Supply Chain Optimization through Value Stream Mapping & Linear Programming

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Abstract - Supply Chain Management (SCM) includes the movement and storage of raw materials, work-in-process inventory, and finished goods from point of origin to point of consumption. This paper is based on the improvement of delivery efficiency at the customer end of the product named 'CP32A' Rock drill which comes under the pneumatic section of 'ATLAS COPCO'. We started with 'ABC' analysis of its 74 raw material components & identified 4 critical components with highest lead times, viz. cylinder, piston, riffle bar and front head. Wer then mapped the entire Value Stream, identifying value added and non-value added activities, in the entire supply chain of CP32A. In the process, we focused on process time & batch size, at each juncture of material and information flow, from customer order confirmation to customer order delivery. We identified the prime focus of improvement in 'Production Planing & Control' department of Atlas Copco, Nasik in India, since the ordering pattern was significantly inconsistent with all the raw material components. As an solution, we optimized the monthly assembly plan, through linear programming and transportation simplex, thereby, synchronizing procurement, manufacturing, assembly and delivery aspects of CP32A. We solved our formulation, aimed at finding an optimum assembly schedule with minimum lead time given the present capacity & demand constraints, using 'GENERAL ALGEBRIAC MODELING SYSTEM' (GAMS). We also validated our solution by formulating the same model in MS Excel & obtaining the same solution.

Keywords —Value Stream Mapping, Optimization, GAMS, Supply Chain, Manufacturing Schedule, ABC analysis.

I. INTRODUCTION

In an era of technology eruptions and proliferations of its applications in business, business competition has become intensive even in matured industries. Breakthroughs are becoming possible through process innovation, new offerings and achieving cost advantage with increased offering of responsiveness to customers. In this paper, we have discussed the application of value stream mapping and linear programming for enabling supply chain efficiencies in a vertically integrated supply network.

A. Supply chain management

Supply chain management in simple terms can be defined as the study of various activities that are performed in house of a firm well out of the firm right from the order taken by the company and delivery of it all the process that are carried out in between this period comes under supply chain which includes various parameter like manufacturing operations raw material purchase soft machining and various others activities that are being performed are all studied and analyzed in supply chain. In other words it integrates all the activities in to a process.

B. ABC Analysis

It is basically a process or an analysis which gives the idea of that product which gives us the maximum outcome in terms of revenue analysis is carried out using three categories named 'ABC' in which the product 'A' is the one which yields us the maximum profit round about 60 % of the total income from the overall profit coming out from the products being manufactured also their demands are also high then the rest of the two categories of products and they are few in numbers of the total products being manufactured in a firm. Whereas 'B' type product are the marginally less profit gainers products also their demand is also slightly on the lower side their profit is about 30% of the total income. In simple words they are the products which are neither huge profit or lose gainers they balance themselves in terms of their manufacturing and sales. Last category that is the 'C' type products are the ones that have the least importance

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also the annual consumption is also not so significant then the rest of the two and also their profit is about 10 % of the total income but they contribute about half of the total products being manufactured. So as an manager of the production department on need to nullify or lessen the impact of 'C' category products and enhance the contribution of 'A' and 'B' products as much as possible and gain more and more profit through it for which 'ABC' analysis plays a critical part.

C. Value stream mapping

Value stream mapping is a lean-management method for analyzing the current state and designing a future state for the series of events that take a product or service from its beginning through to the customer. The procedure of VSM is pretty straightforward. It starts with identifying the target product family or service, creating a flow, defining the problem, setting the goals and objectives, and selecting the mapping team. Next, one must draw, while on the shop floor, a current state value stream map, which shows the current steps, delays, and information flows required to deliver the target product or service. This may be a production flow (raw materials to consumer) or a design flow (concept to launch). There are standard symbols for representing supply chain entities.

One of the things that differentiate a VSM from most other mapping tools is the inclusion of the information flows into the map. We need to include how the customer orders the product, ordering frequency and method, and how we translate that back to our supplier. We also include how we then communicate requirements to our processes to ensure that we produce what the customer wants.

D. Optimization

Optimization is the process of finding the greatest or least value of a function for some constraint, which must be true regardless of the solution. In other words, optimization finds the most suitable value for a function within a given domain. In a way it is the minimization of waste. Optimization can be implied to single or multi-purpose systems. Very often optimization can shed new light in design when considering the coupling of multiple systems. The purpose of optimization is to achieve the "best" solution for a product having a particular constraint. These include maximizing factors such as productivity, strength, reliability, longevity, efficiency, and utilization.

II. OBJECTIVES

The prime objective of this research is to increase 'Delivery Efficiency' of CP 32A at ATLAS COPCO LTD, Nasik, MH, India. Delivery efficiency is broadly used KPI measurement in SCM to measure the fulfillment of the customers demand to the wish date. In today's fast-paced world, the delivery efficiency is important area to concentrate for industries. The increased demand for instant and accurate delivery status and customer information is driving a dire need to ensure shipment integrity in the post and parcel supply chain. Delayed or undeliverable shipments are not accepted by shippers and receivers, making customer service one of the most important factors in delivery operations. This directly links with customer satisfaction; with customers already compensating to rising costs of shipping, they will have less tolerance for errors, and with consumer and brand loyalty decreasing in order to find the lowest overall price, unhappy customers will quickly move their business elsewhere.

III. METHODOLOGY

The project is based on the premise that supply chain can be improved based on effective scheduling in Production Planning & Control department, when laying out future plan of sourcing, manufacturing, assembly & delivery. After identifying project focus in the form of CP32A's delivery, its critical raw material components shall be identified through ABS analysis on sourcing lead time of each component. This will help in narrowing the further investigation in the form of a VSM. The entire value chain of the CP32A product shall be mapped, recording value-added, non value-added times at each step in the chain, with respective batch sizes. The data required includes, but not limited to, past forecast, historical sales, assembly plans in-house, current schedules of sourcing & delivery, cycle times of each operation with batch sizes, product drawing depicting assembly sequence, etc. The expected outcome shall be the total value & non-value added times & locations of different wastes, in the form of inventory, waiting, storage, over processing, etc. After identifying the largest benefactor contributing towards non-value addition time, root cause shall be identified & subsequent solution shall be proposed used suitable tool from operations research. The solution shall be in the form of a mathematical model, after identifying all the constraints & assuming suitable data wherever required. The model shall be solved by simplex algorithm in GAMS & shall be further validated in MS Excel.

Tools and resources:
SAP, GAMS, ABC Analysis, Linear Programming, MS Excel, MS Work, MS PowerPoint, Gantt Chart, MS Visio, MS Project, etc.

IV. PROCESS FLOW DATA

A. General flow diagram

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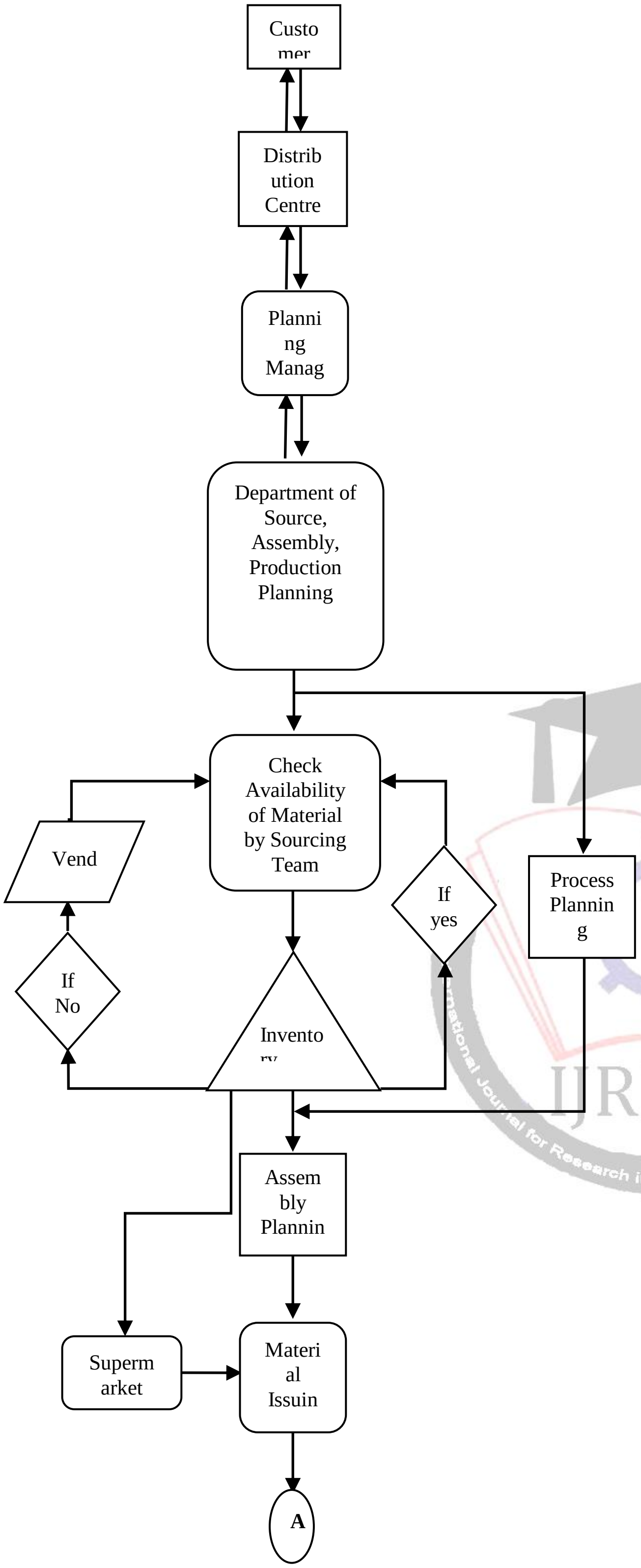

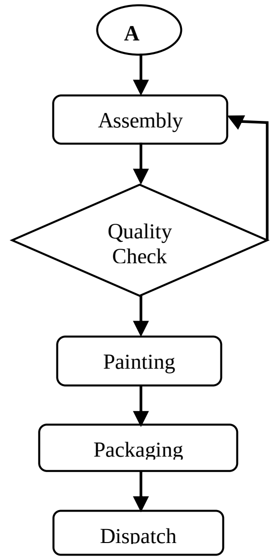

Figure 1: The general Flow Chart of Rock Drill CP32-A

Rock Drill Cp 32-A is one of the product of Atlas Copco India Ltd., Nashik. In supply chain study we obtain the data and process flow chart of CP 32-A. which is presented as below.

The general flow chart which is followed by Atlas Copco India Ltd., Nashik, is as follows: -

- Customer: - The Person, Industry, Contractors who purchase the product from Distribution Centre.
- Distribution Centre: - Its Factory outlet of Atlas Copco India Ltd. Nashik. To provide world class services to customers. Customer gives requirement to distribution center accordingly it provides services. Basically Atlas Copco has 3 distribution centers: -
  1. LOCAL (India)
  2. Power Tool Design (PTD, Europe)
  3. North America Service Centre (NSC, USA)
- Planning Department: - Department who plan and control production in Atlas Copco. According customers' orders and forecast planning they have to manage Production rate and Delivery Time. Before taking order, planning department have to take current inventory status and components for machining. If they have sufficient inventory to fulfil order. Once Atlas Copco has order in hands they have to inform sourcing, production planning team and go for combine solution.
- Sourcing Department: - Another department of Atlas Copco to procure parts and vendor management. This department has to search customer according the needs and provide adequate supply of raw material.
- Production Department: - This department is for production planning accordingly with planning department and assembled the components according design schedule.
- Inventory: - Storage department of Atlas Copco manage finished components required for assembly.

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- Vendors: - These are the suppliers of finished (Machined) components for assembly.
- Process Planning: - For convenient assembly the assembly steps are design by industry.
- Assembly planning: - After getting order from customers the process for assembly accordingly. For eg. Sequencing.
- Supermarket: - Atlas Copco has contracted inventory management system. They established the two bin KANBAN system for inventory management. Also for issuing parts for assembly they have system like supermarket.
- Assembly: - Atlas Copco CTD division has adopted lean manufacturing. The product Rock Drill CP 32-A is assemble on three assembly station it include three sub assembly also.
- Quality Check: - It has two stages of checking first is inspection and after that testing. Once product is assembled it has to pass the quality check. Inspection is done on assembly line by visually and simple measuring devices. After that individual component has to pass through the vibration testing which is conducted in isolated testing rooms.
- Painting: - Atlas Copco has implement FIFO (First In First Out) lean system in painting. Usually the batch of fix lot size has taken for painting accordingly. It has no of stations in painting like cleaning, base coat, baking, final coating, air blowers.
- Packaging: - Once Rock Drill is painted its ready to packing. It's normally packed in box. After packaging it is ready to dispatch.
- Dispatch: - It means product is send to logistic department.

B. Critical production processes:

Atlas Copco has assembling Rock Drills. Machining processes are to be done from vendors. They are only assembling the parts. Atlas Copco does not machinery component internally only if any small rework is there they done as it own. As we conclude from ABC Analysis the 4 major components taking highest lead time to manufactured, after result we traced all manufacturing phases of that four critical component an also the assembly of product as shown below.

Machining at vendors end: -

- Forging: First operation on front head is forging. Forging is process of obtaining required shape work piece from raw material for further machining.
- Soft Machining: Second operation is soft machining which includes milling, drilling etc. As milling and drilling this are material removing processes.
- C, H, T (Carburizing, Heating and Toughing): Material properties are disturbed due to machining. Internal stresses are generating in structure, which causes the failure also material has property of ductility which causes the wear of material. To avoid that wear failure and under stress failure some heat treatment has to be done. This is the third operation done on components.
- Grinding: It is material removing process but it removes very small amount of material usually in microns. After heat treatment material has some burr and outer dimensions are expands due to heating. To obtain exact dimension grinding is done.

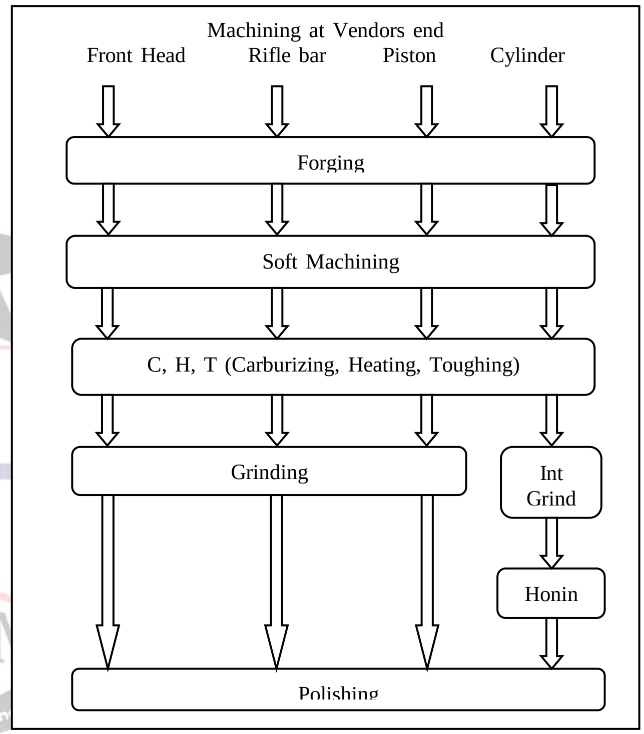

Figure 2: Machining at Vendors End

- Honing: It is also material removing process. But it has good accuracy than grinding due to this it's done on cylinder to obtain prefect surface finish.
- Polishing: After grinding and honing material surface is not so finish to obtain glass finished polishing is to be. The process for polishing surface buffing method is used.

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C. Assembly Operations in Atlas Copco

- Atlas Copco has implementing lean assembly line to optimize non-productive or non-value added time.
- Lean assembly means maximum production with minimum waste of time and money.
- Atlas Copco doesn't machining any component which required for assembly. They were only assembled the component.
- Assembly of rock drill CP 32-A is done in four stages. As explain further:

1. Front head assembly: This is first sub assembly of product CP 32-A. Front head assembly also carry sub assembly like sleeve, retainer, chuck, chuck rotation nut etc.
2. Cylinder assembly: Second assembly of product done after assembly. This also carries no of sub assembly like piston, rifle bar, rife bar nut, case valve etc.
3. Back head assembly: Back head is cover assembled at last in assembly. It contain sub-assemblies like bracket handle, valve throttle, swivel air inlet, tube air etc.
4. Final assembly: final assembly is nothing but a combination of a front head, cylinder and back head these three assembly join together to form final assembly with help of two through bolt.

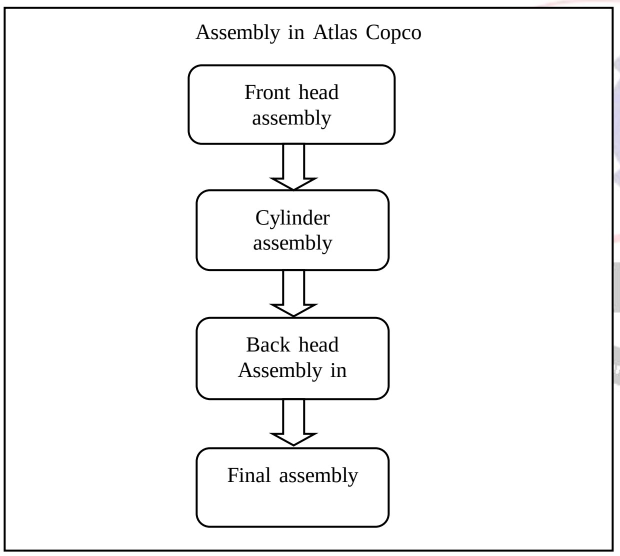

Figure 3: Assembly stages in Atlas Copco

D. Products Ordering Process Flow

Atlas Copco has directly link through the distribution centers. Customers are directly contact with distribution centers and after that it comes to Atlas Copco. Let see in details

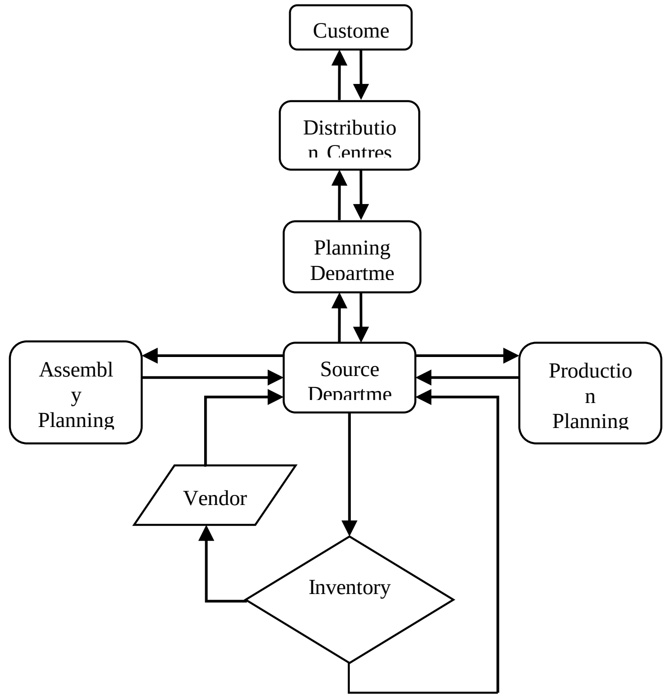

Figure 4: Product order process flow chart

- From flow chart we can see that customer gives order to distribution centres. Atlas Copco has three distribution centres all over the world. Names of distribution centre's are:
    1. LOCAL (INDIA)
    2. PTD (Power Tool Distribution)
    3. NSC (North America Service Centre).
- Distribution centres are directly contacting with planning department to place order. Planning, sourcing, assembly, production department informing that where to be difficult to complete the order.
- Procurement or sourcing team check the availability of inventory stock is sufficient to deliver the order. If there is no sufficient parts to complete the assembly they place the orders to vendors and inform to planning team accordingly when to be the parts are going to available for assembly.
- After calculating all these factors the customers tack time is to be decided and accordingly inform to distribution center.

E. Finished Products Delivery:

Atlas Copco India has three distribution centers over worldwide. Mainly logistic department use water transport for export. For urgent deliveries air transport is use and local transport is by road.

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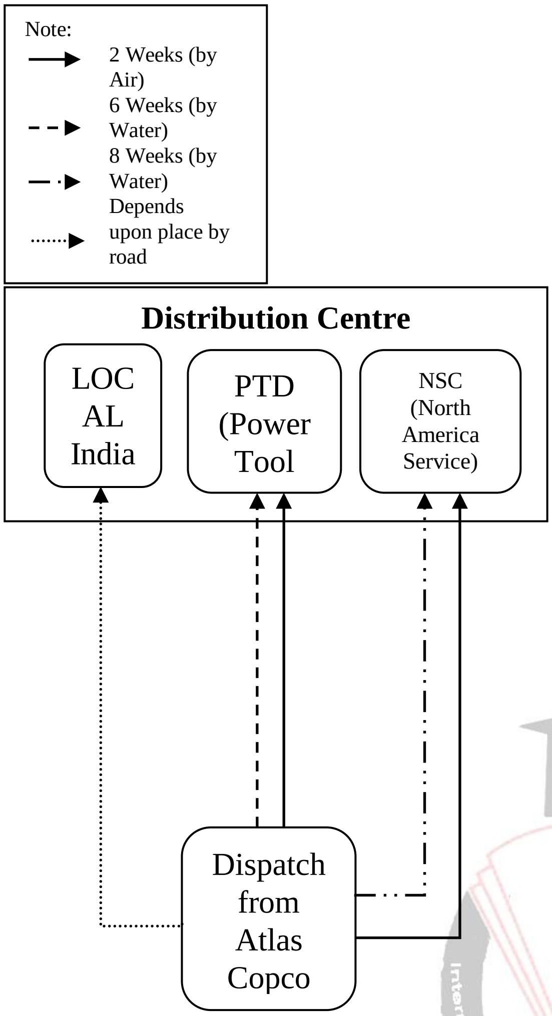

Figure 5: Delivery Flow Chart

- As from flow chart we have seen that customer order places from various distribution centres. Accordingly Atlas Copco is providing services to the destination.
- Atlas Copco using BPCS (Business Planning and Control System) & SAP to control over flow of components.
- For delivery in Europe by using water takes 6 weeks and by air takes 2 weeks.
- In USA takes 8 weeks and 2 weeks for delivery.

V. QUANTITATIVE DATA

A. Product description - CP32A

The Chicago Pneumatics Rock Drill model 32A as shown in figure 6, is used in General Construction, Utility Work, and Plant Maintenance. It serves the purpose for drilling through Granite, Hard Face rock, Quarry Drilling and Drilling Secondary holes for Blasting. It is also used in Wet Drilling application by attractive Valve, Wet tube and Swivel assembly.

Figure 6: CP 32A Rock drill-1

The CP 32A (fig. 6) represents the name which is "Chicago Pneumatics Rock Drill Model32 Air, and T022117 gives the part number for placing an order.

B. Ordering cost interpretation in SAP screen shot.

The ordering cost as shown in figure. 7 indicate the value in Euros. (Value 11.3 Euros). It is calculated as,

Ordering cost = Labor cost/ hour * Number of hours needed by worker for an order.

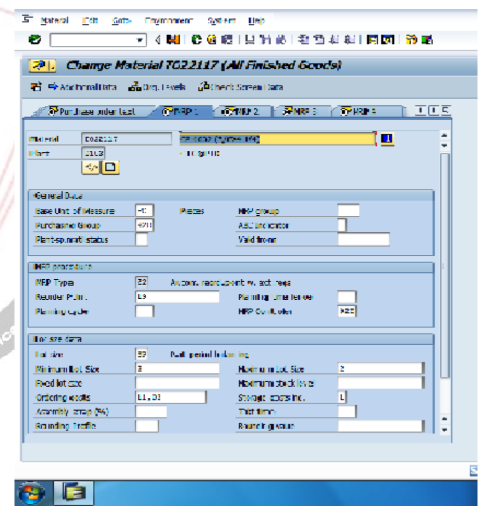

Figure 7: SAP screenshot

C. Storage cost index interpretation in SAP screen shot

Form figure 7, it indicates that the value of storage cost in Euros, i.e. the cost required for the storage of product for specific days, months, or year. (1=35 Euros),

D. Value addition time

As shown in Table 1, the value addition time indicates the process time or cycle time required. Due to which the value of the product increases in terms of money.

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OPERATIONS	VALUE ADDED TIME (min)
1. Customer	
2. Distribution Center	
3.	
3.1 BPCS	
3.2 SAP	
4. PPC	
5. Sourcing	
6. CYLINDER	
6.1 Forging	300
6.2 Soft Machining	6300
6.3 C,H,T	1080
6.4 Honing	17
6.5 Internal Grinding	35
7. PISTON	
7.1 Forging	300
7.2 Soft Machining	6300
7.3 C,H,T	1200
7.4 Grinding	9.5
8. RIFLE BAR	
8.1 Forging	300
8.2 Soft Machining	6300
8.3 C,H,T	720
8.4 Grinding	11.5
9. FRONT HEAD	
9.1 Forging	300
9.2 Soft Machining	4200
9.3 C,H,T	1080
9.4 Grinding	30
10. Polishing	5
11. Raw Material Inspection	
12. Raw Material Store	
13. Front Head Assembly	5
14. Cylinder Sub Assembly	8
15. Back Head Assembly	6
16. Final Assembly	3
17. Vibration Testing	12
18. Footrest Assembly	5
19. PAINTING (Hanging)	2
20. Heating	30
21. Washing	5
22. Cleaning	4
23. Primer	5
24. Cooling with blower	30
25. 1st Coat	3
26. 2nd Coat	5
27. Cooling with natural Air	30
28. Packing	5

Table 1: Value added times

E. Non-Value addition time (cycle time or process time), for each operations in the VSM

As shown in Table 2, it is the time taken for the processes such as storage of product, its handling, transportation and inspection of parts and final product. The non-value addition time is generally occurs or seen between two consecutive process and operation. Possible reasons for non value addition time include transportation, motion, inventory, waiting, over-production, over-processing & defects.

OPERATIONS	NON-VALUE ADDED TIME
1. Customer 2. Distribution Center	6 weeks – Europe And 8 weeks – USA = By Water 2 weeks – For Europe and USA = By Air
3.	
3.1 BPCS	
3.2 SAP	
4. PPC	
5. Sourcing	
6. CYLINDER	
6.1 Forging	37800
6.4 Soft Machining	120
6.5 C,H,T	120
6.4 Honing	20
6.5Internal Grinding	85
7. PISTON	
7.1 Forging	37800
7.2 Soft Machining	120
7.3 C,H,T	120
7.4 Grinding	20
8. RIFLE BAR	
8.1 Forging	
8.2 Soft Machining	37800
8.3 C,H,T	120
8.4 Grinding	
9. FRONT HEAD	
9.1 Forging	37800
9.2 Soft Machining	120
9.3 C,H,T	120
9.4 Grinding	20
10. Polishing	20
11. Raw Material Inspection	5
12. Raw Material Store	20
13. Front Head Assembly	0.10
14. Cylinder Sub Assembly	0.15
15. Back Head Assembly	0.05
16. Final Assembly	1.5
17. Vibration Testing	1.5
18. Footrest Assembly	1
19. PAINTING (Hanging)	1
20. Heating	2
21. Washing	2
22. Cleaning	4
23. Primer	1
24. Cooling with blower	1

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25. 1st Coat	15
26. 2nd Coat	1
27. Cooling with natural Air	5
28. Packing	

Table 2: Non-Value added times

F. Historic sales data, over last since 2014

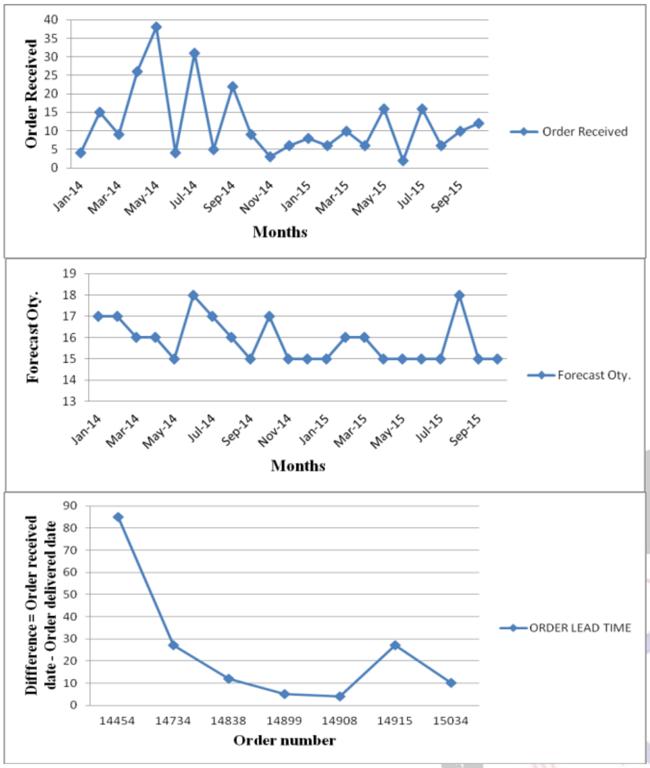

Figure 8: Orders Received; Forecast & Order Lead Time

As shown in Figure 8,

The 1st graph of Order received Vs Month, shows the quantity of order received per month.

2nd graph of Forecast Qty. Vs Month, shows the quantity forecasted per month according to the previous sales.

3rd graph of Difference Vs Order Number, shows the order fulfillment lead time of specific order number.

VI. PROJECT EXECUTION

A. ABC analysis

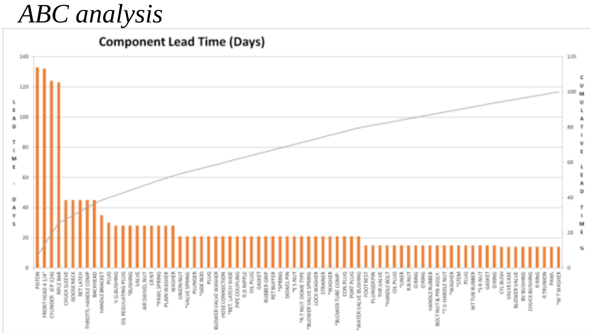

Figure 9: ABC Analysis

The figure 9 gives the information about the actual 'ABC' analysis that we have carried out. 'X' axis has the entire component's that are required to compile 'CP32A' as a whole, while on the 'Y' axis there are two linear parameter parallel to each other. On one side it has lead time which is in days, while paralleling is cumulative lead time which is percentile form. Starting with Piston which consumes the highest lead time (133) following with the least cumulative lead time (7). Next highest lead time consuming component is Front Head (132) with cumulative lead time (13). Cylinder with lead time (124) and cumulative lead time (19). Riffle bar with lead time (123) and cumulative lea time (25). These are the four critical components which consume the most lead time in days as well as the cumulative lead time in percentile. Followed further by chuck sleeve, goose neck, ret latch, throttle handle comp and backhead with lead time of (45) each and with a cumulative lead time of (28, 30, 32, 34, 37) respectively. Handle bracket and plug with lead time (35, 30) respectively and cumulative lead time (38, 40) each. V.G bushing, oil regulating plug, bushing, valve, air swivel nut, CR NT, pawl spring, plain washer and washer with lead time (28) each and cumulative lead time (41, 43, 44, 45, 47, 48. 50, 51, 52) respectively. Union nut, valve spring, plunger side rod, plug, blower valve washer, hose connection, ret catch shoe, pipe coupling, R.D nipple, oil plug, gasket, rubber grip, ret buffer, spring, dowel pin, ES nut, R.T nut dome type, blower valve spring, lock washer, strainer, washer, blower tube comp, CON plug, port plug, water valve, bushing with lead times (21) each and cumulative lead time (53, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80) respectively. Foot rest, plunger pin, throttle valve, handle bolt, oil plug, liner, R.B nut, O ring, handle rubber, bolt nut and rin assembly, T.V handle nut, washer, stem, plug, WT tub rubber, SR nut, gasket, O ring with a lead time (15) each and cumulative lead time (80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94) respectively. And the last group of components having the least lead time are cycle bush, valve case, blower valve, BV bushing, chuck bushing, R ring, pawl, WT washer with a lead time of (14) each and a cumulative lead time of (94, 95, 96, 97, 98, 99, 100) respectively. So according to definition of lead time and cumulative lead the top four products which are piston, cylinder, riffle bar and front head which consumes the maximum time for manufacturing and also being the key parts of "CP32A" so further analysis need to be carried on this four products after sorting it out from the 'ABC' analysis done on the various number of products of CP32A.

B. VSM (Value Stream Mapping)

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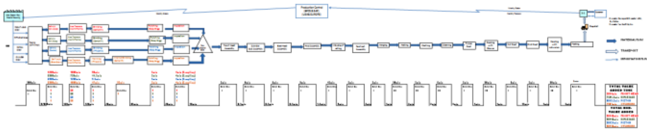

Figure 10: Value Stream Map

From fig. 10, Value Stream Map in this project implies -

- Customer order is received at the Distribution centres weekly, the order is then forwarded from DC to the Production planning and Control (PPC) who registers order from DC of USA in BPCS and the order from DC Europe is registered in SAP.
- The Production planning and control (PPC) plans according to the order and further the order is passed to the sourcing department.
- As per the analysis the critical parts were found those are :- Front head, Riffle bar, Piston, Cylinder
- The lead time for operations of these parts were calculated both as value added and non value added.

The operations and their lead times are listed below:-

1] FORGING

Part	Time (min)	Batch size	Vendor
Front head	300	1	OM NIMJAI
Riffle bar	300	1	
Piston	300	1	
Cylinder	300	1	

Non value added time=37800 min

2] SOFT MACHINING

Part	Time (min)	Batch size	Vendor
Front head	4200	1	SAI UDYOG
Riffle bar	6300	1	SAI UDYOG
Piston	6300	1	PANCHAL
Cylinder	6300	1	GRANDEUR

Non value added time=120 min

3] HEAT TREATRMENT

Part	Time (min)	Batch size	Vendor
Front head	1080	60	NASHIK TECHNO.
Riffle bar	720	60	
Piston	1200	60	
Cylinder	1080	60	

Non value added time= 120 min

4] GRINDING

Part	Time (min)	Batch size	Vendor
Front head	30	1	SAMARTH
Riffle bar	11.5	1	SAMARTH
Piston	9.5	1	PHOENIX

5] HONING

Part	Time (min)	Batch size	Vendor
Cylinder	17	1	PHOENIX

Non value added time= 20 min

6] INTERNAL GRINDING

Part	Time (min)	Batch size	Vendor
Cylinder	35	1	SAMARTH

Non value added time= 85 min

7] POLISHING

Part	Time (min)	Batch size	Vendor
Front head	5	1	BALAJI ENGINEERING
Riffle bar	5	1	
Piston	5	1	
Cylinder	5	1	

Non value added time= 20 min

8] INSPECTION (SAMPLING)

Part	Time (min)	Batch size
Front head	4	1
Riffle bar	4	1
Piston	4	1
Cylinder	4	1

- The operations from FORGING to INSPECTION are done, after inspection if the part is ok it is forwarded to RAW MATERIAL STORE inside ATLAS COPCO LTD.
- The parts are then issued from the 2 bin Kanban system to the assembly line, the lead time required for assembly is given in the table below:-

Type of assembly	Time(min)	Batch size
Front head assembly	5	1
Cylinder sub assembly	8	1
Back head assembly	6	1
Final assembly	3	1

- After assembly the product needs to be tested for vibrations so it goes for vibration testing which takes 12 minutes and then it goes to footrest assembly the take between these two processes is 3 min.
- Further operations are explained in table below:-

Process	Time (min)	Batch Size
Hanging	2	1
Heating	30	40
Washing	5	40
Cleaning	6	40
Primer coat	5	1
Cooling with blower	30	40
1st coat	3	1
2nd coat	5	1
Cooling with natural air	30	40
Packing	5	1

- Post to the packing the finished products are dispatched to Distribution centres (DC).
- The customer in the end receives his order from DC.

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C. Model Formulation (Transportation)

ASSUMPTIONS -

- Product shortage penalty =10,000 hours per month.
- Initial inventory = Zero, at start of 1st month.
- Product scheduled for assembly, in that month, is immediately available for delivery/ dispatch, after processing of all operation/ steps in the value stream mapping.
- Shortage of row material doesn't occur.
- Total demand of month "i" ≤ Total capacity of month "j".
- Units can be assembled (Manufactured) conveniently in all months, to satisfy demand of any month.
- Lead time (Manufacturing and assembly) is precisely known & remain constant across the entire year or time period.
- Inventory holding time is precisely known is remains constant across the entire year or time period.
- The objective is minimizing the total lead time for CP 32A unit in a year, as a whole & not for CP 32A unit in any particular Month/ Week/ Day.

Final optimization model is as following -

1. Time taken for manufacturing and assembly - 46164.5 minutes/unit =769 hours/unit
2. Time taken for inventory storage (For max. 20 units) = 10 hours / month.
3. Miscellaneous time = 1 hour / unit.
4. Assume maximum capacity of plant in month " i ",

a (i)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	20	13	20	13	20	13	20	13	20	13	20	20

5. Assume demand in month " j ",

b (j)	j1	j2	j3	j4	j5	j6	j7	j8	j9	j10	j11	j12
	17	17	16	16	15	18	17	16	15	17	15	15

6. Lead time matrix per month = d (i, j)

	j1	j2	j3	j4	j5	j6	j7	j8	j9	j10	j11	j12
Jan	769	779	789	799	809	819	829	839	849	859	869	879
Feb	10000	769	779	789	799	809	819	829	839	849	859	869
Mar	10000	10000	769	779	789	799	809	819	829	839	849	859
Apr	10000	10000	10000	769	779	789	799	809	819	829	839	849
May	10000	10000	10000	10000	769	779	789	799	809	819	829	839
Jun	10000	10000	10000	10000	10000	769	779	789	799	809	819	829
Jul	10000	10000	10000	10000	10000	10000	769	779	789	799	809	819
Aug	10000	10000	10000	10000	10000	10000	10000	769	779	789	799	809
Sep	10000	10000	10000	10000	10000	10000	10000	10000	769	779	789	799
Oct	10000	10000	10000	10000	10000	10000	10000	10000	10000	769	779	789
Nov	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	769	779
Dec	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	769

7. Lead time in hours,

c (i, j) = 1* d (i, j)

i	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
j	j1	j2	j3	j4	j5	j6	j7	j8	j9	j10	j11	j12

8. Let,

x (i, j)→ Quantity assembled in month "i", to satisfy the demand of month "j".

z → Total lead time in hours.

9. Objective function.

Minimize z = $\sum_j \sum_i$ [c (i, j). x (i, j)]

10. Subject to constraints.

1. x (i, j) ≥ 0
2. x (i, j) belongs to Integer
3. $\sum_j$ x (i,j) ≤ [Maximum capacity of month "i"]→a (i)
4. $\sum_i$ x (i,j) ≥ [Demand of month "j"]→ b (j)

D. Formulation & Solution in GAMS[26], [27], [28], [29], [30].

$Title Assembly Schedule per month for CP32A, at Atlas Copco-Nasik

$Ontext

This problem finds a least time assembly schedule that meets requirements for months and assembles units, accordingly.

$Offtext

Sets

i month / jan, feb, mar, apr, may, jun, jul, aug, sep, oct, nov, dec /

j month / j1, j2, j3, j4, j5, j6, j7, j8, j9, j10, j11, j12 / ;

Parameters

a(i) capacity of plant in month i

/jan 20 feb 13 mar 20 apr 13 may 20 jun 13 jul 20 aug 13 sep 20 oct 13 nov 20 dec 13 /

b(j) demand in month j

/j1 17 j2 17 j3 16 j4 16 j5 15 j6 18 j7 17 j8 16 j9 15 j10 17 j11 15 j12 15 / ;

Table d(i,j) lead time matrix per month

j1 j2 j3 j4 j5 j6 j7
j8 j9 j10 j11 j12
jan 769 779 789 799 809 819
829 839 849 859 869 879
feb 10000 769 779 789 799 809
819 829 839 849 859 869
mar 10000 10000 769 779 789 799
809 819 829 839 849 859
apr 10000 10000 10000 769 779 789
799 809 819 829 839 849
may 10000 10000 10000 10000 769 779
789 799 809 819 829 839
jun 10000 10000 10000 10000 10000 769
779 789 799 809 819 829
jul 10000 10000 10000 10000 10000
10000 769 779 789 799 809 819
aug 10000 10000 10000 10000 10000
10000 10000 769 779 789 799
809

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ISSN : 2494-9150 Vol-02, Issue 01, APR 2016.

```
sep   10000   10000   10000   10000   10000
10000   10000   10000   769   779   789
799
oct  10000   10000   10000   10000   10000
10000   10000   10000   10000   769   779
789
nov  10000   10000   10000   10000   10000
10000   10000   10000   10000   10000   769
779
dec  10000   10000   10000   10000   10000
10000   10000   10000   10000   10000   10000
769
;
 Scalar f  miscellneous time  /1/ ;
 Parameter c(i,j)  lead time in hours ;
        c(i,j) = f * d(i,j) ;
 Variables
      x(i,j)   quantities assembled in month i to satisfy the
demand of month j
      z      total total lead time in hours ;
 Positive Variable x ;
 Equations
      time       define objective function
      supply(i)   observe quantity to be assembled in month i
      demand(j)   satisfy demand in month j ;
 time ..      z  =e=  sum((i,j), c(i,j)*x(i,j)) ;
 supply(i) ..   sum(j, x(i,j))  =l=  a(i) ;
 demand(j) ..   sum(i, x(i,j))  =g=  b(j) ;
 Model schedule /all/ ;
 Solve schedule using lp minimizing z ;
 Display x.l, x.m ;
```

The output obtained after running the modelled formulation in GAMS is shown in figure 11. The optimal solution of the objective function or the total lead is 158617 hours.

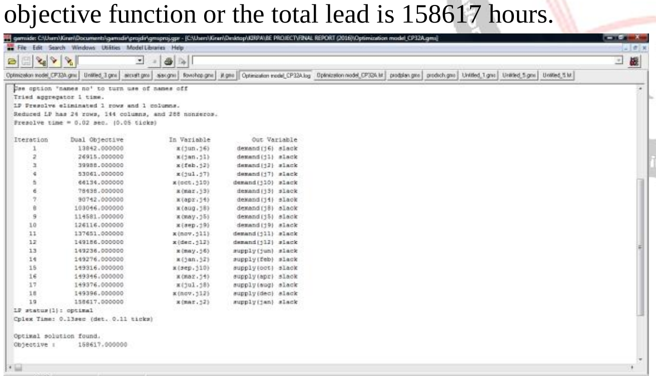

Figure 11: Output from GAMS

E. Formulation & Solution in MS Excel

Production Time per unit product	769	hours
Inventory Holding Time per month	10	hours

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand	17	17	16	16	15	18	17	16	15	17	15	15
Production Time	769	769	769	769	769	769	769	769	769	769	769	769
Capacity	20	13	20	13	20	13	20	13	20	13	20	13

	Production Time + Inventory Holding Time Matrix											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Jan	769	779	789	799	809	819	829	839	849	859	869	879
Feb	10000	769	779	789	799	809	819	829	839	849	859	869
Mar	10000	10000	769	779	789	799	809	819	829	839	849	859
Apr	10000	10000	10000	769	779	789	799	809	819	829	839	849
May	10000	10000	10000	10000	769	779	789	799	809	819	829	839
Jun	10000	10000	10000	10000	10000	769	779	789	799	809	819	829
Jul	10000	10000	10000	10000	10000	10000	769	779	789	799	809	819
Aug	10000	10000	10000	10000	10000	10000	10000	769	779	789	799	809
Sep	10000	10000	10000	10000	10000	10000	10000	10000	769	779	789	799
Oct	10000	10000	10000	10000	10000	10000	10000	10000	10000	769	779	789
Nov	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	769	779
Dec	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	769

	Decision Variable Matrix													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Capacity Utilized per month	Max Capacity per month
Jan	17	3	0	0	0	0	0	0	0	0	0	0	20	20
Feb	0	13	0	0	0	0	0	0	0	0	0	0	13	13
Mar	0	0	16	3	0	0	0	0	0	0	0	0	19	20
Apr	0	0	0	13	0	0	0	0	0	0	0	0	13	13
May	0	0	0	0	15	5	0	0	0	0	0	0	20	20
Jun	0	0	0	0	0	13	0	0	0	0	0	0	13	13
Jul	0	0	0	0	0	0	17	3	0	0	0	0	20	20
Aug	0	0	0	0	0	0	0	13	0	0	0	0	13	13
Sep	0	1	0	0	0	0	0	0	15	4	0	0	20	20
Oct	0	0	0	0	0	0	0	0	0	13	0	0	13	13
Nov	0	0	0	0	0	0	0	0	0	0	15	2	17	20
Dec	0	0	0	0	0	0	0	0	0	0	0	13	13	13
Demand Satisfied per month	17	17	16	16	15	18	17	16	15	17	15	15		
Max Demand per month	17	17	16	16	15	18	17	16	15	17	15	15		
Total Time	158617													

Figure 12: Model Solution in MS Excel

The output obtained after running the modelled formulation in MS Excel is shown in figure 12. The optimal solution of the objective function or the total lead is 158617 hours.

VII. LIMITATIONS

Even though the model is successfully formulated using linear programming as a transportation model, solved using simplex algorithm & validated in GAMS & MS Excel, there are certain limitations, due to non-availability of a variety of data. The numbers of constraints included are, as a result, fewer than ideally expected in a production scheduling facility. Firstly, number of people working is not considered, in particular, at all each individual operation. Capacity of the plants (Atlas Copco & its vendors) is not available at present & it would have been very important for the model to turn out close to reality. Since the objective of the project is to minimize time, various cost factors, such as manufacturing cost, material cost, wages, storage cost, handling costs, transport costs, overhead costs, etc. are not considered. Most importantly, the entire formulation is based on the premise that all operations have a 100% first pass yield. Thus, no reworks or quality oriented repairs/scraps occur & that would have significantly changed the formulation, if available. The pattern of demand forecast & planning horizon are both in a monthly pattern, though there could be variations on a daily or

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weekly basis. We have assumed a perfect Just-in-Time system with zero storage costs & even zero storage times within Atlas Copco facility.

VIII. CONCLUSION

However, in spite of all the limitations, this project has been successful in proving that Value Stream Mapping coupled with Linear Programming, is very pivotal in optimizing a supply chain. Thus, we have attempted to apply theoretical concepts in real world scenario. Furthermore, we also believe that if Atlas Copco follows our proposed production schedule, the delivery efficiency of CP32A is bound to improve, subject to no variation in the assumptions, data used & constraints formulated. The durability of GAMS in application oriented formulation & solution is also proved, apart from versatility of MS Excel.

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