of purchase orders.

The product pooling can be done by using the conditional probability concept. It is the probability of happening of one event given that another event already happened. The formula for combined probability is given by

$$P(A/B) = \frac{P(A \cap B)}{P(B)}$$

P (A/B) = Probability of happening of A given that B is already happened

P (A ∩ B) = Probability of happening of A and B together

To apply this for purchase data, we need to follow the following steps.

1. Assume we got a request for an item A and we identified vendor S for this item. Also, the same vendor supplies another two items B and C.
2. Now observe from historical data that how many times A and B, A and C are ordered together.
3. Then find the conditional probability score of P(B/A) and P(B/C) . Recommendation can be given in the order of values of this conditional probability.

Analytical Applications in Manufacturing:

In the current digital era, many manufactures started generating huge data from multiple systems, devices and applications and this data explosion created new challenges in data management and data analysis which require new approaches in big data era(Wang, Junping & Zhang et al., 2018). Most of the manufacturing companies have started making the changes to streamline their operations, using traditional as well as new technical methods. This change leads to the invention of new readymade tools and software that complete the job of analyzing the collected data in fraction of seconds.

One significant asset that production companies have not completely yet realized is their own data. As all systems are digital and connected to each other, generates machine data for every second and started storing in usable format. So the challenge for all manufacturing industries starts with extracting, integrating and analyzing this big data and draw some meaningful conclusions.. However, due to advancements in analytics and cheaper computational power, process manufacturers can make effective use of data to work. Drawing meaningful insights from available data collected from multiple data sources and taking advantage of visualization platforms and machine learning models to uncover hidden ways to optimize their processes from raw materials sourcing to finished product sales.

Advanced analytics often help manufacturers overcome issues that were previously impenetrable and expose others they never knew about such as secret bottlenecks or unprofitable production lines. EBITDA (earnings before interest, taxes, depreciation and amortization) margin increases as much as 4 to 10 percent can be delivered through these advanced analytical approaches.

By using big data to predict their failure, producers may optimize the operating time of critical issues. To obtain insights that cannot be observed with traditional techniques, predictive maintenance systems gather historical data (structured and unstructured, computer- and non-machine-based). Using advanced analytics, enterprises may identify the conditions that appear to cause a computer to break and track input parameters so that they can interfere before breakage occurs, or be prepared to replace it when it does, thus reducing downtime. Usually, predictive maintenance reduces computer downtime by 30 to 50% and improves machine life by 20 to 40%.

Automated inventory alerts based on Optimum stock level index

Inventory control is very vital domain which had been studied extensively in optimization research topics. There are two important aspects when inventory is insufficient and they are lost-sales model and backorder model(Ohmori ,S., & Yoshimoto,k, 2020).Inventory management can be improved by identifying the difference between being able to fulfill an order or not. Inventory is a major asset to any business, if not effectively managed endless problems start to occur such as inconsistent low- or high-level stocks, delays in fulfillment, and miscommunication between warehouses.

By monitoring and analyzing stock data fluctuations, we can create automated inventory alerts through implementing the Business Process Automation Platform and sent via mail or text to the internal and external recipients, thereby reducing the manual reporting process.

The automated inventory alerts produce the results such as reduced stock waste, optimized inventory levels, and improved cross-department visibility of stock data, enforced best practices in the organization.

The best intelligent part here is to determine the optimum levels for safety stock and minimum stock dynamically in the production environment. This topic is discussed in detail in the next section of this paper.

Route optimization

The key problem in the conventional logistic network approach is that they always focus on deliverer point of view(Jukka,k, Antti Lehmusvaara et al). It is always better to include customers aspect in the deciding the route optimization problems. The process of deciding the shortest possible distance between places is known as optimizing the path. This decreases the price and the travel time in the process. The organization should be able to obtain details on its business routes so that the best possible routes can be predicted by a business analyst. With the new advancements in technology, the route optimization is carried out completely in digital form and predictions are done with advanced algorithms available in data science.

Path Optimization (RO), generally defined, is the process of finding the most cost-effective route, given a set of particular business parameters. It is however, more difficult than simply calculating the shortest distance from point A to B as it involved multiple constraints as well as complexities. In order to have the best possible route, logistics route optimization software can easily test different 'what-if' scenarios and take business constraints such as vehicle availability, traffic congestion, appropriate passenger, etc. into account.

Constraints that should be considered for the solution for logistics route optimization:

Real-Time Traffic Consideration: A Route Optimization program should preferably consider real-time traffic conditions in order to save the logistics costs; ensure on-time delivery and better adherence to key SLAs for increasing customer satisfaction. In this digital era, we can get the real time traffic conditions up-to-date from open resource app like Google maps etc.

Order-Vehicle Constraints: The right combination of product category and vehicle type is another constraint in the route optimization problems. For example, it is not possible to ship various product categories, such as electronics and perishables, together.

Historical Data Inspection: Historical data on three levels - passengers, customers and time of the day - can also be analyzed by the logistics route optimization tools.

Rider Preference Consideration: Resistance from on-ground workers such as drivers and distribution agents are a major constraint in the implementation of logistics route planning tools. These teams are used to functioning in a conventional way, and it's a big transformation for them to change their whole operating system.

Analytical tools for route optimisation problems:

There are various analytical tools and techniques are available and these techniques forms key application part of operations research. In the current study, we discussed couple of basic optimisation techniques for route optimisation problem.

These tools provide basic algorithm for the vehicle routing problem and they are very much suitable for deterministic and certainty conditions are requirements and route. They do not deal with the dynamic changes as static distances were used to arrive at a optimised solution. Some of the basic algorithms in this category are described as follows.

Dijkstra's Algorithm: With Dijkstra's Algorithm, you can find the shortest path from a node (called the "source node") to all other nodes in the graph, producing a shortest-path tree.The algorithm keeps track of the currently known shortest distance from each node to the source node and it updates these values if it finds a shorter path (Bale D.L.T., Ugwu C, 2016)..

This algorithm can be done in two steps. The first step is calculating the distances between nodes based on actual distance and the weightage given to that. Once all the distances are covered between all nodes, the from starting node to target node path defined between multiple options available at each node

A* search algorithm: This algorithm is mostly used in graph traversal as well as path discovery problems. A* uses heuristics to accomplish improved time performance. It is in way modified version of above method where it uses lower limits of target distance to straight the search of Dijkstra's algorithm to the goal.(Bale D.L.T., Ugwu C, 2016).

Dead stock identification:

Dead Stock refers to the inventory that remains unsold to the customers and has been lying for a specific period in the Warehouse. In other words, Dead Stock stands for the product that is not sold to the consumers and has been in the Warehouse for a particular time over the shelves. Slow-moving and dead stocks should be well anticipated in advance and need to handle very wisely as not to impact the company's finance negatively(Sugiono, N.K. & Sandra, Ria.2020) .Maintenance of deadstock using manual methods or paper-based methods is very difficult and an automated system will work more efficiently in this situation. (Neha Addam, Aarti Adsul et al., 2015). The main aim is to reduce the dead stock (D-stock) since overstocking causes consumer declines, quality problems, order/shipment over-order, etc. Dead inventory also costs cash for firms.

By following a standardized process, the reduction of Dead Stock inventory is determined. Initially, to obtain information about the past and current state of the process and capacities of the company, the as-is process is recorded. Then a rule based recommendation system that uses the parameters like number of days untouched, shelf life, scrap value etc. and create alert to the respective owners about D stock. A simple rule may be like "If an X-Item not touched for the past 12 months which has shelf life of 16 months, then create a first level alert".

The different rules are assigned with different positive and negative score where the positive score is right time utilization benefit and negative score is its final scrap value. The total sum of all positive and negative scores determines the effectiveness of implementing the dead stock mobilization engine.

Analytical applications in Replenishment:

Inventory replenishment is the process of re-filling the inventory whenever there is a need with respect to its consumption. It is one of the key activities in the entire supply chaincycle since a small mis-calculation might lead to over stocking of inventory or production halt due to lack of materials. It requires complete understanding of consumption patterns with in the production line and knowledge of different suppliers' behavior in terms of their supplied materials quality and timely deliveries. Good number of studies had been published in the area of using the data mining applications in replenishment area and few of them are discussed in the following sections.

1. **Supplier Reliability score**: The supplier quantity depends on many parameters like price, defect-rate, on-time delivery, discounts etc. (Chunghun Ha.2015),The supplier reliability score is very much useful to compare multiple suppliers and arrive at optimum list of suppliers for any organization. The calculation of supplier score involves some analytical applications and made the number more reliable.

System availability (digital availability) and high quality after-sales service are become important criteria in the recent times when we talk about supplier reliability score (Ibrahim,S.A., Elayat,H.,et al.,2011).The reliability score can be derived as weighted combination of consistency index, stability measure and Volume of business.

Consistency index is derived as ratio of number of correct deliverables to the total number of deliverables and the correctness is in terms of quality, speed and opt delivery. Similarly stability is defined over a period of time, how many changes happened with respect to the supplier list of items and prices. The volume referred as ration of volume of supplies to the total supplies of the company.

A simple approach to calculate the supplier reliability index is

Supp Reliability score = W1 (Consistency Index) + W2 (Stability Index) +W3 (Volume of business) where W1, W2, W3 are different weightages given to different parameters.

Dynamic determination of min stock levels:

The minimum stock refers to the quantity the needs to be maintained in the store for particular item to avoid production halt due to non-availability of the stock. In the traditional manufacturing companies, the minimum stock is determined by the plant engineer when the item arrives at the first time and this value kept untouched for years together. But due to dynamic changes in the real time demand, sometimes the min stock value is obsolete and adds more value to the current inventory.

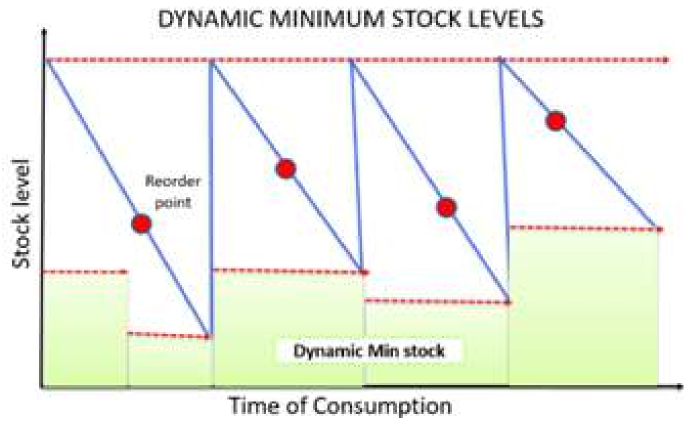
Dynamic determination of minimum stock avoids the problem of over stocking or less stocking and considers the latest demand to arrive at dynamic min stock level. It is not constant and changes as per the recent past consumption levels.

The ideal expression for this might be

The dynamic min stock = (The dynamic average consumption) X (Lead time)

+ X% risk bearing stock.

The dynamic average consumption again arrived as a function of past daily average, monthly average and yearly average with different weight factors. Also, a small X% of stock added as a risk bearing stock to address the unexpected demand. This process can be very well visualized in the following diagram.



Analytical Applications in Customer Demand:

Demand forecasting is one of the key activities in any manufacturing organization and a perfect demand planning always gives an edge to the planning and production departments. Inaccuracy or false predictions always results in overs stocking or un availability of stock for day-to-day production processes (Anna-Lena B, Stefan M, 2012) This activity involves with right data gathering and preprocessing of it before actual application of forecasting models.

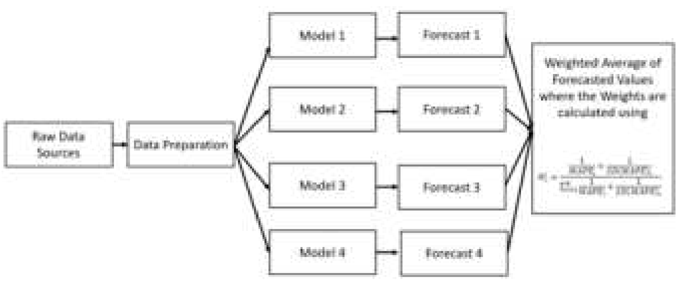
1. Customer demand forecasting:

Form the past happenings we can see that many organizations forced out of business because of not able to understand the market conditions and lagging behind with the speed of growth of technology (Aamer,A.,Eka Yani,L, 2011). The customer demand is always an important part of whole business and unfulfillment of some customer demand might lead to customer churn or business loss for the company. For all practical purposes, the demand never be constant for a longer or infinite period (Shah,N.,Chaudhari,U, 2019)In actual scenario, the customer demand always arrives in the last minute and also comes with lot of dynamic changes in it. Hence it is always very important to have a right prediction numbers for customer demand so that we can plan out production scheduling well in advance and satisfy the customer needs completely.

One of the key limitations of the demand forecasting is the non-availability of historical data or limited availability of historical data (Pavlyshenko,B.M, 2019).The researcher needs to think about some specific models in these cases very carefully. The complexity of demand forecasting is further increasing due to wide variety of products and size of the ware houses along with traditional forecasting approaches (İ. İşlek and Ş. G. Öğüdücü, 2015).

Ensemble approach for forecasting: Because of huge complexity in customer demand data, single model always cannot give the best accuracy. To overcome this problem, ensemble approach is one of the best solutionswherein we are combining the power of different models together to achieve the best accuracy.

In this method, the first step is find forecasted results from the set of models individually (like exponential, ARIMA, ETS etc.)and in the second step we can combine the forecasted results in a intelligent way. The following glow chart will give the details for this approach.



Here the forecasted results are combined by using the formula that is almost similar to precision and recall calculation

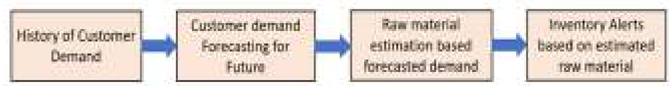
$$W_i = \frac{\frac{1}{MAPE_i} + \frac{1}{SD(MAPE)_i}}{\sum_{i=1}^{8} \frac{1}{MAPE_i} + \frac{1}{SD(MAPE)_i}}$$

Where MAPE is mean absolute percentage error and SD donates its standard deviation of set of MAPE's. This method will help to get the best accuracy for customer demand forecasting problem

Intelligent alerts on stock position based in customer demand:

Inventory optimization is one of the key aspects of manufacturing analytics and data-based inventory alerts always help to maintain the optimum inventory at the lowest cost. This is achieved by creating data-based alerts for stocks replenishment and hence overstock situation can be avoided. The basis for creating this alert is the forecasted results from customer demand project.

The forecasted numbers from customer demand are mapped in to the raw material required and compared with the existing levels of stock. Based on the time, we can create different levels of alerts for those raw materials and ensure the avoidance of "No Stock" situation in the production



Summary and conclusions:

Supply chain management is one of the key areas for all manufacturing companies and they are spending huge amount of time and money in this domain. Due to recent developments in the digital area, all the machines become connected and started storing lot of data along with traditional supply chain data related purchases and costs. The huge power of these data sets is realized by using right analytical tools in each phase of supply chain management. There are many in-built software tools are available in the market for ready use and also companies can build their own tools to deal with data in supply chain area.

Analytical approaches in this domain will help the owners to save lot of time and money for theirorganizationsand in the current study some of the basic approaches are explained in each phase of supply chain domain. There is again lot scope to develop these processes further to get more optimized benefits as research in analytics and machine learning growing day by day.

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