METHODOLOGY FOR POSITIONING MULTIPLE DECOUPLING POINTS IN HYBRID MANUFACTURING SUPPLY CHAIN SYSTEM

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ABSTRACT

Manufacturing companies are hard pressed to produce products faster and keep their cost at possible minimum. Manufacturers are always in search to fit their supply chains both internal (within manufacturing) and external to meet the challenge of competitive market. The delivery time is one of the most critical factors which influence management of the supply chain networks and cost of the product. To respond to a given lead time, manufacturing firms need to adjust their supply chain networks and design an effective interface for decoupling points in the supply chain based on the cost to be incurred. In this paper, a modified cost model is proposed for a hybrid supply chain networks of a manufacturing firm which is applied for determining positions for decoupling points in the entire manufacturing supply chain networks. The cost model is useful in evaluating performance of the supply chain in terms of cost for a given delivery lead time and helps draw a line of multiple decoupling points in the networks which is supposed to yield best possible cost. The application of the model has been demonstrated through an example for its usefulness. The results shows effectiveness of the proposed model and leads to recommendations for developing a comprehensive and integrated methodology for designing interface for hybrid manufacturing supply chain networks for quick response to the delivery lead time.

KEY WORDS: *Hybrid Manufacturing System, Supply Chain System, Multiple Decoupling Points, Delivery Lead Times.*

INTRODUCTION

Now a day's customers like individualized products and services at best affordable cost. To be competitive in the market at best and improve profits, the application of modern techniques and tools are considered to be helpful[1]. Due to fast growth of technology and ease of skill-difficulty, competition among industries has been increased in order to secure their share in the market. Thus companies' objective is to deliver products faster, more reliably and at lower cost to the end user[2]. To fulfil customer requirements, it is essential for the manufacturers to maintain best possible minimum quantity of components in stock to be able to satisfy sudden customer demand by keeping minimum risk of component uselessness[3].

Manufacturing environment where products are manufactured before receipt of a customer order and the decoupling point(s) lies between manufacturing processes and customer order is known as Make-to-Stock (MTS). The MTS is distinguished by customer short order-to-delivery time. It has high forecast accuracy, inventory costs and capacity utilization in the supply chain [J. Köbera, G. Heineckeb, (2012)][4]. In contrast, manufacturing environment where products are made entirely after the receipt of a customer order is called Make-to Order (MTO). Mostly, standardized items (purchased or manufactured) are assembled in MTO environment and is also referred as Assemble-to Order (ATO). In MTO or ATO environment, customers have to wait for delivery lead time to manufacture the products. MTS environments fulfill demand quicker than the MTO and ATO environments[4]. Change in demands by the customers and increase in volumes of products can be handled by Make-to-Order (MTO) and Assemble-to-Order (ATO) systems[5].

To optimize the total cost, supply chain of both systems (MTS and MTO/ATO)is combined to get the desired results by minimizing cost, which is the cost of the time period and inventory[6]. Researchers have addressed information integration and material (logistics) integration problem. It has been investigated that integrations of both information and material flows between supply chain partners have an effect on operational performance[7]. The decoupling point(s) determine the interface between push/pull system and location within the supply chain at which a product is customized[8]. The push/pull models combined with knowledge and

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decoupling point's location as agile manufacturing are used for management of varying demands and lean manufacturing[9] where control points identify output buffers, inventory levels, and ability of systems to automatically adjust to stochastic demand depending on the location of these points[10].

Leagile supply chain attributes, combination of Lean supply(upstream) and agile supply(downstream) during its evolution from traditional to its present are customized[11]. The management model integrates purchase, production and sale plans with logistics plans using JIT philosophy. To build an integrated supply chain system which contains inside and outside supply chain system of manufacturing firm, a conceptual framework of integrated supply chain planning has been considered by Ruilin & Tang[12].

The main issue within assemble to order environment is that push type manufacturing leads to high inventory cost in return of low delivery lead time and in the pull type, high delivery lead time is expected in the return of low inventory cost. In 'Assemble to Order' (ATO) system, due to high manufacturing firm's variability of products, late delivery problems arise. Delivery lead time plays important role in minimizing inventory holding and delivery lead time cost. In 'Assemble to Order' environment, storage point is between manufacturing and assembly, and this storage point is called a decoupling point. Manufacturing is carried out as push system and assembly as pull system. In actual production environment, manufacturing and assembly is carried out in multi-level network of manufacturing and assembly operations. The interface of push-pull systems is variable and flexible to tackle variety of products consisting of multi components, parts and sub-assemblies. The flexible interface which is an imaginary line, connecting all the decoupling points for a particular product can be identified with a suitable model for calculation of cost of the chain. The points where best trade-off between delivery lead cost and inventory cost is achieved will define the hybrid manufacturing supply chain network for the given product. This paper aims at developing a cost model for a given hybrid manufacturing supply chain which is used for determining performance of the chain in terms of cost and designing an interface for a hybrid manufacturing supply chain for a given product. The application of the model is demonstrated through an example for its usefulness.

A Cost Model for a Hybrid Manufacturing Supply Chain System

Consider a typical Hybrid Manufacturing Supply Chain System (HMSCS) as shown in the Figure1. Let raw materials are '*M1', 'M2', 'M3', 'M4'....... 'Mi'*, manufactured parts are 'C1*', 'C2', 'C3', 'C4'.......... 'C5'*, procured parts are '*P1', 'P2', 'P3'......... 'Pi'* sub-assemblies are '*sa1', 'sa2', 'sa3'...... 'sai'* assemblies are 'A1', 'A2', '*A3' ...... 'An'*. Assembly stations are '*ASt1', 'ASt2', 'ASt3'……… 'ASti',* and manufacturing station '*St1', 'St2', 'St3'……… 'Sti'*. The HMSCS consist of push and pull stations, combined at some junction points; *'DP1', 'DP2' and 'DP3'*called decoupling points.

In the Figure 1, manufacturing of parts from materials is shown in rectangles; circle and triangle represents assembly process and storage of parts/material respectively. Green circles are decoupling points, and solid dotted arrows represent material and information flows. Before decoupling point, the system is push type while it is pull type after the decoupling point.

In the proposed HMSCS, the events like material components, sub assemblies and finished products are

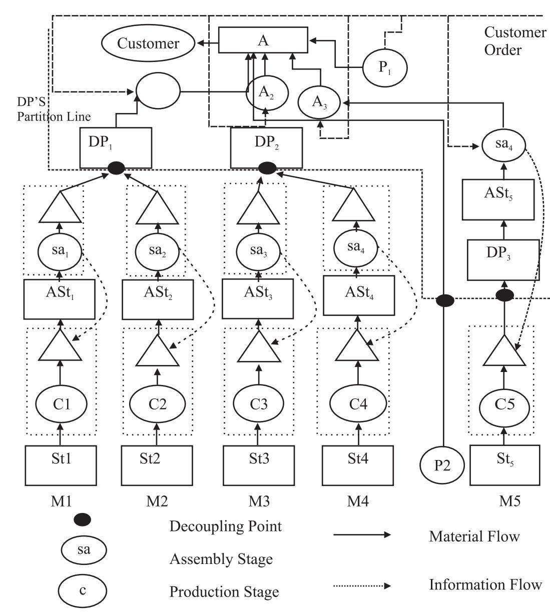

Figure 1: A Typical Hybrid Manufacturing Supply Chain System (HMSCS)

acting as nodes and their transformations are represented by activities like procurement, manufacturing, delivery time, etc. The manufacturing supply network cost and expected customer delivery lead time are the two most important evaluation criteria for most supply chain[13]. In the given HMSCS, materials, components, semi finished/finished parts, sub assemblies and final assembly can be either 'make to stock' (MTS) or 'make to order' (MTO), based on the delivery lead time and the supply chain costs.

Modifying Fisher and Mason model[14,15] by the addition of production cost, the following mathematical model is proposed to measure sum of the inventory and manufacturing lead times costs in the entire manufacturing supply chain and determine performance of the proposed hybrid supply chain network in the manufacturing environment.

MinTC = Supply Chain Cost + Production Cos ___ (1)

Where *'Min TC'* is the objective function of the total cost of the entire manufacturing supply chain system which include supply chain cost and production cost

$Min\ TC = \Sigma^{n}_{i=1} \{(Si) + (li + SOi + Ai)\} + (CINV + CDLT$ ____________________________ (2)

i ~ Component/sub assembly/assembly index,i є Nodes.

A_i *~ Asset specificity cost of component i. It is considerable fixed investments and represented in terms of percentage of the component's cost*[16].

SOi~ Stock Out Cost

Si ~ Production Setup Cost, when firm is 'make to order', pull type environment

Si ~ Si/Oi, when component i uses MTS, where O_i*rder Interval Cost*

Ii ~ Storage Cost

CINV~Cost of Inventory in Production

CDLT~Cost of Delivery Lead Time

The different type of costs used in the proposed model are summarized and tabulated in Table 1:

Di~ Demand of i item per time period

BOM (i,j)~ Quantity of component j needed for each component i,

Using this table, the equation for total cost becomes as:

$Min\ TC = \sum^{n}_{i=1} TC\ (MTS,i) + \sum^{n}_{i=1}\{TC(MTO,i) + CINV + CDLY$ ________________________________ (3)

Table 1: Cost Types in the Proposed HMSCS Model

Cost Type	MTO	MTS	Remarks
Setup Cost	Si	Si/Oi	Si/√((2) Si/hiDi)
Inv holding Cost	0	CINV	
Stock Out cost	0	SOi	
Asset Specify Cost	0	Ai	%age of part cost

or

*Min TC = (TCMTO + TCMTS) + (CINV + CDLT)*_(4)

*Where CINV= Inventory holding cos in production*_(5)

TC MTO ~ Total cost of MTO

TC MTS ~ Total cost of MTS

Subject to:

$PT\ (x) \leq DT,$

$SSp \leq SC,$ *where SSp is store space and SC is store capacity*

$TC \leq BC,$ *where BC Budget Cost*

Production cost is based on the safety stock, batch size, and kanban for the pull system. Moreover work in process cost is to be added to obtain total production cost. Lead time cost is essential part of the system and plays important role particularly in MTO environment. It is added to obtain manufacturing production cost with the supply chain cost to calculate total cost of the system.

Production cost mentioned by Omer et al[6] and Sipper et al[17].

$$TC\ (SS,Q) = (Safety\ Stock\ (SS) + Kanban + WIP) + (CDLT) \quad (6)$$

$$SS=D\ Ltotal, \quad (7)$$

Safety stock of the components is maintained in MTS part of the system to avoid shortages and is determined by the demand rate and total lead time of the push part of the system.

$$D \sim Demand\ Rate\ \left(\frac{unit}{time}\right) \quad (8)$$

$$Ltotal \sim push\ system\ lead\ time \quad (9)$$

$$Kanban = D\ Lmax\frac{1+a}{C}, \quad (10)$$

a is safety factor, C is container size, and Lmax is pull system lead time

$$a = 0 < a < 0.1$$

$$WIP = (Cm + CP/2)\ h\ D \quad (11)$$

$$Cm \sim Cost\ pf\ Material,\ h \sim Holding\ Cost,$$
$$Cp \sim Processing\ Cost$$

The partition line made by the decoupling points affects the total cost. The partitioned environments are MTS and MTO. In proposed model MTS is represented with "0" and MTO is represented with "1". By the increase of MTO stations, numbers of "1s" increases, resulting in total cost reduction and vice versa increases of MTS stations, and numbers of "0s" increases, resulting in increase of inventory cost and total cost. Production time, delivery lead time and characteristics of parts are the decision factors in proposed HMSCS. This also helps in the reduction of risk of loss, as risk of loss is more in the upstream than in the downstream and hence it is valuable to keep the inventories at the lower stages.

Application of Cost Model for HMSCS-an Example of Product A

The product A is being produced in ABC Company and final assembly comprising 3 sub assemblies and 2 purchased parts and 4 manufactured parts in assemble to order environment. Four types of materials 'M1', 'M2', 'M3' and 'M_4' are being used in the manufacturing of parts 'C1', 'C2', 'C3'and 'C4', whereas 'P1' and 'P2' are purchased parts being used in sub assemblies'A1', 'A2' and 'A3' to get the final product A.

Manufacturing of the parts 'C1', 'C2', 'C3' and 'C4' is according to process plan, shown in Figure 2, as stations visited by the part 'C1'are 'Stn1', 'Stn2', 'Stn3' and 'Stn4', by 'C2' are 'Stn1', 'Stn2', 'Stn4', for 'C3' stations are: 'Stn1', 'Stn3', 'Stn4', and similarly for 'C4' are 'Stn2', 'Stn3', and 'Stn4'.

Assembly, sub assemblies, manufactured and purchased parts are represented in a diagram known as activity node diagram with production time for each of the component on the nodes. Using the critical path method, production time for the part A seems to be 46 units of time. Now the delivery lead time will come to play its role in choosing the production environment.

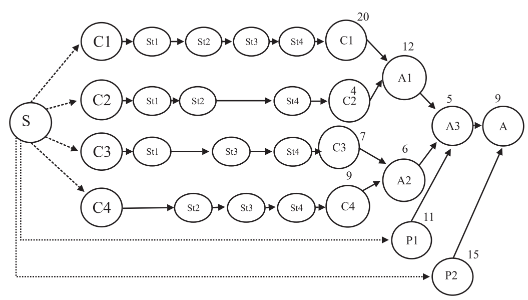

Figure 2: Process Plan Network Diagram for the Product A with production time on the nodes

The environment for production of A can be MTO if the delivery lead time is at least 46. But the delivery lead time is negotiated with the customers and usually less than such production lead time and that's why the production environment cannot be MTO. There is a need to define a DP somewhere at appropriate position of the manufacturing supply chain and design a feasible hybrid environment on the basis of delivery lead time. The following section elaborates it further.

Environment Selection Based on Production Time and Delivery Time

The Production Time (PT) of the individual component, is tabulated in Table 1. Using critical path method; production time comes out to be 46 for a pure MTO system. For the hybrid system having delivery lead time, DLT= 20, the only hybrid manufacturing environment which can meet the challenge is where final assembly A and subassembly A1 and A2 are set to be pull type (MTO) with no inventory and remaining sub assembly A1, manufactured parts and purchased parts are set to be push type (MTS). If the pull type station is represented by '1' and '0' represents the push type, the proposed environment seems to b '0000000111', shown in the Table 2.

The information provided in the Table 2 is used to position the decoupling points (DPs) for the production on the shop floor which lead to declare production of A2, A3 and A as MTO and make suitable point as DP before A2 and A3 on the shop floor. Accordingly the decoupling point forms partition line between A2, A3, A and A1, P1, P2, C1, C2, C3, C4. Kanban is generated with the positioning of decoupling points which is further elaborated in the following section.

Table 2: Production Time (PT) of Product A

Product:	**C1**	**C2**	**C3**	**C4**	**P1**	**P2**	**A1**	**A2**	**A3**	**A**
PT	**20**	**4**	**7**	**9**	**11**	**15**	**12**	**6**	**5**	**9**
Environment	MTS	MTS	MTS	MTS	MTS	MTS	MTS	MTO	MTO	MTO
Type	(0)	(0)	(0)	(0)	(0)	(0)	(1)	(1)	(1)	(1)

POSITIONING OF MULTIPLE DECOUPLING POINTS

A flow chart or product manufacturing network, shown in Figure 3 is developed based on the information in the Table 2, showing DP for each row of manufacturing stations. Circles represent processing; triangles are inventory storages, whereas green triangle is kanban in the pull system. Thick dotted line is a partition line, while thin arrow direction is information flow. Material flow is represented with arrow and triangle with 'M' shows material stock.

The production time (PT) for a product in a hybrid manufacturing environment is computed by considering type of MTS/MTO environment. In case of pure MTS environment, the sale of a product is from the shelf and the production time required is considered to be zero (0). In MTO system, each components in the BOM is either manufactured or purchased, taking their respective lead times requires production time which is at least equal to a critical path from 'Start' to 'Finish' in the network diagram for smooth production.

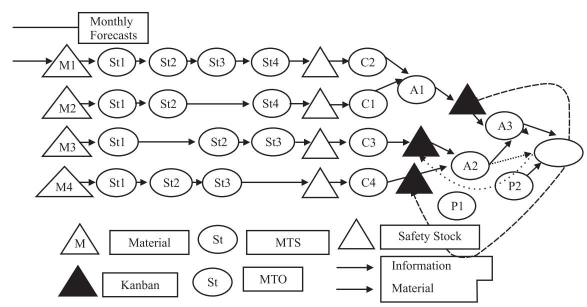

Figure 3: Manufacturing Processes and Supply Network of Example Product A

Relationship between Delivery Lead Time and Feasible Decoupling Points

The feasible decoupling points vary with the variation in delivery lead times. With the increase in delivery lead time, the decoupling points are converted from 0 (MTS) to 1 (MTO). The partition line constructed with decoupling points moves to the upstream. With decrease in the delivery lead time the partition line moves to the downstream, as per column of feasible DP'S of Table 3.

The Table 3 shows the relationship between the delivery time (DLT) and manufacturing environment with feasible decoupling points. The delivery time helps

Table 3: Relationship between Delivery Lead Time and Position of Decoupling Points

Case Type	DLT	Critical Path	Feasible DP'S	Lmax (Pull system lead time)	Ltotal (Push system lead time)
1	**46**	**C1A2 A1 A**	**1 1 1 1 1 1 1 1 1 1**	**46**	**00**
2	32	C2 A2 A1 A	0 1 1 1 1 1 1 1 1 1	30	20
3	27	C3 A3 A1 A	0 0 1 0 1 1 1 1 1 1	27	33
4	29	P1 A1 A	0 0 0 1 1 1 1 1 1 1	29	31
5	24	P2 A	0 0 0 0 1 1 0 0 1 1	25	52
6	25	P1A3A	0 0 0 0 1 1 1 1 1 1	26	40
7	20	A2A3A	0 0 0 0 0 0 0 1 1 1	20	78
8	14	A3A	0 0 0 0 0 0 0 0 1 1	14	84
9	09	A	0 0 0 0 0 0 0 0 0 1	09	89
10	00	00	0 0 0 0 0 0 0 0 0 0	00	98
11	26	A1A3A	0 0 0 0 1 1 1 1 1 1	26	66
12	25	P1A3A	0 0 0 0 0 0 1 1 1 1	25	40
13	46	C1A1A3A	1 1 1 1 1 1 1 1 1 1	46	00
14	29	C4A2A3A	0 0 1 1 1 1 1 1 1 1	29	24

identify the critical path on the Process Plan Network Diagram for production of Product A. This critical path helps find the max manufacturing lead time for pull system (MTO) and push system (MTS) which is used for calculation of production cost.

During negotiation for delivery lead time with customers, different possible lead times may be agreed upon, resulting in different manufacturing scenarios. The Table 3 enlists fourteen (14) different scenarios with different critical path; feasible decoupling points and maximum lead times for pull and push systems. Each scenario cost production differently.

In Case Type 1, all stations are MTO and Lmax is 46. Ltotal is the lead time of the push system , as there is no MTS system, hence Ltotal is 0. For Case Type 2, C2 (manufactured component) is MTS and rest of C2 i.e. C3, C4, A1, A2, A3, P1, P2, A are MTO, Ltotal for C2 is 20, whereas, Lmax by the critical path method for MTO system is 30. Similarly, all fourteen cases are defined.

PERFORMANCE OF MANUFACTURING SUPPLY CHAIN NETWORK

The performance of manufacturing supply chain in terms of cost is computed at different delivery lead times of the parts (scenarios). The manufacturing supply chain cost depends on the delivery lead. If the delivery lead time increases the inventory holding cost decreases and vice versa. The total cost of the product A at various decoupling points against various delivery times is mentioned in following Table 4.

When the system is MTS, its inventory levels are at maximum resulting in high total cost. From above Table 4, when the whole system is MTS, its cost is 8470. On the other hand, when the all stations are MTO, total cost is 2700 resulting in an improvement of about 70%. The manufacturer tries to negotiate the orders and win the customers with more profitable delivery lead time.

For the HMSCS system with multiple decoupling points "case number 12" total cost is 5888 and cost of the ATO "case number 11" with single decoupling point between manufacturing and assembly system is 7320, saving amount 10.96, which results in 11% improvement approximately.

At different decoupling points total cost occurring for product A is shown in above Table 4. The production time varies with the change of decoupling points and delivery lead time as shown in column 3 and 5. The cost of the product is reduced with the application of HMSCS, as

Table 4: Total Cost and Safety Stock Cost at Decoupling Points

Case Type	Environment Type	Production Time	Critical Path	Decoupling Point	Safety Stock (SS)	Total Cost (TC)
Case 1	**MTO**	**46**	**C1 A2 A1 A**	**1 1 1 1 1 1 1 1 1 1**	**00**	**2700**
Case 2	Hybrid	32	C2 A2 A1 A	0 1 1 1 1 1 1 1 1 1	1600	5090
Case 3	Hybrid	27	C3 A3 A1 A	0 0 1 0 1 1 1 1 1 1	1520	5477
Case 4	Hybrid	29	P1 A1 A	0 0 0 1 1 1 1 1 1 1	2640	5453
Case 5	Hybrid	24	P2 A	0 0 0 0 1 1 0 0 1 1	4160	5763
Case 6	Hybrid	25	P1A3A	0 0 0 0 1 1 1 1 1 1	3200	5779
Case 7	Hybrid	20	A2A3A	0 0 0 0 0 0 0 1 1 1	6240	7993
Case 8	Hybrid	14	A3A	0 0 0 0 0 0 0 0 1 1	6720	8138
Case 9	Hybrid	09	A	0 0 0 0 0 0 0 0 0 1	7120	8203
Case 10	MTS	00	00	0 0 0 0 0 0 0 0 0 0	7840	8470
Case 11	Hybrid (ATO)	25	P1A3A	0 0 0 0 0 0 1 1 1 1	5280	7320
Case 12	Hybrid (ATO)	25	P1A3A	0 0 0 0 1 1 1 1 1 1	3200	5888
Case 13	Hybrid (ATO)	46	C1A1A3A	1 1 0 0 1 1 1 1 1 1	1920	6224
Case 14	Hybrid (ATO)	29	C4A2A3A	0 0 1 1 1 1 1 1 1 1	1920	5126

mentioned in case 4 and this leads to improvement as in Case 14 of the above Table 4.

Although delivery lead times play important in the selection of types manufacturing environment with decoupling points but there are also other factors like demand variation, characteristic of parts etc which may affect selection of the type of environment with feasible decoupling points. The change in demand of the product changes the environment selection which leads to change in cost. The characteristics of parts some times over rule the criteria of minimum cost of the supply chain for selection of decoupling points.

Although the proposed model seems to be useful but it involves too many inputs and data, shown in tables which can impede its easy use. However, if a data base of all the relevant data required for cost calculation is maintained, not only the inputs could be a matter of one command and can improve its application to real world problem but the database will also play effective role in MRP problems. Hence the proposed cost model seems to be useful in developing a detailed methodology which should include other factors like characteristics of parts and demand variation for material planning and scheduling of Hybrid Manufacturing Supply Chain Systems.

CONCLUSION

The manufacturing and delivery lead times are the two main important factors where manufacturing firms need to play around for maximizing benefits. While negotiating delivery lead times with the customers, the manufacturers would need an handy tool for costing of the manufacturing order to make a best deal with best possible profits. The proposed model for costing of the HMSCM is quite helpful to generate hypothetical manufacturing scenarios with their corresponding costs which is really helpful in decision making processes of delivery lead times with the given constraints of space and budget.

The usefulness of the proposed model was elaborated through an example for a typical Product A where costs have been calculated for different scenarios with multiple decoupling points. The values of costs obtained for the product clearly identify that there could be upto 70% saving from moving pure MTS to MTO environment which is quite logical. Similarly, the benefits of multiple of decoupling points over a single decoupling point have been shown in a case where about upto 13% saving can be obtained for the same delivery lead time.

Future Recommendation

The application of the proposed model necessitates a tool to retrieve the required inputs for cost calculation of the HMSCS. MRP systems can be developed which will not only help calculate the cost of HMSCS quickly but also help doing planning and scheduling of material requirement for any given BOM for a product.

The proposed model can be integrated to a comprehensive methodology where other factors like demand variation and characteristics of part, important for consideration of decoupling points, could be incorporated for more realistic interface for the hybrid system.

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1-A.1 HYBRID SYSTEM FOR PRODUCT A OF ABC COMPANY

Total cost of product A of ABC company

Total Cost = Supply Chain Cost + Production Cost (For product A)

= Cost of MTO + Cost of MTS + Production Cost

Total Cost = Supply Chain Cost + Production Cost (For product A)

= Cost of MTO + Cost of MTS + Production Cost

= (Si + SOi + Ii + Ai) + CInv + CDLT

Cost for MTO = Si

Cost for MTS = Si / √(2xSi/h D)+Oi + Ii + Ai

Production Cost = (SS + Kanban + WIP) + CDLT

Estimated costs provided by the company

Demand Rate D for product A (Unit/Time) D = 80

Setup Cost of product A Si = 2500

Delivery Lead Time cost of product A CDLT = 52

Inventory holding cost of product A h =5

WIP (work in process) of product A (Cm+Cp/2) = 45

Order Interval Cost Oi = 80

Storage Cost Ii = 120

Asset specify cost Ai = 10% of 3330

For Case 1 (1 1 1 1 1 1 1 1 1 1)

Ltotal = 0

Lmax = 46

Inventory holding Cost = 0

Supply Chain Cost (MTO) = 2500

Supply Chain Cost (MTS) = 0

Production Cost = (SS + Kanban + WIP) + CDLT

= (D Ltotal + D Lmax (1+ α) / C + (Cm + CP/2) h DT + CDLT

= (D x 0 + D x 46 (.11)/ 25 + (Cm + CP/2) x 0 x DT

= 80 x 0 + 80 x 46 (0.11) /25 + 52

= 200

Total Cost = 2500 + 200 = 2700

For Case 2 (0 1 1 1 1 1 1 1 1 1)

Ltotal = 20

Lmax = 30

Inventory holding Cost = 4

Supply Chain Cost (MTO) = 2250

Supply Chain Cost (MTS) = 2250 / √(2x2250/4x 80) + 80 + 120 + 10% of 3330

= 1133

Production Cost = (SS + Kanban + WIP) + CDLT

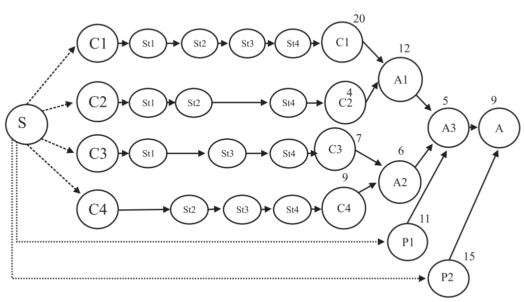
= (D Ltotal + D Lmax (1+ α) / C + (Cm + CP/2) h DT+ CDLT

= (D x 20 + D x 30 (0.11)/ 25 + (Cm + CP/2) x 0 x DT+ CDLT

Table A-1.1 Relationship between Delivery Lead Time and Position of Decoupling Points

Case Type	DLT	Critical Path	Decoupling Points	Lmax (Pull system lead time)	Ltotal (Push system lead time)
1	**46**	**C1 A2 A1 A**	**1 1 1 1 1 1 1 1 1 1**	**46**	**00**
2	32	C2 A2 A1 A	0 1 1 1 1 1 1 1 1 1	30	20
3	27	C3 A3 A1 A	0 0 1 0 1 1 1 1 1 1	27	33
4	29	P1 A1 A	0 0 0 1 1 1 1 1 1 1	29	31
5	24	P2 A	0 0 0 0 1 1 0 0 1 1	25	52
6	25	P1A3A	0 0 0 0 1 1 1 1 1 1	26	40
7	20	A2A3A	0 0 0 0 0 0 0 1 1 1	20	78
8	14	A3A	0 0 0 0 0 0 0 0 1 1	14	84
9	09	A	0 0 0 0 0 0 0 0 0 1	09	89
10	00	00	0 0 0 0 0 0 0 0 0 0	00	98
11	25	P1A3A	0 0 0 0 0 0 1 1 1 1	26	66
12	25	P2A3A	0 0 0 0 1 1 1 1 1 1	25	40
13	46	C1A1A3A	1 1 1 1 1 1 1 1 1 1	46	00
14	29	C4A2A3A	0 0 1 1 1 1 1 1 1 1	29	24

1-A.1.2 Total cost of product A of ABC company for product A against feasible decoupling points



1-A.1.1 Process Plan Network Diagram for the Product A

= 80 x 20 + 80 x 30 (0.11) /25 +45 + 52 + 333

= 1707.6 + 1133 + 2250

Total Cost = 5090

For Case 3 (0 0 1 0 1 1 1 1 1 1)

Supply Chain Cost (MTO) = 1750

Supply Chain Cost (MTS) = 1750/√ (2x1750/4x 80) + 80+ 120 = 626.15 + 333

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 33 &Lmax = 27

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 33 + 80x 27 (0.11)/ 25 + 45 + 52

= 2746.5 +1750 + 626.15 + 333

Total Cost = 5477

For Case 4 (0 0 0 1 1 1 1 1 1 1)

Supply Chain Cost (MTO) = 1750

Supply Chain Cost (MTS) = 1750 / √ (2x1750/4x 80) + 80+ 120 = 623.8 + 333

= 956.8

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 30 &Lmax = 27

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= 80 x 33 + 80x 27 (0.11)/ 25 + 45 + 52

= 2640 +9.5 + 45 + 52

Total Cost = 2746.5 + 1750 + 956.8

Total Cost = 5453.3

For Case 4 (0 0 0 0 1 1 0 0 1 1)

Supply Chain Cost (MTO) = 1000

Supply Chain Cost (MTS) = 1000 / √(2x1000/4x 80) + 80 + 120 = 497

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 52 &Lmax = 25

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 52 + 80x 25 (0.11)/ 25 + 45 + 52

= 4160 + 105.8

= 4265.8

Total Cost = 4265.8+1000 + 497

Total Cost = 5762.8

For Case 5 (0 0 0 0 0 0 0 1 1 1)

Supply Chain Cost (MTO) = 750

Supply Chain Cost (MTS) = 750 / √ (2x 750/4x 80) + 80 +120 + 10% of 3330 = 879.41

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 78 &Lmax = 20

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 78 + 80x 20 (0.11)/ 25 + 45 + 52

= 6344

Total Cost = 6344+750+879.45

= 7973.45

Total Cost = 7973.45

For Case 6 (0 0 0 0 1 1 1 1 1 1)

Supply Chain Cost (MTO) = 1500

Supply Chain Cost (MTS) = 1500 /√(2x 1500/4x 80) + 60 +90 + 10% of 3330

= 489.89 + 150 + 333 = 972.89

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 40 &Lmax = 26

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

Table A 1.2: Characteristic Table of Product A

S. No	Properties of Parts	Purchase Part P1	Purchase Part P2	Mfg Part C1	Mfg Part C2	Mfg Part C3	Mfg Part C4	Sub Assy A1	Sub Assy A2	Sub Assy A3
1	**Shelf Life**	**01 Month**	**03 Months**	**06 Years**	**06 Years**	**06 Years**	**06 Years**	**06 Years**	**06 Years**	**06 years**
2	Battery Based	No	Yes	No	No	No	No	No	No	No
3	Coating Type	Silver Plating	Nil	No	No	No	No	No	No	No
4	Material Type	Glass	Mg Alloy	Al	Al	Steel	Al	Steel	----	-----
5	Design Variation	Average	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Maximum
6	Storage Conditions	Vacuum Jar	Store	Store	Store	Store	Store	Store	Store	Store

Table A-4.3 Grouping of Parts into Cells for Information Sharing

Action	Group A	Group B	Group C
	A A1 A2 A3 P1 P2	**C1 C2**	**C3 C4**
Information Sharing	Real Time	Real Time	At different levels
	27	C3 A3 A1 A	0 0 1 0 1 1 1 1 1 1
Suppliers	29	P1 A1 A	0 0 0 1 1 1 1 1 1 1
	Low delivery lead time	Low delivery lead time	Low cost
Customer Interaction	Shared	Shared	As per requirement

= (80 x 40 + 80x 26 (0.11)/ 25 + 45 + 52 =

= 3306

Total Cost = 3306+ 972.89 + 1500

Total Cost = 5779.042

Case 7 ATO (0 0 0 0 0 0 0 0 1 1)

Supply Chain Cost (MTO) = 500

Supply Chain Cost (MTS) = 500 / √(2x 500/4x 80) + 80 +120 + 10% of 3330 = 815.84

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 84 &Lmax = 14

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 84 + 80x 14 (0.11)/ 25 + 45 + 52

= 6821

Total Cost = 6822 + 500+815.84

Total Cost = 8137.768

Case 8 ATO (0 0 0 0 0 0 0 0 0 1)

Supply Chain Cost (MTO) = 250

Supply Chain Cost (MTS) = 250 /√(2x 250/4x 80) + 80 +120 + 10% of 3330 = 733

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 88 &Lmax = 9

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 89 + 80x 9 (0.11)/ 25 + 45 + 52

= 7140.168

Total Cost = 7140.168 + 250 + 733

Total Cost = 8203.68

Case 9 MTS (0 0 0 0 0 0 0 0 0 0)

Supply Chain Cost (MTO) = 0

Supply Chain Cost (MTS) = 0 / √(2x 0/4x 80) + 80 +120 + 10% of 3330 = 533

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 98 &Lmax = 0

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 98 + 80x 0 (0.11)/ 25 + 45 + 52

= 7937

Total Cost = 7937 + 533 = 8470

Case 10 ATO (0 0 0 0 0 0 1 1 1 1)

Supply Chain Cost (MTO) = 1000

Supply Chain Cost (MTS) = 1000 / √(2x 1000/4x

Table 1- A.4: Safety Stock for Push system, Feasible DP's and Total Cost

Case	Environment Type	Production Time	Critical Path	Decoupling Point	Safety Stock of Push System	TC (Total Cost)
Case 1	**MTS**	**46**	**C1 A2 A1 A**	**1 1 1 1 1 1 1 1 1 1**	**00**	**2700**
Case 2	Hybrid	32	C2 A2 A1 A	0 1 1 1 1 1 1 1 1 1	1600	5090
Case 3	Hybrid	27	C3 A3 A1 A	0 0 1 0 1 1 1 1 1 1	1520	5477
Case 4	Hybrid	29	P1 A1 A	0 0 0 1 1 1 1 1 1 1	2640	5453
Case 5	Hybrid	24	P2 A	0 0 0 0 1 1 0 0 1 1	4160	5763
Case 6	Hybrid	25	P1A3A	0 0 0 0 1 1 1 1 1 1	3200	5779
Case 7	Hybrid	20	A2A3A	0 0 0 0 0 0 0 1 1 1	6240	7993
Case 8	Hybrid	14	A3A	0 0 0 0 0 0 0 0 1 1	6720	8138
Case 9	Hybrid	09	A	0 0 0 0 0 0 0 0 0 1	7120	8203
Case 10	Hybrid	00	00	0 0 0 0 0 0 0 0 0 0	7840	8470
Case 11	Hybrid (ATO)	25	P1A3A	0 0 0 0 0 0 1 1 1 1	5280	7320
Case 12	Hybrid (Dyed)	25	P1A3A	0 0 0 0 1 1 1 1 1 1	3200	5888
Case 13	Hybrid (Dyed)	46	C1A1A3A	1 1 0 0 1 1 1 1 1 1	1920	6224
Case 14	Hybrid (Dyed)	29	C4A2A3A	0 0 1 1 1 1 1 1 1 1	1920	5126

80) + 80 +120 + 10% of 3330 = 933

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 66 &Lmax = 26

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 66 + 80x 26 (0.11)/ 25 + 45 + 52

= 5386.152

Total Cost = 6822 +933+1000

Total Cos = 7319.152

From above table it is evaluated that purchased parts P1, P2 are MTO based on the coating type, shelf life and power loses, whereas A3 is MTO due to frequent design changes.

Low Level Codes of Product 'A'

Level 0	A
Level 1	A1 A2 A3 P2
Level 2	C1 C2 C3 C4 C6
Level 3	C5

Case 12 Hybrid Manufacturing Supply Chain (0 0 0 0 1 1 1 1 1 1)

Supply Chain Cost (MTO) Setup Cost = 1500

Supply Chain Cost (MTS) setup Cost = 1500 / √ (2x 1500/4x 80) + 80 +120 + 10% of 3330

= 1031.5

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 40 &Lmax = 26

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 40 + 80 x 26 (0.11)/ 25 + 45 + 52

= 3306

Total Cost = 3306 + 1031.5 = 4337.5 + 1500

Total Cost = 5887.5

Case 11 Hybrid Manufacturing Supply Chain (0 0 1 1 1 1 1 1 1 1)

Supply Chain Cost (MTO) Setup Cost = 2000

Supply Chain Cost (MTS) setup Cost = 2000 / √ (2x 2000/4x 80) + 80 +120 + 10% of 3330

= 565.68 + 200 + 333 = 1065

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 29 &Lmax = 24

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 24 + 80 x 29 (0.11)/ 25 + 45 + 52 =

= 1920 + 107.2

= 2027.2 + 1098.7

Total Cost = 3125.9 + 2000 + 1098.7 = 6223.9

Case 12 Hybrid Manufacturing Supply Chain (1 1 0 0 1 1 1 1 1 1)

Supply Chain Cost (MTO) Setup Cost = 2000

Supply Chain Cost (MTS) setup Cost = 2000 / √ (2x 2000/4x 80) + 80 +120 + 10% of 3330

= 565.68 + 200 + 333 = 1065

Production Cost = (SS + Kanban + WIP) + CDLT, Ltotal = 24 &Lmax = 29

= (D Ltotal + D Lmax (1+α)/ C + (Cm + CP/2) h DT + CDLT

= (80 x 24 + 80 x 29 (0.11)/ 25 + 45 + 52 = 1920 +105.45

= 1920+ 107.2

Total Cost = 2027.2 + 1098.7

Total Cost = 5125.9