Lean thinking in the supply chain operations and its integration with customer order decoupling point and bottlenecks

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Master Thesis

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Abstract
The thesis study reveals that the position of bottleneck is a significant importance in supply chain process. The modern supply chain is characterized as having diverse products due to mass customization, dynamic production technology and ever changing customer demand. Usually customized supply chain process consists of an assemble to order (ATO) or make-to-order (MTO) type of operation. By controlling the supply constraints at upstream, a smooth material flow achieved at downstream. Effective management on operational constraint will results in speed up customer delivery. A throughout evaluation of demand constraints is necessary to gain the competitive benefits over the entire market.

The study is based on a conceptual model, comprises of engineer to order (ETO), MTO, ATO and make to stock (MTS) separated by decoupling point. All these represent the particular process in supply chain. The important perspective of this study is that the constraints are allocated in particular part of supply chain, which will become the supply chain more versatile. This thesis study explains the use of detail capacity and material planning techniques in upstream, midstream and downstream of the customer order decoupling supply chain. A shifting bottleneck concept has been studied in a better way, in order to keep relative stability and reduce the complexity in production management. This thesis study tries to find out some possible factors that reduce the bottleneck shifting in supply chain.

This research provides the guideline about the implementation of lean, leagile and agility in customized supply chain. Also key factors are discussed which are necessary to achieve these paradigms. Basically leagile is the mixture of both lean & agile strategies. Leagile is inclined towards sustaining the flow for mixed-model production. Its intent is to achieve the efficiencies in mass production, while producing a medium variety of products. The focus in leagile strategy is to gain effective control at shop floor planning, including capacity and material planning systems.

Different relevant aspects of standardization and customization are considered through the production processes. In addition to this rate base, hybrid and time phase material planning techniques are sorted in different supply chain parts through multiple level of bill of material.

Keywords:
Customer order decoupling point, Bottleneck, Lean, agile, leagile, mass customized supply chain
Acknowledgement
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<tr>
<td>CODP</td>
<td>Customer order decoupling point</td>
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<tr>
<td>MTO</td>
<td>Make to order</td>
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<tr>
<td>ATO</td>
<td>Assemble to order</td>
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<td>MTS</td>
<td>Make to stock</td>
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<td>TOC</td>
<td>Theory of constraints</td>
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<td>ASC</td>
<td>Agile supply chain</td>
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<td>LSC</td>
<td>Lean supply chain</td>
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<td>HSC</td>
<td>Hybrid supply chain</td>
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<td>JIT</td>
<td>Just in time</td>
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<td>SCM</td>
<td>Supply chain management</td>
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<td>TQM</td>
<td>Total quality management</td>
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<td>LM</td>
<td>Lean management</td>
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<td>DP</td>
<td>Decoupling point</td>
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<td>TPS</td>
<td>Toyota production system</td>
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<tr>
<td>BOM</td>
<td>Bill of material</td>
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<td>MRP</td>
<td>Material requirement planning</td>
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<td>CRP</td>
<td>Capacity requirement planning</td>
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<td>SS</td>
<td>Safety stock</td>
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<td>SCI</td>
<td>Supply chain integration</td>
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<td>FAS</td>
<td>Final assembly scheduling</td>
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<td>EOQ</td>
<td>Economic order quantity model</td>
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<td>PPB</td>
<td>Part product balancing</td>
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<td>LFL</td>
<td>Lot for lot</td>
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<td>POQ</td>
<td>Production order quantity model</td>
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1 Introduction

1.1 Background

Supply chain management is an area that has been currently researched with great concern both industry and academia. In general supply chain comprises of a network of operation that purchases raw material, process them into intermediate parts and final assembly and deliver these finished products to consumers through a distribution system. It is subjected to a continuous process from the total market supply and demand for products to customer cash flows. Supply chain management and other related terms such as value stream management, supply pipeline management, and value chain management have become most fascinated field of study within recent years (Christopher, 1992).

The success and failure of supply chains are recognized in the market place by the end users of products. Delivery of the right product at the right time and at the right price to the end user is not only necessary to competitive success but also an important factor to sustain in the market. Thus the factors, customer satisfaction and marketplace knowledge are important considerations when designing a new supply chain strategy. And this will lead to understand the constraints of the marketplace and attempt to develop a strategy that will meet the needs of both the supply chain and the end consumer (Mason Jones et al 2000).

The use of decoupling points in production and supply chain has gained increased interest in recent years; see, e.g. Pagh and Cooper (1998), Naylor et al. (1999), Van Donk (2001), Olhager (2003). Normally customers describe their requirement in terms of product functionality and quantity in supply chain. Decoupling points are used to measure the value-adding activities in terms of product demand information and describe the need for different management approaches in a manufacturing system. Normally customer order decoupling point (CODP) typology contains four typical elements, i.e. engineer-to-order (ETO), make-to-order (MTO), assemble-to-order (ATO) and make-to-stock (MTS), as depicted by (Wortmann et al,1997).

A majority of research was carried out on the subject of lean production system focusing on the connection between implementation of lean and performance indicator. However the focal point of studies have emphasized on a limited aspect of lean and its performance implications (Hackman and Wageman, 1995). Naylor et al, (1999) describe that a lean system is best applied upstream from the “decoupling point” in a supply chain while an agile system should be applied downstream from this point.
In manufacturing system the concept of CODP can be utilized in strategic, tactile and operational level. However the position of CODP in manufacturing supply chain influences many important decisions of organization. For example if the match between the position of CODP & manufacturing planning and control does not exist properly, probably this issue would generate the inefficiencies in supply chain operations. There are many industrial cases which face such kind of challenges that changes from forecast driven approach to customer order driven production. This transformation phase demands not only to update planning & control system but also to introduce a variety of planning tools to assure the reliability in markets (Mason and Towill 1999). To analyze the changes in manufacturing related issues, a number of methods have been developed. Typically the focus of these methods is on the match between production and marketing from a process choice perspective (Berry and Hill 1992). It has been stated that the selection of manufacturing process is closely related to the positioning of the CODP (Olhager 2003).

1.2 Problem formulation and research questions
Delivery of products to end users depends on complex tasks that require several companies to collaborate simultaneously as a supply chain. The never ending struggle for high level quality products with satisfactory customized level, put a heavy responsibility on the supply chain. The ever increasing product modularization increased the burden on the supply chain to be responsive at low cost. Capital cost of recovery in product research & development, processing and tooling setups should be reduced with the decreasing product life cycle. Normally the responsiveness in physically efficient supply chain can be afforded by enough supply in the form of finished products inventory. However for personalized customers demand, companies sometimes find it more and more difficult to achieve the desired level of responsiveness by using inventory level alone.

The speed at which customer requirements changes over time can shorten the life of products and this will lead to increase the risk of obsolescence of inventory. It is a challenge for a supply chain to keep the costs of delivering products as low as possible, while maintaining its flexibility to cope with changes in market demands.

Generally the theory of constraints (TOC) described by Goldratt (1990) has been known as management philosophy. The aim of this theory is to implement the continuous improvement through focusing on bottlenecks. The bottlenecks are a big challenge which prevent a system to achieve higher level goals. Thus TOC motivates organization to identify what is keeping away from achieving the targets and also guide to establish clear solution to overcome the system restrictions. The purpose of this study is to understand the relationship between the CODP and bottleneck in mass customized supply chain.
The following research questions are discussed in the thesis study:

- How the concept of customer order decoupling point (CODP) & constraints are incorporated to improve the responsiveness in customized supply chain. The task is to imply both the buffer management and capacity planning in upstream, midstream and downstream supply chain.

- What are the main parameters to achieve lean, leagile and agility in supply chain.

The thesis research includes a different supply chain reference model, with a view to addressing both upstream and downstream aspects from the decoupling point. Furthermore it considers the factors, which are necessary to achieve lean, leagile and agility in supply chain. The study would include the first tier suppliers and the customer.

1.3 Limitations

The objective of thesis study is to allocate the constraints in particular manufacturing supply chain framework and build a conceptual model. Only market demand, operational and material constraints are considered. The other type of constraints are not considered here such as financial, logistics etc.

In the thesis research model, first tier of customer and supplier is considered. The customer of the customer and suppliers of the suppliers are not being focused here.

In the thesis scope the environments such as ETO, MTO, ATO and MTS are considered. Ship to stock is not included.

1.4 Structure of report

The thesis report is organized as follows. In Chapter two the types of research methodologies in operation management research are reviewed. Also the relation of theory to the thesis study is examined. In Chapter 3, a detailed theoretical framework is presented in which different variables and factors are highlighted. This will provide the general relationship between the factors so that readers can understand the theoretical importance between variables. In section 3.1 the detailed literature has been reviewed about the supply chain management and coordination among the supply chain network. In section 3.2, issues about lean, leagile, agility and comparison has been presented. In 3.3 the definition of CODP and its importance in material and capacity planning is explored. A couple of bottleneck definitions are described in section 3.4, the basic methods to recognize the bottleneck, and different planning techniques to resolve the bottleneck operations. The relationship between the CODP and
bottleneck is also explored in section 3.5. This is the most critical part of the theoretical frame work.

In the analysis part, a conceptual model is discussed which shows the relevant positioning of the bottleneck along the up, middle and downstream of the supply chain. Different but problem related concepts and theories are utilized to reach the optimal solution. In section 4.1, the role of information and its importance in supply chain is highlighted. In further section, material and capacity planning techniques, different scheduling approaches are discussed. Most of these techniques are discussed with respect to focusing the bottleneck issue. Moreover necessary variables are mentioned in section 4.6 to achieve the leagility in midstream supply chain. Discussion on important study result is also presented in section 5.
2 Research Methodology

The purpose of research in any field is to gain knowledge and understanding and helps creating an explanatory theory. It might be used to discover previously uncovered phenomena and provide new information for measurement (Meredith 1998). Dubois & Gadde (2002) described it in a more general way and wrote that “the main objective of any research is to confront theory with the empirical world”. Stuart et al (2002) described a number of research objectives and ways of contributing to knowledge, which are: discovery, description, understanding, mapping, relationship building, theory validation, extension and refinement.

The aim of the any research study can be regarded as exploratory, descriptive and explanatory. Exploratory research helps to find out the best research design and data collection techniques. This research often extracts data from secondary researches such as focusing on the existing literature data and quantitative approaches. Usually the outcome of this research is not useful for decision making process but it can provide deep understanding of the problem. In descriptive study the statistical tools are used to identify the pattern and trends in the given scenarios. Also this study leads to generate the hypothesis for further research. An explanatory study provides the connection between the events and variables. It also tries to establish theories and assumption where possible. This is done by using the scientific method to test the evidence to extend an idea or theory (Saunders et al., 2007).

Normally methodology research largely depends on statistics theory in experimental design and analysis, and these concepts have been well explained in the book (Law & Kelton 2000). Research model presented by Mittroff et al., (1974), play an important contribution in the operation management research methodology field (see fig 2.1). Particularly this model is very helpful in choosing research methodological path. In this model the operational research can be organized in four phases which are: conceptualization, modeling, model solution and implementation. In first phase the boundaries and framework for research are defined. Also the variables and general characteristics of process which may be a part of research are elaborated. In the next phase a quantitative model is established which will describe the causal relationship between the model. The model may be presented in formal or mathematical relationship depending upon the nature of system variables. This can be helpful for further analysis. After this the different relevant methods /techniques are incorporated to find out the reliable solution.
Operations management is defined as “the effective planning, organizing, and control of all resources and activities necessary to provide the market with tangible goods and services”. It applies to manufacturing, service industries. (Waller, 2003). Model-based quantitative research refers to the research where models of causal relationships between control variables and performance variables are developed, analysed or tested. In causal relationships, a change of value $\alpha$ in one variable will lead to a change of $f(\alpha)$ in another variable, so that a model can be utilized to predict the future state of the modeled processes (Bertrand and Fransoo, 2002).

The thesis study focuses on model-based quantitative research in operations management. Since different variables are discussed to obtain the reliable result, so most of the strategic choices support the quantitative modeling search. The overall contribution of the knowledge extracted during this thesis was to contribute with understanding rather than validating, extending or refining existing theories. For this reason, the study was started out with an explanatory research approach.

Theoretical model based operation management research can be categorized in two types: The first one is named as axiomatic approach and mainly this type of research is driven by model itself. The primary focus in this research is to obtain the solution based upon the defined model. The solution can be predicted within the model assumption and limitation. Moreover existing techniques are utilized to optimize the problem and these may be taken to other fields such as statistics, mathematics and computer sciences. Usually strong background knowledge of mathematics is required in this field. Axiomatic research is normative and aimed at developing policies and strategies to improve the result in the existing literature (Bertrand & Fransoo 2002).

The second class of model driven research is called empirical model based research. In this research an effort is made to maintain the close match between observation and problem in action. The model used is not much perfect. However there is high
opportunity for further advancement in theory in this type of research. The research type used can be descriptive and normative. (Bertrand & Fransoo 2002). In comparison with axiomatic quantitative research, empirical quantitative model based research has not been more beneficial in industry. This is based on application of theoretical research which might be useful in real life operational process. However it is fact that quantitative model based research is a rational and precise approach. It must have objective and a rational way to deal with existing problem (Bertrand & Fransoo 2002).

Bertrand and Fransoo (2002) divided axiomatic and empirical quantitative research into two sub-categories, namely normative research and descriptive. According to classification scheme Bertrand and Fransoo (2002), this research might be in line with empirical normative quantitative research, because the objective model was achieved by empirical findings; and the objective of this study is to establish a capacity and material planning in the presence of constraints.

Wacker (1998) classified operations management research as analytical research and empirical research for the purpose of theory building (see Fig 2.2). According to the classification scheme Wacker (1998), this research might be in line with an analytical quantitative conceptual study, because this study investigates conceptual modeling in different scenarios.

<table>
<thead>
<tr>
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<th>Types of research included</th>
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<tbody>
<tr>
<td><strong>Analytical</strong></td>
<td></td>
</tr>
<tr>
<td>Conceptual</td>
<td>Futures research scenarios, introspective reflection, hermeneutics, conceptual modelling</td>
</tr>
<tr>
<td>Mathematical</td>
<td>Reason/logical theorem providing normative analytical modelling, descriptive analytical</td>
</tr>
<tr>
<td></td>
<td>modelling, proto-typing, physical modelling, laboratory experiments, mathematical</td>
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<tr>
<td></td>
<td>simulation</td>
</tr>
<tr>
<td>Statistical</td>
<td>Mathematical statistical modelling</td>
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<tr>
<td><strong>Empirical</strong></td>
<td></td>
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<tr>
<td>Experimental</td>
<td>Empirical experimental design, descriptive analytical modelling</td>
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<tr>
<td>design</td>
<td></td>
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<tr>
<td>Statistical</td>
<td>Action research structured and unstructured research, surveying, historical analysis,</td>
</tr>
<tr>
<td>sampling</td>
<td>expert panels</td>
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<tr>
<td>Case studies</td>
<td>Field studies, case studies</td>
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*Figure 2.2: Research category in operations management (Wacker, 1998)*
Reliability and validity are the two important aspects of measuring and assessing the quality of research. While validity indicates whether the means of measurement are accurate and whether they are actually measuring what they are intended to measure, whereas reliability means whether the result is replicable (Golafshani, 2003). Kirk and Miller (1986) identify three interrelated reliability aspects in quantitative research, which are: (1) the extent to which a measurement, given repeatedly, remains the same; (2) the consistency in a measurement over time; and (3) the resemblance of measurements within a given time period.

Three types of validity approaches are used in scientific research: Construct validity concerning operational measures which are used for the observed theoretical concept. To ensure construct validity, a lot of variables are reviewed to increase the understanding of concept as well as the relationships between them. Internal validity establishes the causal relationship between the variables. This is more suitable for constructing and analyzing the model. External validity is the extent that up to which level the research results are applicable to other fields (Yin, 1994). The scientific quality of the research has a strong relationship with “Optimality” concept. In normative study the optimality describes the degree with which best possible solution can be obtained. But in case of descriptive research optimality concerned the level to with which the model results can be streamlined with the exact process characteristics (Bertrand & Fransoo 2002).
3 Theoretical framework

3.1 Supply chain
Supply chain is a system whose network consists of material suppliers, production facilities, distribution services and customers integrated together through forward flow of material and backward flow of information. In supply chain, the series of linked activities inside the company as well as outside which contribute to the process of design, manufacture and delivery of products and services. (Yusuf et al, 2004). Generally supply chain is viewed as a sequence of material suppliers, production facilities, distribution services and customers which are linked together with the flow of goods and information (Towill et al, 1992). According to Arshinder et al. (2009), a supply chain consists of different members which are independent of each other to manage various resources (such as inventory, money and information). Supply chain is a set of facilities and distribution options that fulfills the functions of procurement of materials, transformation of these materials into intermediate and finished products. Finally delivery of these products is also the task of supply chain (Kaihara, 2003). A supply chain consists of interdependent units within a company and across the company that belong to both downstream and upstream partners (Ballou et al., 2000).

There are various business entities (i.e., suppliers, manufacturers, distributors, and retailers) in supply chain. They work together in order to achieve the coordination among (1) raw materials/components (2) convert the raw material into specific products (3) deliver the final products to retailers. Traditionally this chain is characterized by both the flow of materials and information within and between business entities. At its highest level, a supply chain is comprises two basic, integrated processes: i.e. the 1st one is Production Planning and Inventory Control Process, and the other one is the Distribution and Logistics Process. These Processes, illustrated below in Figure 3.1, provide the basic framework for the conversion and movement of raw materials into final products. (Beamon, 1998). Traditionally there are three stages in supply chain which are procurement, production and distribution. Each one of these stages may be composed of several facilities in different locations around the world (Thomas and Griffin 1996).
Generally supply chain is complex and is characterized by various activities spread over multiple organizations and functions. The interesting challenge is to couple these activities with effective supply chain coordination. To achieve these challenges, supply chain members must work towards an integrated system and coordinate with each other (Arshinder et al. 2008). According to Cao et al., (2008), Coordination achieved by organizing the activities among two or more functions of supply chain so that they work together efficiently. In other words, the functions are responsible for individual activity tasks but also work interdependently for common purpose. According to Lau et al. (2004), supply chain must be coordinated among the independent organization in order to enhance the performance of the whole supply chain system based on their individual needs. The main activities in supply chain is to transform natural resources, raw materials and components into a finished product that is delivered to the customer. Stank et al. (1999) have observed that inter firm coordination process is characterized by effective communication system, information exchange, partnering and performance monitoring.

According to Sahin and Robinson (2002), a supply chain is completely coordinated when all decisions have a good balance to fullfil global system objectives. Lack of coordination occurs due to incomplete information or incentives that are not compatible with system-wide objectives. Lack of coordination will cause in distortion of demand, i.e. bullwhip effect. It will increase manufacturing cost, inventory cost, replenishment lead time, transportation cost, labor cost, which will of course decrease in efficiency, profit. (Paik and Bagchi, 2007). Soroor et al. (2009) have observed that coordination plays an important role in integrating different departments in an organization along the supply chain to enhance performance. The coordination can be achieved by incorporating scheduling of manufacturing and supplies of raw materials and assembly of final products. Konijnendijk (1994) observed the coordination process at tactical and operational levels about product specification, volume, mix and lead times between sales and manufacturing in engineer to order company.
Effective coordination between functions in a supply chain has come to play a main role in focusing on the flexibility, innovation, and speed, which are necessary for survival in global competition (Fisher, 1997). Overall the purpose of coordination is to achieve collective goals that an individual element cannot achieve. Coordination capability is affected by two main issues: 1st one is information sharing along the supply chain; and the other one is allocating decision rights across channel members (Anand and Mendelson, 1997).

Lee (2000) describes the concept of supply chain integration, which consists of various levels such as information sharing, coordination and organizational linkages. In globalized supply chain environment, integration is regarded as a prerequisite for winning performance. Moreover he suggested the three powerful factors by which to analysed the extent of supply chain integration (SCI): organisational relationship linkages; information integration and co-ordination and resource sharing. Van Donk and Van Der Vaart (2005) also propose similar dimensions but they divide co-ordination and resource sharing into flow of goods plus planning and control.

Typically, supply chain can be categorized into three types: lean supply chain (LSC), agile supply chain (ASC) and hybrid supply chain (HSC). Continuous improvement in processes to focus on the elimination of waste or non-value activities stops across the chain is an important aspect of LSC. It is supported by the reduction of set-up times to allow for the economic production of small quantities. In this way organization achieves the benefits of external responsiveness by responding to customer requirements, flexibility. The LSC can provide higher profits and internal manufacturing efficiency when product demand is stable and can be forecasted accurately. ASC basically focuses on responding to unpredictable market situation. It is used to achieve a quicker delivery and lead time flexibility. It deploys new technologies and methods, utilizes information systems/technologies and data interchange facilities, puts more emphasis on organization issues and people (knowledge and empowered employees). Moreover ASC integrates the whole businesses process, enhances innovations throughout the organization. Different product types at different stages of life cycle might need different supply chain strategies. (Wang et al, 2004).

Lamming (1996) states, “Lean supply chain is an arrangement which should provide a flow of goods, service and technology from supplier to customer without waste”. The primary objective of a lean supply chain is to get access from the communication data on inventories, capacities, and delivery plans and fluctuations, within the framework of just-in-time (JIT) principles (Womack et al., 1990). Goldsby et al., (2006) claim the objective of the lean supply chain is one that produces just the right product at the right time with as little waste as possible. By doing this, lean supply mainly follows a ‘pull’
order replenishment principle based on demand since lean believes revenue is limited by demand rather than supply. This, in turn, indicates that increasing customer value can be achieved from cost reduction on the supply side (Ohno, 1988). Thus, it is necessary to reduce and eliminate waste or non-value added activities in the total supply chain flow (Mohammed et al., 2008).

Along with the lean and ASC, there is another type of supply chain known as the hybrid supply chain which is proposed by (Huang et al., 2002). It combines the capabilities of lean and agile chains to create a supply network that meets the needs of complex products. Generally HSC involves “assemble to order” products whose demand can be quite predictable. The chain helps to achieve mass customization by postponing product differentiation until final assembly.

There are two types of supply chain: physically efficient supply chain and market responsive supply chain. First one is more suitable for the standardized product and the other one is more appropriate for the innovative type of product. see fig. 3.2 (Fisher, 1997). According to Christopher (2005), the responsive supply chain is highly integrated. They are internally integrated across functions and they are externally integrated with upstream suppliers and downstream customers.

![Matching supply chain with products](Fisher, 1997)

3.1.1 Supply chain Management:
The purpose of the integrated supply chain is to create easiness in terms of information, material as well as cash flows (Stevens 1989). The ever increasing depth, size and complexity of the global market put more emphasis in links and collaborations between supply chain parties in order to improve coordination and manufacturing sustainability (Saad & Ariruzo, 2007). The aim of integration within the supply chain is to ensure commitment to cost and quality, as well as achieving minimum distortion to plans, schedules and regular delivery of small volumes of orders (Yusuf et al, 2004). Lee and Amaral (2002) indicated that the goal of supply
Supply chain management is to increase customer service and reduce costs. Many firms wish to achieve the benefits of both responsiveness and low cost (Hull, 2005). Global supply chain must take into account the differences in economies, cultures, Politics, infrastructure and competitive environment (Schmidt & Wilhelm, 2000).

Supply chain management is the use of information technology to empower automated intelligence to the planning and control of the flow of supply chain. The purpose is to speed time to market, reduce inventory levels, lower overall costs and ultimately, improve the customer service and satisfaction (Wang et al, 2004).

Many authors have a different point of view about supply chain management (SCM). The term SCM has been used to explain the planning and control of material and information flow as well as the logistics activities not only within an organization but also externally between organizations (Cooper et al., 1997). The aims of Supply chain management are to create trust, exchange information on market requirement, introducing and designing new products, and reducing the supplier base to a particular original equipment manufacturer (Berry et al., 1994). Supply chain management covers materials, supply management from the supply of basic raw materials to final product (and possible recycling and re-use). Moreover it focuses on how firms utilize their suppliers’ processes, technology and capability to get competitive benefits. It is a management philosophy that extends traditional intra-enterprise activities by bringing trading partners together with the common goal of optimization and efficiency (Tan et al, 1998). Supply chain management describes the networks of manufacturing and distribution sites that purchase raw materials, value added them into intermediate and finished products, and distribute the finished products to customers. (Lee and Billington 1992).

Network of organizations that are connected, through upstream and downstream linkages, in the different processes and activities that create value in the form of products and services for ultimate consumer (Christopher, 1992). Monczka and Morgan (1997) stated that integrated supply chain management is about going from external customer and then controlling all the processes that are needed to provide the customer with value in a horizontal way.

Supply Chain Management is the task of integrating organizational elements along a supply chain and coordinating material, information and financial flows. The purpose of coordination and integration is to fulfil order for end customer demands with the aim of improving the competitiveness of a supply chain as a whole (Stadtler & Kilger, 2005). The House of SCM (see Fig. 3.3) illustrates the various aspects of SCM. The roof stands for the ultimate goal of SCM which are competitiveness and customer service. Competitiveness can be achieved in many ways, e.g. by reducing costs, increasing operations flexibility with respect to market changes in customer demands.
or by providing excellent quality of products and services. The roof builds up on two pillars shows the two main components of SCM. The name of these components are integration of a network of organizations and the coordination of information, material and financial flows. From the figure it is clear that there are many disciplines that formed the foundations of SCM.

![Image of SCM diagram]

Figure 3.3: House of Supply chain management, (Stadtler & Kilger, 2005)

3.2 Lean thinking:

“Lean thinking” describes the principles of lean production that are applied on both strategic and operational levels (Womack and Jones, 1996). At strategic level the lean principles are applied to understand customer value and identify the value stream but at the operational level, these are configured for the elimination of waste and provide a guideline for continuous improvement (Hines et al, 2004). The purpose of Lean thinking is to create a value added operation in product/service as defined by the customer. Lean thinking transforms the management focus from perfecting individual operations (technologies, assets, people and processes) to achieve perfect flow of products/services through the business to the end customers. The result is a more effective, flexible resource utilization for the customer (Womack, 1996).

Shah and Ward (2003), mentioned that lean practices used in lean manufacturing consist of four different bundles; namely JIT, total quality management (TQM), total productive maintenance (TPM) and human resource management. Furthermore two major forms of waste can be addressed by JIT through the associated practices: work-in-process inventory and unnecessary delays in flow time. Meanwhile total productive
maintenance helps to maximize the effectiveness of equipment throughout the utilization period. But what is waste? Ohno (1988) identifies seven types of waste, see fig 3.4.

![Diagram of seven wastes]

Lean production (LP) initiated from the Toyota production system (TPS) seems to be a best-practice manufacturing strategy in recent era (Voss, 1995). Lean production is a combine set of operations which is designed to achieve high volume production by using lowest level of inventories of raw materials, work-in-process, and finished goods” (Lewis, 2000). LP diffuses in whole organization (Fig. 3.5). It consists of lean development, lean procurement, lean manufacturing (LM) and lean distribution (Karlsson and Ahlstrom 1996). LP is not only a set of practices connected to the value creation process. Rather, LP is a way to achieve excellence through the setting of performance parameter, continuous improvement and organizational change (De Toni and Tonchia, 1994). Lean production uses half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. It requires keeping half the needed inventory, results in many fewer defects, and produces a larger and growing variety of products (Womack et al., 1990). Lean production is an integrated system that fulfills production of goods/services with minimal buffering costs (Hopp and Spearman, 2004). Shah and Ward (2007) define lean production as mutual understanding of supplier, customer and internal related operational constructs in a manufacturing environment. Additionally they define ten operational features such as supplier feedback, JIT delivery, developing suppliers, involved customers, pull flow, low setup, controlled processes, productive maintenance and involvement of employees in the process.
In TPS the basic idea is to produce the kind of units needed, at the exact time with exact quantities needed such that unnecessary intermediate and finished product inventories can be eliminated. The sub-goals in TPS is cost reduction (waste elimination), quantity control, quality assurance, and respect for humanity. These are achieved through four main concepts: JIT, automation, flexible workforce, and capitalizing on worker suggestion (Monden, 1983). The basis of TPS is the absolute elimination of waste. The two pillars needed to support the TPS are JIT and automation. TPS can be described as an effort to make goods as much as possible in a continuous flow (Ohno, 1988). TPS includes standardization of work, uninterrupted work flows, direct links between suppliers and customers, and continuous improvement based on the scientific method (Spear and Bowen, 1999). Karlsson and Ahlstrom (1996) identify the following building blocks of LM: elimination of waste, continuous improvement, multifunctional teams, zero defects/JIT, vertical information systems, decentralized responsibilities/integrated functions. (see Fig 3.5).

### 3.2.1 Comparison between Lean and Agile manufacturing:

Lean manufacturing is defined as: It is an integrated manufacturing system that is designed to achieve maximize capacity utilization and minimize buffer inventories through minimizing system stochasticity (De Treville and Antonakis 2006). Lean manufacturing is characterized by certain JIT flow and quality practices (McLachlin 1997).

Agile manufacturing involves the ability to respond quickly and efficiently to changes in market demand (Brown and Bessant 2003). Agile manufacturing is describes as the ability to fulfill to unexpected changes of customer requirements in terms of price, specification, quality, quantity, and delivery (Prince and Kay 2003).
manufacturing programs focus on performance improvements in the function of responsiveness, product customization, reduction in new product development time, reduced system changeover time and cost (Narasingan et al., 2006). Manufacturing tools associated with agility emphasize use of advanced manufacturing technologies, supplier alliances, high skill employee training, and customer sensing and sales linkages (Brown and Bessant, 2003; Prince and Kay, 2003).

Christopher (2000) states that agility is a business-wide concept including logistics process, organizational structure and information systems. Goldman et al. (1995) summarize the core characteristics of agile manufacturing from the six dimensions of marketing, production, design, organization, management and people, as shown in fig 3.6.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Agile characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marketing</td>
<td>Customer enriching, individualized combinations of products and services.</td>
</tr>
<tr>
<td>Production</td>
<td>Ability to produce goods and services to customer orders in variable lot sizes.</td>
</tr>
<tr>
<td>Design</td>
<td>Holistic methodology integrating suppliers, business processes, customer and products use and disposal.</td>
</tr>
<tr>
<td>Organization</td>
<td>Ability to synthesis new productive capabilities from expertise of people and physical facilities regardless of their internal or external location.</td>
</tr>
<tr>
<td>Management</td>
<td>Emphasis of leadership, support, motivation and trust.</td>
</tr>
<tr>
<td>People</td>
<td>Knowledgeable, skilled and innovative employees.</td>
</tr>
</tbody>
</table>

Figure 3.6: Core characteristics of Agile manufacturers, (Goldman et al, 1995)

Naylor et al. (1999) differentiated between the leaness and agility as they relate to supply chains. Agility depends on the use of market knowledge and a virtual corporation to get match from rapidly changing market opportunities. On the other hands leaness means to create a value stream to eliminate all types of waste including time and to ensure a level schedule. Naylor et al. (1999) argue that while both lean and agile systems play an important role in supply integration, waste reduction, and lead time compression. An agile system puts more focus on rapid reconfiguration and robustness, whereas a lean system puts more emphasis on leveling the production schedule.
Figur 3.7: Different characteristics of leaness and agility, (Naylor et al., 1999)

3.3 Customer order decoupling point (CODP):
Different scholars have different opinions for CODP definitions. The decoupling point separates the part of the supply chain oriented towards customer orders from that part which is based on forecast planning (Hoekstra & Romme, 1992). The customer order decoupling point (CODP) is a stage in a manufacturing process where a product is being delivered to the customers. For a manufacturing organization view point it is located inside the operations (Olhager, 2010). Naylor et al (1999) wrote that it represents the stock point where the customization of the customer order started. The decoupling point is the point at which real demand penetrates upstream in a supply chain (Christopher, 1998). Decoupling point (DP) is also the point at which strategic stock is held as a buffer between fluctuating customer orders and smooth production output (Sun et al, 2008).

The concept of CODP has been used widely to differentiate value-adding activities in terms of customer demand information, which will further highlight the need for different management approaches. Basically the application of these approaches depends on whether the activities are upstream or downstream of the decoupling point (Mason & Towill, 1999). Furthermore the CODP represents a strategic choice for those organizations which try to create a balance between market requirements and resource capabilities. This idea leads to decide which activities needed to be performed under uncertainty situation, and which activities can be based on certain information concerning actual customer demand (Wikner et al, 2007).

The CODP is an important buffer position in the supply chain, and can be located according to the market-orientation of the company. Normally the market-orientations vary from make to stock, assemble to order, produce to order, to purchase and produce to order. However the positioning of the CODP is also an important issue in supply
chain, as upstream from the decoupling point planning is performed based on forecasts, whereas downstream from the decoupling point, planning is managed by orders. This leads that upstream operations are managed by a master production schedule (MPS), where job shop control and buffer management are used to manage and control downstream activities (Ashayeri, 2005).

A supply chain describes the series of linked activities inside the company as well as outside that contribute to the process of design, manufacture and delivery of products and services (Yusuf et al, 2003). A customer order decoupling point separates decisions related to manufacturing process which are made under confirm situation from those which are decided under uncertainty concerning customer demand (Wikner & Rudberg, 2005). A very similar idea presented that the CODP is normally defined as the point in the flow of goods where forecast-driven production and customer order driven production are separated (Giesberts & van den Tang, 1992); (Wortmann et al, 1997); and (Olhager, 2003); see fig 3.8.

![Diagram](Figure 3.8: Different product delivery strategies relate to different order penetration points, (Olhager 2003))

Sharman (1984) introduced the term CODP in a logistics context. Also according to his point of view, the CODP is a product stage in a manufacturing environment, where the product dimensions are technically frozen. Only after this assembling operation are needed to complete the customized product. One important issue he added that the readjustment in the positioning of the OPP depends on a balance between competitive pressure among organization and product cost and complexity.

Wikner et al (2007) defined the supply chain in terms of lean and agile. Researchers argued that mass customized supply chain can be visualized as a combination of the lean and agile strategies. By incorporating the application of lean and agile in the supply chain, an organization creates the high degree of flexibility and responsiveness in a cost effective manner. The definition of Agile manufacturing as the capability to survive in an environment of continuous and unpredictable change by reacting quickly
and effectively to changing markets, driven by customer-designed products and services (Gunasekaran, 1998).

It is stated that agile manufacturing is suitable for fluctuating demand environment in terms of products variety and volume, where as lean manufacturing is appropriate for a level schedule. More specifically agility is concentrated towards market trends, analysis and based upon this information it leads the organization processes towards the profitable opportunity. On the other hand leaness means create a value stream to eliminate all types of waste including time and to ensure a level schedule. Furthermore these two terminologies focus towards positioning the decoupling point in the supply chain. He defined that apply the lean on those processes which are being upstream from the decoupling point and those which are downstream take as agile (Naylor et al., 1999).

The decoupling point is important for a number of reasons: It separates the order-driven activities from the forecast driven activities such as purchasing, fabrication, assembling etc. This is not only important for the distinction of different types of activities, but also for the related information flows like delivery lead time, customer order management and for capacity planning issues. Furthermore it is the main stock point from which deliveries to customers are made and the amount of stock should be sufficient to satisfy demand in a certain period (van Donk, 2000).

Normally in order to satisfy the customized order, typically organizations make their product design based upon the modularization concept. Consequently this leads to the ATO situation. Sometimes order penetration point is called CODP (Olhager, 2003). A successful modularization of the products may drastically reduce delivery lead times, because some standard components are produced in anticipation of customer orders (Olhager & Östlund, 1990). Furthermore mass customized in manufacturing system can be achieved through ATO by incorporating the concept of postponement of product configuration and the use of a modular product (Hoekstra & Romme, 1992).

The material flow decoupling point can also be used to establish postponement strategy. Postponement basically moves product differentiation close to the end consumer as possible via a strategic stock at the material decoupling point. The supply chain produced a generic product for as long as possible, thereby further smoothing the upstream dynamics via reduced product variety enabling the chain to both respond faster to consumer demand and limit the effect of obsolete stock (Mason & Towill, 1999).

Sun et al (2008) introduced the multiple decoupling point concept to separate the supply network. From upstream multiple DPs supply networks, the nature of the
components are made to stock while the components are made to order from the multiple DPs to the end of the supply network.

There are two different flows across the supply chain i.e. material flow and information flow. The whole supply chain can be treated as a ‘U’ shaped process with customer orders information moving upstream through the supply chain while physical material flowing downstream. Furthermore the material decoupling point act as a buffer between upstream and downstream of the supply chain. see fig 3.9; (Mason & Towill, 1999).

![Figure 3.9: Comparison of Material and Information Decoupling Point Positions within a Supply Chain (Mason & Towill, 1999)](image)

Sometimes resources planning in a manufacturing process depends on the number of potential OPP positions. In a job shop a lot number of resources to be planned at specific time, therefore it might be require the positioning of the OPP more than once in a process. As dedicated line or continuous process can be treated as a single production unit and therefore this requires a limited OPP (Olhager, 2003).

3.3.1 Connection of CODP with supply chain

Several researchers have noted that CODP is related to supply chain. There are a range of structures that describe the characteristics of different supply chains. The majority of models use the customer order decoupling point as a way of distinguishing between different structures (Gosling & Naim, 2009). The appropriate positioning of the decoupling point is an important design issue in the supply chain management (Jeong, 2011).

Based on Hoekstra and Romme (1992), Naylor et al.(1999), Yang and Burns (2003), and Olhager (2003), six different supply chain structures can be observed to describe
the range of possible operations which are: engineer-to-order (ETO), buy-to-order (BTO), make to order (MTO), assemble to order (ATO), make to stock (MTS) and ship to stock (STS). The ETO supply chain is generally regarded as a supply chain where the ‘decoupling point’ is located at the design stage, so each customer order penetrates the design phase of a product.

Hoekstra and Romme (1992) describe much of the conceptual foundation for supply chain structures in their five different logistics structures for the decoupling point (see fig 3.10):

The first supply chain structure, Buy-to-Order, would be appropriate for products which are unique and do not necessarily contain the same raw materials. Also it’s named as engineering to order (ETO). The decoupling point is located at the supplier (see fig 3.10). Usually end user is prepared to accept long lead times and the demand for products is highly variable. Typically the ETO structure involved the designing of a various product, and develops the business processes according to the nature of the markets. A key competitive factor for ETO market is delivery performance. This can be improved by considering the two main factors: reducing the processing lead-time and increasing the reliability of lead-time estimates. Processing Lead-time reduction would be achieved by reducing the make span of individual operations (Hicks et al, 1999). BTO-SC can be defined as “the system that produces goods and services based on individual customer requirements in a timely and cost competitive manner by leveraging global outsourcing, the application of information technology and through
the standardization of components and delayed product differentiation strategies” (Gunasekaran and Ngai, 2005)

In second supply chain structure, Make to Order, the raw material and components are common for most of the products but can be configured into wide variety. Normally decoupling point is located at purchase goods. The lead time will be reduced but the end-users might still have to accept a considerable wait to get the product they desire. The demand for the product can be variable and with a high level of customization both in terms of numbers of different configuration and the amount of the basic product that will need to be customized. This supply chain is only exposed to the risk of holding raw materials and components as stock (Naylor et al, 1999). In MTO strategy, basic design of product is developed prior to the reception of a customer order (Olhager & Östlund 1990). Those organizations which only have a focus at demand driven market follows a make to order (MTO) manufacturing environment. Normally such organization supplies a wide variety of products, and in small quantity ranging from standard products to all orders requiring by a customized product (Hendry & Kingsman, 1989). Furthermore MTO companies must stay in market due to shorter delivery time and reliability in meeting due dates (Easton & Moodie, 1999).

In the third supply chain structure, Assemble to order (ATO) the decoupling point moves to within the manufacturers and assemblers in the supply chain. With this strategy the supply chain will be able to respond to a varied product mix from the available range of products. The lead time will be reduced considerably and will depend upon the final assembly operation. Olhager (2003) created an excellent difference between ATO and MTO strategies. He describes that if customization initiated in a broader way and started from the early production stages, an MTO strategy is appropriate. If customization enters at late stages then ATO would be more suitable. With an Assemble to order supply chain customization is postponed until as late as possible.

The final two supply chains Make and ship to stock (STS) and Make to stock (MTS), both represent cases where a standard product is provided from a defined range. The Make-to-Stock strategy means that the supply chain can cope with demands in varied locations but calls for a steady overall demand of a standard product. The Ship-to-Stock strategy provides a standard product in fixed locations. The members of the supply chain must be able to forecast demand accurately if they adopt these two strategies (Naylor et al, 1999). Furthermore variability in terms of product cannot be delivered to the customer on the basis of the MTS operations (Olhager, 2003).

From the literature review Wikner and Rudberg (2005) reveal that four CODPs are most frequently used in manufacturing supply chain: engineer to order (ETO), make to order (MTO), assemble to order (ATO) and make to stock (MTS). Olhager (2003)
classified the supply chain in make-to-stock, where the decoupling point is positioned at the shipment stage, assemble to order, where the decoupling point is positioned at the final assembly stage, make to order, where the decoupling point is positioned at the fabrication and procurement stage and engineer to order, where the decoupling point is positioned at the design stage.

3.3.2 CODP and material planning

Giesberts & Tang (1992) wrote about the importance of CODP in a production control system. The configuration of production control system is significantly influenced by the extent to which a customer describes the product specification (material, design). Furthermore, this configuration is influenced by the point in the material supply chain where forecast driven production and customer order driven production are separated. With respect to these two characteristics, three different situations (MTS, ATO, ETO) are categorized and each has a different impact on production control system. In MTS situation, end product is manufactured in a standard form and delivered to customer from the stock. The main production control issue in this situation is forecast of end product demand and the preparation of production plan, considering restricted capacity availability (Berry & Hill, 1988).

In ATO situation a wide variety of standard end products exist, producing all end products to stock would result in high stock and poor customer service. Therefore it needs exact matching of end products and components. This issue can be solved by two level master production scheduling technique Berry & Hill (1988). In ETO situation the product is not completely specified by the customer, so a network of aggregate task is prepared based on a rough specification of customer order (Bertrand & Muntslag, 1993).

When some organization positions the CODP in the further downstream of the material flow, then organization must have to perform more value adding activities under uncertainty, and by further positioning of the CODP upstream they perform more activities based upon confirmed information provided by a customer order commitment (Olhager et al, 2001). Olhager & Wikner (2000) categorized the upstream and downstream activities in terms of rate base and time phase planning. Those methods that are based on time-phased demand are applicable downstream the CODP. MRP is the dominating tool towards downstream. Furthermore, methods that require demand to be rate based are suitable upstream of the CODP, as high-volume items can be made to forecast and stocked. In this category, we need the re-order point (ROP) and kanban systems (Olhager et al, 2000). Time phased material planning is based on explosion of requirements, where shop and purchase orders are created for batches of components. Planning is carried out on a level by level basis with respect to the level of bill of materials. Rate based planning includes repetitive manufacturing, assembly lines, just in time and other flow systems. Normally single level planning bill
of material information is used to convert rate based master production schedules into material plans (Vollmann et al., 2005).

A lot of authors neglect the role of a product’s bill of material (BOM) when they position a decoupling point. The BOM plays an important role in performing activities in different departments of a manufacturing company such as production, inventory control, finance, purchasing, engineering and marketing (Erens et al., 1992). The orientations of planning BOM are an art itself, and must be fitted to the planning and control environment (Olhager & Wikner, 2000).

Typically, the demand rate is fairly stable upstream of the CODP and it is better to implement classical inventory management techniques upstream the CODP. Normally in a mass customized manufacturing environment the demand pattern appears dynamically downstream of the CODP therefore traditional tools and techniques are not applicable (Wikner et al., 2007). The normal approach in traditional planning is to plan material requirements and check for capacity at each material planning level. However, with increasing competition, most manufacturing companies need to focus more on capacity, especially if high resource utilization and short lead times are needed simultaneously to compete on price and delivery reliability (Olhager & Wikner, 2000).

MTS and MTO can be differentiated from a materials management perspective, from a strategic perspective and from a production control system perspective (Wikner et al., 2007). Sun et al. (2008) wrote that the basic difference between MTS and MTO systems is based on the trigger point of production activity. A MTO system is based on customer orders, while an MTS system is based on forecasts. Further they explained that trigger information originates from a workstation down-stream in the production line, when a part or product is delivered to customer.

Fluctuation in demand in MTS environment can be controlled through adjustment of the inventory level. But in MTO environments fluctuations in demand are managed by changes in the order backlog, i.e. increasing or decreasing the backlog, which of course affects the delivery lead times and reliability (Olhager et al., 2001).

By fixing the CODP downstream in the value adding material flow, organization can get the productivity (economy of scale) advantage. Therefore, price (cost) is to be set normally as the competitive priority in the process (Hill, 2000); (Olhager et al., 2001). In contrast by locating the CODP upstream in a value adding material flow, organization can get a higher degree of mix flexibility in process and the customer take the advantage of customized products (Wikner & Rudberg, 2005). Slack et al. (2010) defined the mix flexibility as the operation’s ability to produce a wide range or mix of products and services.
3.3.3 CODP and capacity planning:

Capacity Management is defined as “the function of planning, establishing, measuring, monitoring, and adjusting levels of capacity so that sufficient capacity is available to permit execution of the manufacturing schedules” (APICS, 1995). Wikner & Rudberg (2005) wrote that during the order confirmation process with the customers, an organization either considers the material or capacity resources (or both). Material resources are those related to the limited availability of material (raw material, modules, final products, etc.), whereas capacity resources are a result of limited productive capacity. If capacity and materials are not allocated before and after to a resource center then manufacturer will face problem which might be in terms of increased costs of operations to achieve a short delivery time due to, e.g. rush orders from suppliers and use of overtime (Nielsen et al 2010). One important challenge for organization is to be able to give accurate order promises to customer and to delivery dates for the stochastic demand nature of the products (Higgins et al, 1996).

Customer-order-driven production is characterized by matching production and demand quantities as much as possible. In order to realize synchronized production, an organization must ensure that the capacities of the resources are flexible to cope with varying demand in a short period of time with minimal costs. Therefore in a strategic perspective, organization has to make sufficient investments for build up the capacities (Zäpfel, 1998).

One of the major challenges in MTO environment is to reserve the right capacity and the right materials at a specific resource centre (Berry & Hill, 1992). Stevenson et al (2005) wrote that MTO companies cannot accurately forecast demand, order materials and produce in advance or effectively apply batch production methods. In addition, the material and production requirements of a job may be largely different to those of other jobs in the factory, hence a lack of parts commonality and variable job routings add to the difficulties of planning and control.

OPP is also used to distinguish between MTS, ATO and MTO in the master planning level (Berry & Hill, 1992). In the case of Forecast-driven production, a hierarchical planning concept such as the MRP II system is particularly appropriate. But production planning control by a MRP II concept is a complex and difficult method for handling demand uncertainty. The new concepts like Just-in-Time, Kanban, Time-Based Manufacturing, or the more extended concept of Lean Production, which are suitable for customer-order-driven production (Zäpfel, 1998).

Normally in S&OP performs the volume planning, whereas master scheduling plans the product mix. A major feature of the master scheduling process is the available-to-promise (ATP) capability, which also indicate the quantities in the master production
schedule that are not already promised to existing customer orders. The planning object may be end products in MTS environments, modules in ATO, and critical components or raw materials in MTO/ETO environments. This situation leads to minimize the number of items in the master schedule that represent the entire manufacturing system (Olhager & Wikner, 2000).

Soman et al (2004) argued that the importance of the decoupling point cannot be ignored during the production planning, inventory policy and operational decisions. For example in a hybrid MTO–MTS system, the capacity allocation among MTO and MTS products, the determination of the safety stock for MTS products, the order acceptance/rejection decision for MTO products and the scheduling and sequencing of products. MPS is developed somewhat differently depending on the customer order decoupling point that an enterprise chooses (make-to-stock versus make-to-order). For make-to- stock firms, demand forecast and on-hand inventory as well as the desired inventory level of the product groups are essential for determining the MPS. For make-to-order firms, the known customer orders determine the master production schedule, and the material and goods flow of the enterprise can be classified as immediately customer-order-driven (Zäpfel, 1998).

Normally company uses three strategies for production planning such as level, chase, and mix. Level strategy maintains a constant output rate or workforce level over the planning horizon by cumulating anticipation inventory using under time. Furthermore it keeps a stable workforce level or output rate to match the demand for a planning horizon. Chase strategy adjusts output rated or workforce level to match the demand over the planning horizon without considering the anticipation inventory. Mix strategies cover both like level and chase strategy (Olhager et al, 2001); see fig 3.11 According to Johansen & Riis (1995) the purpose of level production is to achieve a uniform and high utilization of production resources, including a minimization of costs related to changes in production rates. Buxey (1990) defines chase strategy is exactly synchronization between the customer demand and supply. According to Pan & Kleiner (1995) the aim is to minimize investment in inventories and/or the order backlog by producing to the actual sales plan or customer orders. Normally in continuous process, level strategy is suitable and a pure chase strategy is applied in Engineering to order processes (Olhager et al, 2001).

According to Safizadeh & Ritzman (1997), when demand uncertainty is low, a MTS business model is recommended. When demand uncertainty is high, an MTO business model is recommended for the supply chain. According to Gupta & Benjaafar (2004) in a MTS business model, production planning initiated based on forecast, and start the production before the order confirmation, maintain a finish goods stock, and shipped
upon receipt of orders. According to Buxey (2003), when using this business model, an inventory-oriented level strategy should be used. In the case of the MTO business model, according to Gupta & Benjaafar (2004), production planning is scheduled on actual orders (rather than on forecast), allowing to eliminate finish goods inventories. When using this business model, a capacity-oriented chase strategy should be used (Buxey, 2003).

There are three different strategies dealing with capacity management: lead, lag or track. Lead means that capacity is added in anticipation of increasing demand. The possible disadvantage to this strategy is that it often results in excess inventory, which is costly and often wasteful. Lag strategy means to adding capacity only after the organization is running at full capacity or beyond due to increase in demand. It decreases the risk of waste, but it may result in the loss of possible customers. Track is a switching strategy, where the differences between capacity and demand levels are kept to a minimum. This is a more moderate strategy as compared to other one (Olhager et al, 2001); see fig 3.11.

<table>
<thead>
<tr>
<th>Process types</th>
<th>Low volume, nonstandard, one of a kind</th>
<th>Low volume, many products</th>
<th>High volume, few major products</th>
<th>High volume, few major products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job shop</td>
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<tr>
<td>Flow shop</td>
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<td>Line</td>
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<td>Continuous process</td>
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<td>Typical order winner</td>
<td>Flexibility</td>
<td></td>
<td>Price</td>
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<td>Typical order penetration point</td>
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<td>Make to order</td>
<td>Assemble to order</td>
<td>Make to stock</td>
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<tr>
<td>Planning strategy</td>
<td>Chase</td>
<td></td>
<td>Level</td>
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</tbody>
</table>

*Figure 3.11: Typical capacity strategies and planning strategies for different product/process environments. (Olhaer, Rudberg, 2001)*
The use of finite scheduling for considering capacity at a detailed planning level is increasing. Finite scheduling clearly establishes a detailed schedule for each job through each work center based on work center capacities and the other scheduled jobs. Furthermore it is a short term capacity planning technique. No more work is assigned to a work centre than a set limit, related to what the work centre can be expected to execute in a given period. Work over and above this capacity is not allocated, and is shifted in the next period. The result is a set of start and finish dates for each operation at each work centre (Vollmann et al, 2005).

Olhager & Wikner (2000) wrote about the complexity of production planning and scheduling, when the CODP and bottleneck are situated at different positions in the supply chain, might be this leads to three-level master scheduling. The use of a multi-level master schedule also leads to an increasing use of planning bills. At the top level, (the capacity for) a product family may be planned.

3.4 Bottleneck management

3.4.1 Bottleneck definition
A bottleneck workstation is defined as the workstation which narrows down flow of production in the production line. It is usually an expensive workstation that has a lower speed throughput than other workstations in the production line. The bottleneck workstation may consist of a single machine or a workstation with multiple identical machines (Duwayri et al, 2006). In “Theory of constraints” (TOC) it is mentioned that each production system has at least one bottleneck resource and this resource determines the throughput of the whole system. The concept of a bottleneck has been generalized into “constraints” which also include market place constraints. Also the identification of constraints is important for an organization in order to achieve the goal (Vollmann et al, 2005). Lawrence and Buss (1991) summarized three mostly used definitions of bottleneck: A bottleneck resource is one for which (1) short-term demand exceeds capacity; (2) WIP inventory is maximum; or (3) production capacity is minimum, relative to demand (i.e., capacity utilization is maximal). The above mentioned definitions are also named as, short-term definition, inventory definition and production definition respectively. The production definition indicates that the bottleneck machine whose capacity utilization is maximal has the most possibility to block other machines or operation. (Lu et al, 2006).

Shifting bottleneck phenomena are might be the result due to the stochasticity such as order's arrival time, machine failure, and probability of operator's mistakes. However Shifting bottlenecks create control problem in the shop floor such as over timing, extra labor. (Lawrence and Buss 1994). Main factors which considered for bottleneck shifting are including product mix, production lot-size and load-balanced level, etc. (Lu et al, 2006). Market demand uncertainty is another factor would causes the
shifting bottleneck, and production managers should improve the scheduling from time to time (Jones & Roberts, 1990). Lu et al, (2006) described the shifting bottleneck as “in production system, if one non bottleneck resource's capacity is less than its load in one period, at the same time, its WIP inventory is more than any other resource’s inventory including the bottleneck resource's inventory, then this resource becomes the new bottleneck or the temporary bottleneck”.

3.4.2 Different approaches to identify the Bottleneck operation

Identifying a bottleneck might be difficult in a complex production process and should be investigated with great care. Normally bottleneck identified by analyzing the operational parameter such as Inspecting queue lengths, machine utilizations or loading levels (Duwayri et al, 2006). One approach to identify the bottleneck machine is to measure the utilization of the machines used in the production system (Law & Kelton, 2000). The machine with the highest utilization is considered to be the bottleneck. However the utilization of different processes might be same, so in that case it’s hard to detect the bottleneck operation. The utilization method is also unable to determine the momentary bottleneck (Roser et al, 2002).

Another frequently used method to evaluate the bottleneck operation is to measure the “queue lengths of the machines” in the production systems. In this method, either the queue length or the waiting time is determined, and the resource with the longest queue length or waiting time is considered to be the bottleneck (Lawrence and Buss 1994). This method has the advantage that a momentary bottleneck can be determined by simply comparing the queue lengths or waiting times. However this method has some sort of shortcomings. For example many production processes have limited queue capacity, so in this scenario queue length cannot be used to detect the bottleneck process. Furthermore, if the batch sizes vary for different machines throughout the production system, the waiting time or queue length may give in some cases incorrect results (Roser et al, 2002). Adams et al, (1988) used mathematical technique such as disjunctive graphs to detect the bottleneck in order to optimize the scheduling in a shifting bottleneck environment.

Roser et al (2002) developed a “bottleneck detection method” used to predict the bottleneck process, applicable both for steady state and non steady state. As an initial step that they sorted all the machines states into two groups such as active state and inactive state. A state is active whenever the machine may cause other machines to wait. Afterward if no machine is found active at one point of time, then there would be no bottleneck and if more than one machines are active, then the one who has the longest time in active state would be considered the bottleneck machine. Moreover the overlap section between the current bottleneck machine and the former bottleneck machine or the latter bottleneck machine is represented as the section of the shifting

### 3.4.3 Methodologies to improve the Bottleneck process

Improvement in bottlenecks in a manufacturing system is a way to increase efficiency (throughput) of the whole system (Ingemansson et al, 2005). Achieving continuous improvement in high-mix, variable-demand manufacturing is not an easy task. But gradual development in manufacturing philosophies that focuses on process mapping tools identifies the ways to improve the potential bottlenecks. Normally such mapping tool yields better results than by simply introducing a new process in the shop floor (Jochen & Lipp 2006). The management of bottlenecks has come under great research in recent years. Most of the researchers solved this problem by incorporating the well known theory of constraints (Goldratt, 1991) and drum buffer rope principle (Umble & Srikanth, 1990).

There are various techniques to improve the production system throughput. One way is to reduce the cycle times of the main bottleneck machine. The other way is to reduce the idle time of the main bottleneck machine by ensuring a consistent supply of parts to the bottleneck machine in order to achieve a maximum utilization (Roser et al, 2002). Goldratt (1984) developed a key capacity management idea in the book “The goal”. He stated that capacity can be effectively managed in an appropriate way after the identification of bottleneck process in a factory. Furthermore an hour of capacity lost in a bottleneck work center is an hour of capacity lost to the entire system OPT theory. Therefore to maximize the output of the manufacturing system, it is necessary that the bottleneck source must be utilized at maximum level (Brown et al, 2006).

For the purpose of capacity planning and management, “Theory of constraints (TOC)” teaches that the capacities of bottleneck work centers need to be planned and managed much more carefully than those of non bottlenecks. This is because the bottleneck work centers limit the overall production output of a plant. Further output beyond the constraint of the bottleneck can be achieved only by improved utilization of the bottleneck facilities, using approaches such as reduced downtime, improved productivity and reduced changeover times. Some researchers address production bottlenecks problem around the bottleneck resource instead of managing directly (Lawrence & Buss, 1995). For example Billington et al. (1986) investigated heuristics for lot sizing in the presence of a bottleneck.

Short term bottleneck can be managed by temporarily increasing the capacity of bottleneck work center. This is accomplished by; working through breaks and lunch periods, and generally perform work more quickly rather than with a normal pace. But this policy has some positive and negative impacts on the production system. For example it decreases the mean job flow time but on the other hand it shifts the
bottleneck to the other work center. Furthermore, his simulation experiment on the long run bottleneck clearly reveals that by adding the capacity of the long run bottleneck comes with shortening the mean job flow time, but the overall shiftiness of the system increased (Lawrence and Buss 1994). Adams et al. (1988) developed a shifting bottleneck algorithm which schedule the job shop in order to minimize makes span.

3.5 Relationship between bottleneck and CODP

The position of the bottleneck of the production process relative to the OPP is important in a manufacturing system. With respect to resource optimization point of view, it is better to have the bottleneck upstream the OPP, so the bottleneck does not have to deal with fluctuating demand and a variety of different products. With respect to the just-in-time process of elimination of waste, it would be best to have the bottleneck downstream the OPP so that the bottleneck only needs to work on products for which the firm has customer orders (Olhager, 2003).

A bottleneck or constraining resource limits the output of the whole manufacturing system, and must therefore be monitored closely with respect to both capacity and material. Downstream activities are typically critical with respect to timing of orders, whereas the focus for upstream activities is to provide the bottleneck with material. Thus, the CODP and the bottleneck are key issues for the design of planning and measuring points (Olhager & Wikner, 2000).

In TOC the shifting bottleneck is described as in production system, if one non-bottleneck resource's capacity is less than its load in one period, at the same time, its WIP inventory is more than any other resources inventory including the bottleneck resource's inventory, then this resource becomes the new bottleneck or the temporary bottleneck” (Lu et al, 2006).

Moreover, the production system may change over time or due to random events, and subsequently the bottleneck may shift from one machine to another machine. The change in bottleneck shift might be due to the sequence of random events or due to a gradual change in the manufacturing system technology. A non bottleneck machine may become a bottleneck, for example due to a machine failure, and similarly a bottleneck machine may become a non-bottleneck machine (Roser et al., 2002).

Continuous improvement is an integral part of the TOC philosophy. However this theory suggested that continuous improvement is always initiated from the “constraints”. For scheduling the activities at operational level TOC incorporated the Drum buffer rope. The basic idea behind this principle is that pull all the material from non drum to drum resource. The objective of the scheduling is to maximize throughput. But increasing utilization of non bottleneck will result in higher inventories and increase confusion in the production system (Vollmann et al, 2005).
Olhager and Östlund (1990), stated that the manufacturing continuum can be categorized as make-to-stock (MTS), Assemble-to-Stock (ATS), MTO, and Engineer-to-Order (ETO). They show that the bottleneck in the production system is the important decision point at which the production system is chosen due to the tight integration of customer supplier connection along the value chain. Conceptually it is important to take both the CODP and bottlenecks into accounts when designing the supply chain operations.
4 Analysis

All the information in this chapter has been provided to find the solution of research question by incorporating the relevant theories and methods. In order to handle the complex situation of problem, author divided it in three categories and corresponding to each category, capacity and material planning related issues are analyzed. Section 4.1 contains the general description about the research model and the importance of information flow. Issues about safety stock and available to promise are discussed in 4.2 and 4.3 respectively. Section 4.4 outlines the characteristics of individual part of supply chain and relevant capacity planning method. Also the issues about forward and backward scheduling are highlighted. A variety of planning techniques are discussed to get control over the material flow in section 4.5. In further section a couple of factors are identified to achieve the lean, hybrid and agility in a particular part of supply chain.

4.1 Partitioning the supply chain

It is observed that the location of decoupling point varies between product groups and within the product family. The elements of the supply chain network are ETO, MTO, ATO and MTS. Starting with the most upstream location of a decoupling point an engineer to order (with no make to stock at all), followed by manufacture to order of product, then assemble-to-order and make to stock. Suppliers & customers are also the part of integrated supply chain. The attribute major constraints give an impression what the main bottlenecks of the entire supply chain are. These may be included, limited production capabilities of some member(s) or the limited availability of some critical materials, the limited capacity of the flow lines and the multiple use of tooling & fixturing etc. Moreover some of them are shift frequently (depending on mix of demand, process flexibility) and some are stable along the whole supply chain. For detail see; (Roser et al, 2002).

In order to achieve the control over resources along with coordination in terms of material and capacity throughout the supply chain, it is better to separate constraints into three main parts. The first one is supply constraint which comprises of limited supply of critical raw materials and components. Second one is operational constraints which mainly occurs due to mix of product, multiple use of tooling and fixturing and routing of the product in shop floor. The last one is market constraint based on demand exceeds than supply etc. Mainly these three constraints are located at upstream, between the decoupling point and at downstream of the supply chain respectively; see fig 4.1. The performance of the supply chain is limited by these constraints. In general, the nature of upstream constraints are stable due to stable demand while downstream they are frequently shifting and are unknown due to stochastic behavior of customer in terms of product demand, mix and volume.
The main emphasis in the research is to consider these constraints specifically between the CODP and the extreme ends of supply chain. Primarily author analyzed existing capacity and material planning techniques by considering the constraints and identified the positive and negative aspect of each supply chain area. The supply chain can be divided into three parts:

1: Upstream both CODP and bottleneck

2: Between the CODP and bottleneck

3: Downstream both.

Normally information flows go upstream, consisting of customer orders, sales forecasts, internal orders for warehouse inventory replenishment and purchasing orders to the suppliers. This way, the whole supply chain is driven by the customers. Material flows go downstream, coordinate subordinate plans by means of master planning and forecast planning result. Typical information is in aggregate quantities, allocated to production sites, or processes.

Upstream flows provide more detailed data on the performance of the supply chain, e.g. actual manufacturing costs, production rates, utilization of the equipment, products lead times etc. In particular demand information is passed from finished goods stages through the chain to raw material, where as cost and lead time data is passed in the opposite direction. This information can be used in the master level planning for anticipating the consequences for the more detailed processes on the downstream level. However, the exchange of additional information in both directions and between neighbored element, can improve the visibility of supply chain significantly.

4.2 Material coordination along the supply chain

4.2.1 Safety stock and safety lead time

Soman et al (2004) describe the importance of the decoupling point that it cannot be ignored during the production planning, inventory policy and other operational decisions. There are uncertainties on both the inbound (machine breakdowns) and the outbound (unknown customer demand, unreliable suppliers) in the manufacturing
supply chain. The key sources of uncertainty in this area are the variability in supply timing, quantity and the variability in terms of demand timing and quantity. The supply timing variability is due to the unreliable suppliers lead time and shop floor processing time. The variability in supply quantity arises when there is shortage of material in shop floor due to scrap losses. Demand timing uncertainty occurs due to frequent variation in customer demand and the forecasting errors.

There are two practical means of dealing with variability in supply or demand: carrying safety inventory or maintaining safety capacity. Although generally one should consider trade-off between carrying safety inventory and safety capacity. Safety stock has to protect against uncertainty which may arise from internal operations like production lead time, unknown customer demand and unreliable supplier lead times. This implies that the main drivers for the safety stock level are production and supplier disruptions, forecasting errors, and lead time variations. A higher supply or demand uncertainty results in higher inventory and excess capacity cost.

Safety capacity is built up in order to add sufficient value added operations in peak load situations. Due to the interdependencies in a production system, a resource can start a production operation only if all preceding operations have been completed. Moreover load variability of a resource increases with the number of preceding operations. Thus, load variability is higher in midstream resource and because of that excess capacity is often built up in the midstream supply chain (see in fig 4.2).

Normally lean operations tend to avoid carrying safety inventory. It would be only true in that case when the demand forecast error is zero and the supply lead time is less than customer lead time. Another factor which emphasis to maintain the safety capacity is the frequency of equipment breakdown. Safety capacity may be kept in the form of available extra machines, workers or overtime.

Typically in supply chain, a safety stock is held at the decoupling point. SS is allocated in the form of subassemblies and components in the midstream, and raw material or common component at the upstream. Since downstream supply chain is driven by confirmed customer order, so there is no need to allocate safety stock at downstream. Moreover, by keeping the safety stock for critical raw materials at the upstream supply chain, enables continuous flow of goods among the supply chain element. In this way the organization gets the advantage of achieving the desired service level and reduce the cost of emergency shipment and avoid from the customer lost sale. It is more appropriate to keep safety capacity in the midstream to fulfill the unique customer need up to certain extent (see fig 4.2).
Generally organization should think about inventory capital when allocating safety stock placement among all elements. Indeed an optimum tradeoff must be required between customer service level and safety inventory cost at each element. Safety inventory level might be influenced by the replenishment lead time and the number of stock points in the supply chain. Thus, not only the determination of the total amount of safety stock, but also the allocation of safety lead time within the manufacturing system is an important planning task.

By definition customer service is realized only by the availability of safety stock and safety capacity at CODP. The service level to the customer is defined as the order lead time and the ability of the supply chain to offer a good promise for customer orders. For a MTS, the service level can be increased by allocating the suitable safety stock at shipping stage and to provide a better material coordination at the bottleneck source.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Upstream</th>
<th>Midstream</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety stock(SS)</td>
<td>Safety stock should be placed in form of raw materials.</td>
<td>SS can be placed in form of subassemblies and options.</td>
<td>As downstream is driven by customer order, so there is no need to allocate the safety stock.</td>
</tr>
<tr>
<td></td>
<td>It Protects from unreliable supplier and longer lead time.</td>
<td>It couples supply chain during machine down time.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Support order winner by reducing material cost through bulk purchasing.</td>
<td>Increase production run lengths reduce setup cost and increase capacity utilization</td>
<td></td>
</tr>
<tr>
<td>Safety capacity</td>
<td>Keep safety capacity to manage supplier lead time variability</td>
<td>Keep safety capacity for value adding activities during peak load</td>
<td>Keep safety capacity to manage demand timing variability.</td>
</tr>
</tbody>
</table>

Figure 4.2: Advantage of Safety stock in the supply chain

4.3 Available to promise (A TP)
(Higgins et al, 1996) describe about importance of order promise in case of stochastic demand. Order promise is defined as the current and future availability of supply and capacity that can be used to accept new customer orders. In addition to on time delivery the delivery performance plays an important role in demand fulfilment of customer. Delivery performance in contrast to on time delivery depends mainly on the forecast accuracy of the demand planning and the ability of the supply chain to satisfy the demand signal of the demand plan. Likewise the on time delivery, the actual order promising is an important aspect of the customer service level.
Traditionally promising of order is carried out against existing inventory and supply lead-time often will result in order promises that are not feasible. ATP can be expressed on any stage of the supply chain e.g; downstream, midstream and upstream. The decision where to express ATP would be connected to the location of the decoupling point in that particular supply chain area. As the decoupling point separates the forecast-driven parts of a supply chain from the order-driven parts. Therefore the decision on which level ATP is being expressed i.e. where the decoupling point is defined also influenced by the forecast accuracy that can be achieved on that level of the supply chain. The forecast accuracy at the decoupling point must have a enough quality to purchase, produce and distribute products based on this forecast. The more the decoupling point is shifted to the left (upstream), the easier it is to forecast the demand on that level. Normally forecast accuracy on raw material level is higher than on finished goods level in the supply chain.

4.3.1 Allocation of ATP in the downstream supply chain
In downstream part of supply chain, the ATP is express based on material and capacity availability. The complete production process in a make-to-stock business is forecast-driven; (see fig 3.8). Further, parts of the delivery processes can be forecast driven (for example if products are transported to regional distribution center). The ATP would be provided under consideration of availability of finish goods stock and delivery times; see fig 4.3. Examples for make to stock industries are consumer packaged goods, food and beverages, and other retail items.

4.3.2 Allocation of ATP in midstream supply chain
In midstream supply chain (ATO), all components produced and purchased are driven by the forecast. Only final assembly and delivery are based on order driven; for detail see fig 3.8. In ATO environment ATP is measured on component level based in the master plan. Thus, ATP in assemble-to-order environment is represented by considering both the availability of raw material (sub assemblies, finish module) and the availability of existing capacity of the processes; see fig 4.3.

In ATO the forecast is created on finished products or product group level; the forecast is then translated by master planning into a supply plan on component level. Based on customer order information, the BOM of all relevant components is exploded and availability is checked from the information system. The latest availability of all components and final assembly lead time added with delivery time provides the ATP for the requested customer order.

4.3.3 Allocation of ATP in upstream supply chain
In upstream (MTO) the ATP is represented in a similar way as in case of midstream supply chain, but decoupling point is located more upstream. In a make-to-order environment, procurement is driven by forecast. Production, final assembly and
distribution are driven by customer orders; for detail see fig 3.8). Finish products and components are either customer specific or there are so many different variants that their demand cannot be forecasted with a great accuracy. Besides material availability, the required capacity is also an important constraint for the fulfillment of customer orders. For this purpose ATP is represented based on purchasing lead time combination with manufacturing and delivery lead time. By estimating the availability of both materials and resources capacities, returned the customer promised date.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Upstream</th>
<th>Midstream</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available to promise (ATP)</td>
<td>Represented based on purchasing, operation and distribution lead time.</td>
<td>Represented based on sub component stock and assembly lead time and delivery lead time.</td>
<td>Represented based on material &amp; capacity availability and delivery lead time.</td>
</tr>
</tbody>
</table>

Figure 4.3: Allocation of available to promise in the supply chain

4.4 Capacity planning

According to APICS (1995), Capacity Management is “the function of planning, establishing, measuring, monitoring, and adjusting levels of capacity so that sufficient capacity is available to permit execution of the manufacturing schedules”. Modern supply chain is very complex and in a supply chain, hundreds and thousands of individual tasks have to be committed and integrated every moment. They comprise the rather simple question like “Which job has to be scheduled next on a respective machine and how much resources are required to complete a specific operations?” Capacity planning provides the rough cut estimate of the necessary completion time for finished product. One issue here is to balance the available capacity with the plans, either by providing the enough capacity to execute plans or adjust plans to match capacity constraints.

Generally at shop floor level each job is assigned to a work center or a couple of various other machines. No planning difficulty to be faced, when a manufacturing operation takes place on a single machine, or only one job is to be planned in a sequence of machines. However, if a job can be loaded on multiple work centers, and there are multiple jobs to process, the planning process becomes more complicated. Even it becomes more challenging in case of frequently shifting bottleneck in manufacturing system. However one must need some techniques to assign jobs at shop floor in such a way that waiting time and number of setups are minimized along with idle time of critical work center. According to Stadtler, & Kilger (2005) supply chain is working more profitable if it is “operated on the edge”. It means that capability of a
supply chain to produce more or less than demand is an indicator of inefficiencies in
the supply chain. The profitability in supply chain can be achieved by eliminating the
inefficiencies in the form of excess capacity, extra stock (raw material, WIP, Finished
goods) and unnecessary waiting time.

Mainly material type of constraints is dominant upstream, the operational constraints
are in midstream and capacity constraints are dominant in downstream of the supply
chain (see fig 4.1). Traditionally in downstream operations, organizations allocate the
capacity based on the confirmed orders but this is not true in case of supply
constraints. The interesting fact is that if CODP moves towards the supply constraints
then organizations allocate the capacity of downstream processes with respect to
availability of material. Otherwise there might be a danger to lose the reliability of
customer order. Typically in this case downstream processes face the problem of less
(slack) supplies than customer order. The issue of coordinating the availability of
finished product parts (component, subassemblies) is especially important when
specific parts going into assembling process. The waiting time for all required
components is likely to increase if there is insufficient inventory at the upstream
locations. However orders that do not have all of the necessary resources, tooling,
material, and capacity, should not be released because they only cause excess work-in-
process inventory and may interrupt other shop floor orders that might be finished
within the available time span.

According to TOC concept, planning in supply chain must be done around the
constraint. So in upstream execute the planning process around the supply constraints.
Normally upstream supply chain is engaged by material planning techniques and
downstream the focus is on capacity utilization of resources in a manufacturing
system. Midstream supply chain rely on both capacity and material planning
simultaneously. Moreover in upstream environment optimal investment in stock is an
essential factor while in downstream the investment in building the capacity is
necessary factor.

The main content of waste (unnecessary stock & waiting time) in supply chain
(upstream) can be optimized by focusing on both CODP and supply constraints.
Moreover by doing so, rest of the supply chain behaves as a level production. On the
other hand if CODP moves towards market constraints, then the upstream supply chain
behaves as (material) pull. A similar idea is highlighted in the research of Olhager &
Östlund 1990. Particularly in this situation, organization sets the clear criteria for the
value added operations among the supply chain processes.

In another situation when CODP and bottleneck switch frequently over a time horizon,
company needs to adjust both their product configuration and manufacturing process
flexibility. This is the most complex situation and normally this situation exists in
midstream supply chain. There are couple of factors considered to be switching phenomena such as complex BOM, multiple products are produced in a limited resources (limited capacity), most of operations (load) are being covered by a single resource, etc.

Downstream supply chain can be characterized with low volume, low standardization and highly customized production involved. Products are very complex (large designing operations per order) with deep and wide bills of material. The important characteristic related to planning is that the products are more or less designed and engineered to customer order, i.e. it is an engineer-to-order type of operation. Manufacturing batch sizes are typically small and in many cases it is equivalent to the order quantity. The production throughput times and the delivery lead-times can potentially be long. The production process is designed for individual product, and a functional layout is often utilized to manufacture a product. In considering the appropriate level of vertical integration with suppliers a number of factors to be considered. These may include: customer delivery times with available capacity; reducing costs; the availability of capital for investment in equipment; internal and external capabilities and flexibility.

In midstream supply chain the production process can be characterized as an assemble- or make-to-order type of operation. Variety of products can be configured by combining standardized and stocked components and semi finished items. The number of customer orders is rather large and the delivery lead-times much less than from the downstream supply chain. The frequency of customer orders is high but each corresponding to a small volume. Throughput times for finishing operations and final assembly are short. Line and cellular layouts are more common than functional layouts. Advance manufacturing technologies, high employment skills and training is usually involved to satisfy the customers. Market driven strategy is utilized to compete with competitors. Normally Constraints management, APS, JIT and OPT are preferred techniques to control the operational and tactical level issue.

Upstream supply chain can be characterized by repetitive mass production. Products are made in large volumes with repetitive and more or less continuous process. Usually products are characterized by having flat and simple bills of materials and order winner is delivery speed and price. Typical throughput times are very short, often smaller than delivery lead time and batch sizes are bigger than that of customer order.

Concerning the position and management of the CODP in supply chain, the following can be written in section three: The upstream operations from the CODP are based on forecasts information, and are controlled by a MPS. Downstream from the CODP, the planning is managed by orders and controlled by job-shop-control or buffer-
management. Capacity allocation to the downstream of the CODP is completely based on confirmed orders, whereas upstream it is based on forecasted demand. The uncertainty involved in planning and capacity allocation is the highest for a downstream supply chain, and is almost negligible in upstream supply chain.

Based on capacity planning and control techniques proposed by Vollmann et al., (2005), Capacity planning, using overall factors (CPOF), represents the simplest method of capacity planning. Of the four capacity planning methods described, it requires the less detailed information and calculations are straightforward. This approach cannot work properly in case of changes that occur either in product volume or in the BOM structure. Consequently, a prerequisite for its successful implication is that the products have a homogeneous BOM from a manufacturing point of view. Also there is another assumption that the load from manufacturing a product is in the same planning period as the delivery date. This means that the method should only be used in environments with a flat bill of material and short lead-times, compared to the length of the planning period. This environment is most appropriate in particular upstream supply chain (see fig 4.4). The characteristics, complex products and typically long lead-times make this method inappropriate in downstream supply chain.

Capacity bills (also known as capacity bill of resources approach) required detailed data on the time standards for each product. This method also provides direct connection between individual end products and the capacity required for individual work centers. Therefore, poor time standards can become obstacles when using this method. The capacity bills method also assumes that the load from manufacturing a product is in the same planning period as the delivery date and, like overall factors. Due to this reason it is not feasible to use in downstream. Also this planning technique does not take stock-on-hand for components into account. The match between capacity bills and mid and upstream is therefore considered poor.

Neither the CPOF nor the capacity bill procedure considers the specific timing of the workloads at individual work centers. Resource profiles consider the production lead-time data to provide the time phased of the capacity requirements for individual production facilities. Resource profiles allow the lead-time off-setting of a load relative delivery date. This capacity planning method has benefits compared to the previously mentioned methods for planning environments with considering the specific timing of work load at each resource. This means that relative to capacity bill planning, the resources planning has a good match with midstream supply chain. In common with capacity bills, resource profiles depend on time standards and do not consider the previous stock of components used in the products.

In capacity requirement planning (CRP), the amount of labor and machining resources needed to complete the required production are considered in detail. Planned orders
from the MRP and open shop orders (scheduled receipts) are taken into account for each work center in each time period. This process takes into consideration the lead times for operations and offsets the load in case of over capacitated resource. The inputs needed for a CRP are open shop orders, planned order releases, routings, time standards, lead times, and work center capacities contained in the computer files. A routing file must consist of every component manufactured and contains the operations (work) to be performed, the sequence of operations, the work centers to be used, the possible alternate work centers, the tooling needed at each operation, and standard times (setup and run times) per piece. Capacity requirements planning (CRP) can be utilized successfully in all the environments in supply chain but it seems more favourable in environments with complex BOM products or complex products that are assembled from standardized components. These characteristics can typically be found in planning downstream supply chain (see fig 4.4). This method also considers previous component stock. It means that it has major advantages in environments where components are manufactured in batches to stock.

In midstream supply chain the decoupling point exists in the manufacturing process. Typically in this environment, components and subassemblies are produced according to a forecast, while finished products are assembled only after customer’s orders entry. In other words, components and subassemblies are replaced in a make-to-stock (MTS) fashion, but finished products are assembled in a make-to-order (MTO) manner.

Since midstream supply chain characterized by high demand of product mix, low volume and flexible manufacturing technology. So this environment demanded that planning made around the manufacturing resources and the material level simultaneously. This might lead to incorporate the finite loading for assigning the job in a planning period. So in this way organization gets the advantage of delivery speed and price both (order winner). Particularly in case of capacity constrained environment the vertical loading seems more effective. The basic principle of this technique works around the capacity utilization of individual work centers rather than to complete all orders within due dates. However this technique has some drawbacks. For example a work center is occupied with existing work order. Meanwhile in the same time a high priority order enters in job shop and required to be complete In that work center which is already loaded with the existing order. So two options are considered, first option is to complete the existing order and then load the highest priority order. In second option terminate the existing work order and produce the highest priority order, which of course is not beneficial for the work center capacity utilization due to extra set up. In this case WIP inventory piles up and cause blockage in manufacturing system due to limited capability of WIP storage.
More over the horizontal loading is better due to lower work in process inventory and will also complete whole jobs faster than vertical loading. The basic idea behind this method is schedule those jobs first which have highest priority at all work centers. Then the job with the next highest priority is loaded on all required work centers, and so on. A drawback of this method is that jobs may be kept waiting at a work center, even though the work center is idle. This happens when a higher priority job is expected to arrive within a short period (Vollmann et al 2005).

Normally organization increases the batch size quantity in case of market constraint situation to overcome the capacity problem. Such a particular way might be better for high volume and low product mix. But using this technique in case of low volume and high product mix does not give the better result. Because this situation not only increases

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<th>Upstream</th>
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<tr>
<td>Capacity planning by using over all factor (CPOF)</td>
<td>Appropriate for Standard BOM product, Constant &amp; determinant product mix. More or less suitable for “A” shapes of product profile. Planned the demand perfectly for those products which have a shorter lead time as compared to the length of planning period.</td>
<td>Unable to manage load offsetting in case of extra demand. Not appropriate due to lack of adjustment in multiple level of BOM.</td>
<td>Unable to manage the capacity for a variety of product structure. Unavailability of historical data.</td>
</tr>
<tr>
<td>Capacity Bills</td>
<td>Provide better result if product routing data available.</td>
<td>Suitable due to plan a capacity for a limited variety of product configuration. But it cannot work perfectly in terms of lot sizing.</td>
<td>Unable to manage backlogged buffer (capacity, demand). Not suitable due to longer production lead time than planning period time.</td>
</tr>
<tr>
<td>Resource profiles</td>
<td>It is also valid here. Work better when product mix varies and routing data is available. It work more effective when the operation and set up time are available</td>
<td>Suitable due to consideration of production lead time, capacities for individual work centre. Better connection between end item and sub components. Suitable for “X” product profile.</td>
<td>Unable to allocate capacity among different product families &amp; in different planning periods.</td>
</tr>
<tr>
<td>Capacity requirement planning (CRP)</td>
<td></td>
<td></td>
<td>Generally applicable throughout the supply chain but work perfectly in downstream. It is suitable due to adjustment in load off setting. Consider the lead time both for open and shop floor order. Consider the on hand material and capacity. Also plan the load for service parts</td>
</tr>
</tbody>
</table>

Figure 4.4: Capacity planning in the supply chain
the delivery lead time of the existing order but also creates the long queue of other shop floor orders (due to shifting bottleneck phenomena). The best criterion is to optimize the available capacity in this situation, to increase the set up frequencies upto certain extent while putting more emphasis on reducing the set up times. However one must need to make adjustment between the tradeoff in buffer inventory (WIP) and the lead time. Moreover set up time reduction is most effective when a large portion of available capacity is dedicated to setup operations.

4.5 Material planning

To manage and produce the finished products in a specific time period is not an easy task. It takes into account the number of components to be assembled (quantities), at which level and particularly when they are needed (timing). Producing the parts/component before the time they are needed might lose some aspects which are necessary for a customer. On the other hand producing these components afterwards the customer order, take larger manufacturing lead time. However this type of production process is more effective when there is a certainty in the change of customer product design. Complex product structure and multiple level of BOM lead two level of production system which are component manufacturing and final assembly of the manufactured components.

Material requirement planning (MRP) plays a vital role in material planning & control. It converts the overall plans into time phase production for each product/sub assemblies and gives information for developing the capacity plans. The aim of the MRP is to keep lowest possible inventory level by releasing the orders to the production and suppliers only if there is a need for it. In addition to that different types of inventories (finished goods, components, raw materials) the system also plans purchasing (for raw materials and finished components), production activities and delivery activities. Using information about inventory level, production lead time, order receipts etc. It generates planned order quantities and the time of planned order released for different models in order to satisfy the final customer.

In advance material planning best efforts are realized to identify the constraints in earlier stages. Alternate options are evaluated which of course reduce cost and improve the profit margin in manufacturing supply chain. Material requirements planning is, however, most effective in complex standardized products or product options, long manufacturing lead-times and items with time variations and uneven demand.

In time phase planning the production process is designed based on batch manufacturing and materials are also purchase in batches. Usually this type of planning need lot of information which include demand from MPS stated in BOM terminology ,on hand inventory, open job shop orders to determine the net
requirements, production lead time and safety stock for delivery promising. Time
phase planning is more suitable for low volume per order and for a highly mix of
products. Usually this is suitable downstream the CODP. Normally MRP, lot for lot
are more appropriate to manage the material planning issues. see fig 4.5.

Normally in upstream supply chain, standard bill of material and a customized bill of
material used in midstream. While unique bill of material is created in downstream
supply chain for individual customer needs. The depth in BOM’s structure increases
the complexity in material planning. Those product structures which have a single
level of BOM’s are easy to manage with respect to those which have indented BOM’s.
Indented BOM’s represents the list of component from the end item all the way down
to the raw materials. It also shows the component structure level by level. To manage
the complexity in assemble to order system, the BOM’s are designed based on
manufacturing or customer perspective. However the commonality factor increases
downwards level and options/multiple configurations are increases upward of BOM’s
structure. Moreover each new option in assemble to order system increase the
difficulty in final assembly scheduling.

Variety of lot sizing policies such as economic order quantity (EOQ), Production
order quantity model (POQ), lot for lot (LFL) and part product balancing (PPB) exist
to control and manage the material flow in manufacturing system. Most of them are
useful in time phase rather than rate base planning. A number of factors to be
considered when these are incorporated in MRP. These are; volume and frequency of
customer order, stability in customer demand, dependent and independent demand,
ordering lead time, inventory policies of organization, material holding cost,
processing setup cost and expected time between the order. An optimal lot quantity
depends upon the product structure (level in BOM’s), value adding cost, purchased
ordering cost and lead time etc.

The focus in EOQ model is the balance between inventory holding costs against the
fixed ordering costs. Two major problems associated with EOQ are that it assumes that
the demand requirements are constant period to period and replenishment time is
almost zero. The POQ lot-sizing policy overcomes this issue by determining the
replenishment period needed to cover the demand .In POQ policy number of periods
calculated between orders by using the EOQ formula divided by average demand and
then rounds the result to the nearest integer. LFL generates planned order quantities
equal to the net requirements in each period. Moreover it does not support extra on
hand inventory cost.

Lot sizing policy used for end product in an MRP system has a direct impact on the
net requirement of its connecting components. One might use different lot sizing
policies at different level of BOM structure. Since the commonality factor increases by
moving downward and customization/modularization increases upward along the BOM’s structure in ATO supply chain. So it’s a wiser decision to apply FOQ at bottom level to purchase the raw materials and standard components. As value addition cost increases in top level, so it’s better to use LFL. Most of factors support that FOQ is better to utilize upstream the CODP and LFL in downstream to manage the material planning. However this will increase the holding cost in upstream and number of setup in downstream. Typically LFL does not support in capacity constrained production system. But it will achieve by thoroughly reducing the set up time for each work center.

Rate base planning can be characterized by high rates of material flow, negligible work in process inventory level, short manufacturing lead time and relatively small variety of final products. Of course due to these parameters the size of manufacturing data bases are comparatively small and the number of material planning personnel are less than time phase planning. In rate base planning the primary focus is to establish rates of production for each part in factory. This type of planning is suitable for standard and high volume products. Typically single level planning bill of material information is used to convert rate based master production schedules into material plans. Rate base planning covers the repetitive manufacturing, assembly lines, just in time of flow system. Normally less detailed Capacity Requirements Planning is required to produce the customer order. Rough cut capacity planning is used to monitor impact of mix and volume on repetitive manufacturing system.

As in section 3.3.1, that ROP and kanban are suitable techniques for material planning to the upstream supply chain. Re-order point (ROP) describes as the stock level at which an order be placed to replenish the inventory. The level of ROP reflects the amount of inventory which triggers the order placement activity. The ROP has a direct impact on product availability and service level. The key factors; demand rate, replenishment lead time and the safety stock are necessary to determine the ROP. The basic formula used to calculate the level of ROP is;

\[ ROP = (Expected \ demand \ rate) \times (Lead \ time) + \ safety \ stock \] (Adopted from vollmann et al, 2005).

However this formula does not take into account the stochastic in demand, defective parts provided by suppliers, process uncertainties etc. Re-order point system is basically used for component and independent demand items. It cannot work perfectly for dependent items demand. Re-order point systems can use reasonably standard product components with longer life cycles and the more stable demand.

Toyota’s Taichi Ohno implemented kanban as a production tool in Just In Time manufacturing. It is a scheduling system that pulls production based on actual demand.
It streamlines the exact timing and quantity of the item to be produced. This process works well in a manufacturing environment and final assembling also. As customer orders replenishment process decreases the level of finished items. And this will trigger the production order and purchased orders sent to the external supplier. Production order specifies the type and quantity of the product which the preceding process must produce. Depending on the complexity of the manufacturing operation, there may be many locations for kanban cards. A complex assembly’s process might generate production kanban cards to several departments in the factory.

In a single card kanban system, components are produced and transferred according to a daily schedule, and deliveries to the consumers are controlled with the use of withdrawal kanban. This system is suitable for a environment with a relatively small range of end products and in a stable demand levels. The general formula for calculating the number of kanban is;

Number of kanban= expected demand during lead time+ safety stock/size of container (vollmann et al, 2005).

A kanban system requires a fairly level and regular demand, as well as careful analysis of the capabilities of the manufacturing process. It is also suitable for those products which have a simple and flat bill of material and short lead-times. It is a simple technique not involving computers so its cost is low. A well-implemented kanban system is capable of delivering cost savings by reducing inventory, warehousing and manufacturing expenses. In order to achieve the benefits of kanban in manufacturing system, these practices might be implemented. Never forward the nonconforming item towards downstream work center. Each process only generates a kanban signal when it receives confirm customer order. Maintain the smooth flow of production in the manufacturing system. Only produce those quantity which ordered by the downstream processes.

Kanban system does not work perfectly in downstream supply chain. Because this system has no capability to control the variability in terms of volume and mix. But it is less suitable for limited mix and volume fluctuation. Moreover this system itself has no capacity to control the variability. For this reason it is not be suitable in unpredictable processes which results nonconforming products. An independent organization cannot rely on this system because break down in this system may result the shutting down of the entire assembly process. It is not suitable in those processes which are used to produce multiple products. In this way each product needs separate signaling card which creates the difficulty to manage the work in process inventory.

In the midstream supply chain (ATO) both standard and customized components exist. Upstream of this supply chain is forecast driven and downstream is driven based on
customer orders. After confirmation of customer order, production department set the right mix and quantity of products to be produced. Mix production system may make it more difficult to balance work load and identify restriction in midstream supply chain. A mixed production effective when the majority of items are in repeated orders, but many infrequent items are also needed for final assembly. The primary function for this environment is to minimize the sum of inventory holding cost and delivery lead time.

In this environment, raw material can be transformed into common semi finished products. In order to respond quickly, limited stock of standard component is necessary while subassemblies and final assembly are configured based on customer orders. Basically inventory of material at decoupling gives cost and increase the overall throughput time. Since upstream no customized items or component to be stocked but the stock held at upstream contains large contents of standard parts. And these part used by a group of finished products in downstream. This stock will reduce the risk of stock out cost in case of unexpected customer demand shift.

Variety of techniques can be incorporated to control the material planning issue in midstream. These are MRP/kanban, combination of rate/ time phase planning, postponement, advance planning & scheduling (APS) and final assembly scheduling (FAS). (see fig 4.5). The material planning in the earlier upstream of ATO is controlled by rate base planning, while the later downstream of ATO is controlled by time phase planning. In rate base planning, production is initiated in anticipation of expected future demand. In this system organization bears high inventory holding cost but gets the advantage of overall low delivery lead time. In time phase planning, production and distribution are triggered by customer order. In this system organization get the benefits of low inventory cost but compromise in the lead time.

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<th>Midstream</th>
<th>Downstream</th>
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<tbody>
<tr>
<td>Material</td>
<td>Rate base planning is perfectly suitable to control the material flow.</td>
<td>Mix of rate base and time phase planning.</td>
<td>Time phase planning is applicable to control the material flows.</td>
</tr>
<tr>
<td>planning</td>
<td>Material can be controlled limited (most of the case in single level) level bill of materials.</td>
<td>Both timing and quantity can be controlled through multiple level of bill of material.</td>
<td>Material must be managed through many level of bill of materials.</td>
</tr>
<tr>
<td></td>
<td>The main objective is to reduce the purchasing lead time &amp; achieve the benefits of economy of scale.</td>
<td>The primary objective is to minimize the sum of inventory holding cost and lead time.</td>
<td>The main focus is on achieving the delivery reliability.</td>
</tr>
<tr>
<td></td>
<td>Frequently material planning techniques are Kanban, ROP, FOQ model etc.</td>
<td>Final assembly schedule (FAS), MRP/Kanban, and postponement techniques are used to manage material.</td>
<td>MRP, lot for lot is more appropriate to manage the material planning.</td>
</tr>
</tbody>
</table>

Figure 4.5: Material planning in supply chain
4.6 Key factor to achieve lean and agility in supply chain

Naylor et al. (1999) describe that apply the lean on those processes which are being upstream from the decoupling point and those which are downstream take as agile. The terminology “lean” means a series of activities to eliminate waste, remove non value added (NVA) operations, and improve the value added (VA) operations. Lean thinking supports those operations which create the value for customer perspective. Value added operations involve the processing of raw materials or semi finished products through the use of manufacturing process. This would involve activities such as: purchasing of raw material, casting of component, machining of casting products and the assembling of finished parts, etc. Non value added activities involve unnecessary actions which must be eliminated completely. Examples would include unnecessary waiting time, stock of intermediate products and unnecessary material handling, defects and unused employee creativity, overproduction, over processing etc.

By eliminating non value operations, organization increases the manufacturing efficiency and reduces the cost. In addition to this lean process provide the flow of products without waste. A couple of tools to be used to identify the waste but value stream mapping (VSM) is mostly used in manufacturing system. The VSM links all operations from raw material to final customer smoothly. It provides a complete material and information flow to support the decision making. It highlights and identifies the wastes clearly. It develops a plan to eliminate waste and continuous improvement.

Normally standardization in supply chain process can be achieved at three stages: design, process and at the skill level. At design stage standardization is achieved by designing the component which can be shared across the different models, building new model variation on common platform, use of modularization concept and reduce the product complexity. In integration to this the design for lean manufacturing that creates robust reusable design configuration is also an important factor for standardization. In the second stage standardization includes the detailed work instruction for product manufacturing, sequence of operations during the process development. In the third stage standardization can be achieved by standard skill and capabilities across engineering and technical teams. This type of standardization is based on the deep commitment to people development and growth through the level competencies (Morgan & Liker 2006).

However in case of increasing the standardization at design level (commonality factor), then the company might lose the aspect of customization in different models. On the other perspective that organization increases the customization factor, there is a factor to new investment during the new product and process development. In
upstream supply chain the flexible capacity might be generated by utilizing the
standardization and modularization methods.

Lean philosophy works well with the repetitive of nature of sales order. Key factors to
achieve the lean in upstream are; reducing the demand forecast error by selecting the
suitable statistical tool, synchronization of the production flow against customer
demand, focusing on elimination of all type of wastes etc. Forecasting errors directly
affects to material level stock. Frequent adjustment in demand forecasts can lead to
sudden changes in plans and nervousness in production system. So highly emphasis
has to be done during the selection of forecasting models. Normally the tools that
applied are JIT, total quality management (TQM), total productive maintenance
(TPM), kanban system etc, (see fig 4.6)

Lean techniques allow the organizations to design value streams supporting high
throughput that can produce mass products or services for customer. Lean
manufacturing reduces the manufacturing lead time and improve the productivity
significantly. However this also leads to lower the operational cost which are in the
form of energy consumption, unnecessary tooling used for non value added operations
etc. Thus lean manufacturing helps organization to maintain and significantly increase
their profit margin. Effective lean strategies at shop floor level improve the work flow
and reduce the physical floor space. Elimination of wastes and disturbing activities in
the work place will physically help worker to their task with much smoother way.

Downstream operations of supply chain are driven by customer with more product
research and short development time. The focus is on quickly satisfying the customer
orders. Customer express their requirements in terms of shape, colour and volume etc.
Each customer has their individual configuration in terms of design and volume of
product. Over the time period product configuration are varied to facilitate the
customer need. Fundamentally markets are dynamic due to increasing customer
choices and facilities are quite stable. In such situation it seems hard to manage the
capacities of processes and stock of products. It means that the production process
must be designed to respond quickly against the change in information from the
market.

Agile strategy focus on inducing velocity and flexibility in the manufacturing supply
chain. Agility in downstream supply chain can be increased by reducing the demand
forecast errors, effective customer order management and information sharing. The
information sharing is streamlined and connected through electronically at every
decision point, so that information flow is direct and without delays. By speeding up
the information, parts, and decision flow across the supply chain will result the quicker
respond to customer needs. Of course this will increase the profitability and
responsiveness in supply chain (see fig 4.6).
Agile methods allow organizations to design value streams supporting sustainable throughput that can produce customized products for innovative markets. The focus of the value stream includes the complete value adding process from the processing of raw material until the consumer’s receipt of product. As a result, organizations are able to develop value streams that fulfill individual customer order need, and work better in new markets. Moreover agile approach supports the high levels of integration between processes within the firm and between the firms.

Leagile is the mixture of both lean & agile strategies. Leagile is inclined towards sustaining the flow for mixed-model production. Its intent is to achieve the efficiencies in mass production, while producing a medium variety of products. Leagile focus on the shop floor, including machinery and material handling systems. A supply chain can be considered leagile when it has two parts, one part of the chain is agile and the other is lean.

The concept of a leagile in supply chain is very common for highly responsive market. This concept would allow a firm to achieve maximum benefit from the supply chain. The leagility can be implemented in mid stream supply chain through the combination of agile and lean techniques. It can be achieved through the smoothness and realizing the customer demand in advance by eliminating the ambiguity in customer order. Effective information sharing among product design, process integration & market sensitivity are also important factor for leagility. In addition to this leagility achieve the suitable level of standardization and customization.(see fig 4.6)

The continuous improvement allows the organizations to increase their productivity at a shop floor level and align their decision at strategic level. Continuous process improvement focuses on the manufacturing performance which tends to sub-optimize the process and market related factors. Those organizations that fail to implement the agile, lean & leagile approaches in the supply chain will likely see their productivity remain unchanged or might be decreased.
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<tr>
<td><strong>Lean</strong></td>
<td>Utilizing the concept of standardization &amp; commonality. By synchronization the product flow and level scheduling against customer demand. Reducing the demand forecast errors by selecting the suitable statistical tools. Implement the continuous improvement (Kaizen) and uninterrupted flow strategy. Focus on eliminating the waste, this will increase productivity and manufacturing efficiency. Frequently tools that can be used in upstream are, just in time (JIT), Total quality management (TQM), Total productive maintenance (TPM), single minute exchange die (SMED), Kanban, Process mapping etc.</td>
<td>Create the smoothness and realizing the customer demand in advance by eliminating the customer ambiguity. Effective information sharing among product design, process integration &amp; market sensitivity. To achieve the optimum level of standardization and customization. By adopting the flexible manufacturing technology and multiple worker skilled. Through the utilization of postponement &amp; modularization</td>
<td><strong>Inducing the flexibility and velocity in supply chain process. Effective information sharing at each decision point. Advance manufacturing technology and rapid use of automation. Rapid configuration and capability of customized product design. Effective customer order management. Knowledgeable, skilled and multifunctional employees. Sustain alliance with partners and suppliers. Focusing on organizational structure and information system.</strong></td>
</tr>
<tr>
<td><strong>Leagile</strong></td>
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<td><strong>Agility</strong></td>
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*Figure 4.6: Key factors to achieve lean, leagile & agility in up, mid & down stream supply chain*
5 Discussion

Taking into consideration all previously mentioned knowledge, I had to make what the best decision regarding of the selection and development of model in a particular supply chain environment. Different factors have to be considered, the most important ones are discussed below. The summary of the analysis part is presented in fig 5.1.

From the analysis part it is observed that the quality of model’s result depends largely on several actors. These include constraints, customers, suppliers and different supply chain environment. As upstream the CODP, supply constraints are allocated and consequently different strategies are discussed as well. No doubt that the inefficiency in material supply limits the output of supply chain. The primary cause of supply shortage is the implicit uncertainty associated with procurement quantity and suppliers’ manufacturing lead times. This situation might arise due to a variety of reasons ranging from unexpected delays in shipping, transportation, and receiving times etc. Frequently used solutions are; multiple sourcing for unreliable suppliers, optimum stock for critical component etc. However these situations have a direct influence by the customer demand pattern and organization policies. It seems beneficial that the stock of component is better in case of limited capacity and high inventory turnover. While stock of raw materials seems better when the purchasing lead time and ordering cost are high.

In the midstream, operational constraints switch around the decoupling point. It is fact that bottlenecks for one product type are not the same for other products in the same manufacturing line. As mentioned earlier this variation is due to process time for the different products in different machines, improper use of mix flexibility. Usually operational constraints comprise of limited availability of process capacity, dynamic situation in BOM, complicated product routing, multiple use of tooling in different products etc. Sometimes these arise due to the combined effect of upstream and downstream constraints. One way to overcome this issue is to classify the constraints as primary and secondary. Limited process capability might fall into primary class while routing and tooling are considered in secondary class. Traditionally new process capacities are added in order to reduce the impact of limited capacities. However this will require new investment. If there is consistent increase in customer demand then the new investment in generating capacities is not a bad decision. While in case of fluctuating demand, this will increase overhead cost sometimes during low demand periods, decrease overhead cost in peak demand periods. Consequently this will affect the marginal profits.

Since midstream supply chain can deal with high product mix demand and flexible manufacturing technology. It is observed during the study that several types of finishing operations are performed simultaneously to achieve a desired production
rate. For example cellular & group technology, automated assembly lines and general purpose equipment. One can use suitable processes to overcome the restrictions related to product routing and tooling. Particularly a group technology is suitable for those components which are common among different families. In this way organization gets the benefits of material handling, material flow and reduction in WIP. Also one can easily control over bottlenecks (tools, jigs & fixtures). For customized component cellular manufacturing is appropriate. In such particular situation routing and sequencing restriction can be managed in a better way. In addition to this reduction in set up times and moves time, improves the material flow.

The product complexity has significant impact on supply chain efficiency. Complex products with many incoming parts are more difficult to manage. Therefore these products can be planned in a different way than standard products. It is sometimes difficult to get a smooth and efficient final assembly flow, when dealing with complex products containing many incoming parts.

The product structure is normally shown in BOM, which describes the connections of assemblies and their components. Specifically the number of levels in BOM, determines the sequence of steps in which a product is assembled from raw material to end item. Majority of product structure in midstream supply chain have several numbers of levels in their BOM structure and most of them are frequently replaced by other new component. A number of factors are to be considered to simplifying the planning issue at design and manufacturing level.

One proposal is to analyze the design of the product at engineering level. May be some of product attributes can be redesigned/adjusted to the connected (coupling) component. I believe that fewer components in the product lead to a simpler product structure and less levels, which leads to easier production planning in supply chain.

Another opinion is to find out the critical path along the product structure. After the identification of critical path, a necessary action can be taken to reduce the effect of bottlenecks. For example in some cases it is possible to purchase or outsource the production of some item and thus gain the advantage of shorter lead-time. In some cases a sub suppliers may be better suited to produce the item, and can therefore give better delivery.

Downstream of the CODP, demand constraints are dominant. It is fact that to cope with a constantly fluctuating market, the production line must be able to respond to schedule changes. In reality, however the information system and production constraints make change difficult. Frequent market diversification causes heavy investment in stocks. I emphasize that smoothness in customer demand planning can be achieved by reducing the forecast errors in each product model with the help of
proper utilization of statistics techniques. Generally Quantitative forecasting models are suitable for standard components/sub assemblies and final assemblies are triggered based on the confirm orders.

ATP is an important concept in supply chain, implying to promise an order based upon available quantity and capacity. In practice, ATP means to create a production schedule in real time operations by considering both the operation capacity and material inventory constraints in the supply chain. For ATP in cases of Make to Stock (MTS), organization needs to allocate the inventory for an order and calculate the delivery lead time. In case of make to order, organization needs to calculate the production lead time based on a schedule within the range of usable parts, materials and resources, and determine ATP. It is observed that if the availability of raw materials and components are properly made sure, then the chances that the final assembly of products is also reliable.

Globally working organizations face difficulties to satisfy their customers with traditional techniques. These organizations face problem including delay in delivery, non conformance in products, lower profit margin etc. When such kind of problems appear frequently, then the chances to improvement in operations become vital. Since a couple of continuous improvement methods are discussed for a particular business processes. I believe that it is a crucial to establish an ideal system that fully manages the future challenges concerning to product, process and customers. Even it becomes more necessary in case of changing market requirements. Among other factors, effective knowledge sharing and coordination in supply chain system is an important factor to achieve agility. It is quite effective if the knowledge being shared through the product development phase to sales of product. In addition to this the use of computerized information systems with suitable protection may provide the safeguard against sensitive information. I emphasis that shared understanding in marketing and manufacturing operations would lead to effective customer management.

Another factor which seems significant for agility is the use of advance technology and rapid configuration in customization process. Neither the advance technology guides to achieve efficient design process but also lead to sufficient improvement in final assembly line. The application of advance technology in product designing process would stream line the customer needs effectively. And of course a happy customer will determine the ultimate success in designing process.

Achieving full volume production with high quality products in a minimal time is vital for rapid configuration. However this requires a detailed integration between design and manufacturing processes. This will involve forward feed of design information to rapidly configure new manufacturing processes. Through the study analysis it is concluded that to induce the responsiveness in supply chain, a proper use of
knowledge sharing with customer and manufacturing process has an extreme importance.

One of the key factors for the success of a lean system is the management of the product flow. If the product flow is poorly managed, products may have long manufacturing lead time and material may spend a large amount of time in queues as work in process inventory. But if the flow of material through manufacturing process is properly leveled with material moving smoothly and continuous from one process to the next. It would guide to attain short manufacturing lead time and short waiting. Thus lean management seems to be a powerful tool for managing inventory turnover. Companies that implement lean practices in manufacturing processes have considerable better inventory turnover for each type of inventory.
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<td>Capacity planning by using over all factor can be appropriate for standard BOM product, Constant &amp; determinant product mix. More or less suitable for “A” shapes of product profile. It planned the demand perfectly for those products which have a shorter lead time as compared to the length of planning period. However this technique has no flexibility to manage load offsetting in case of extra demand.</td>
<td>Resource profiles is suitable in midstream due to taking account of production lead time and capacities for individual work centre. It works perfectly for “X” product profile and has a capability to manage the products routing effectively. It also coordinates the capacity planning through multiple level of bill of material.</td>
<td>Capacity requirement planning has the best match with downstream supply chain. It effectively adjusts the level of capacity for low standardization and high customization process. It effectively monitors the capacity plan for deep and wider bill of materials. This technique has the capability to optimize the load offsetting and product routing. Capacity planning can be organized by considering the production lead time, on hand material and availability of capacity both for open and shop floor order.</td>
</tr>
<tr>
<td>Material planning</td>
<td>Rate base planning is perfectly suitable to control the material flow. Material can be controlled limited (most of the case in single level) level bill of materials. The main objective is to reduce the purchasing lead time &amp; achieve the benefits of economy of scale. Frequently used material planning technique are Kanban, ROP and FOQ model.</td>
<td>Mix of rate base and time phase planning. Both timing and quantity can be controlled through multiple level of bill of material. The primary objective is to minimize the sum of inventory holding cost and lead time. Final assembly schedule (FAS), MRP/Kanban and postponement techniques are used to manage material.</td>
<td>Time phase planning is applicable to control the material flows. Material must be managed through many level of bill of materials. The main focus is on achieving the delivery reliability. MRP and lot for lot is more appropriate to manage the material planning.</td>
</tr>
<tr>
<td>Available to promise</td>
<td>Represented based on purchasing, operation and distribution lead time.</td>
<td>Represented based on sub component stock and assembly lead time and delivery lead time.</td>
<td>Represented based on material &amp; capacity availability and delivery lead time.</td>
</tr>
<tr>
<td>Safety stock</td>
<td>Safety stock should be placed in form of raw materials. It protects from unreliable supplier and longer lead time. Support order winner by reducing material cost through bulk purchasing.</td>
<td>SS can be placed in form of subassemblies and options. It couples supply chain during machine down time.</td>
<td>As downstream is driven by customer order, so there is no need to allocate the safety stock.</td>
</tr>
<tr>
<td>Safety capacity</td>
<td>Keep safety capacity to manage supplier lead time variability</td>
<td>Keep safety capacity for value adding activities during peak load</td>
<td>Keep safety capacity to manage demand timing variability.</td>
</tr>
<tr>
<td>Lean</td>
<td>Lean</td>
<td>Leagile</td>
<td>Agility</td>
</tr>
</tbody>
</table>

Figur 5.1: Summary of analysis
6 Conclusion

In the thesis study, an attempt has been made to (i) Study the scope of the customer order decoupling point in supply chain management. (ii) Develop a conceptual model for illustrating the various concepts related to combination of constraints and customer order decoupling point.

This model deals with capacity and material planning issues in upstream, midstream and downstream part of the supply chain while considering the bottleneck position. (iii) Present a framework for the implementation of capacity and material planning. The issues of lean, leagile and agility have been discussed from different perspectives, but the main focus has been on the key parameters concerning the implementation in manufacturing supply chain.

It is concluded that effective management of all constraints would lead an organization to achieve the competitiveness related to reduce the delivery lead time and sustain the continuous flow in manufacturing supply chain.
7 References


Available at: http://www.assemblymag.com/Articles/Cover_Story. [accessed 15th October].


