

# Building a Supply Chain Network for Manufacturing of Steel Columns

By

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## Abstract

Product design is a process of creating a new product by a manufacturing firm or a business organization for its customers. It's very important that an utmost effort to be made at this stage to avoid problems faced by the organization in the near future. This project makes use of process improvement technique like DMADV for analyzing the manufacturing processes which could be used for these product designs and estimation of manufacturing costs. The define phase utilizes some quality tools to identify all the elements which are going to be part of these product designs supply chain and also the customer requirements. This project also estimates the manufacturing costs of these product designs by roughly establishing the parameters required to estimate these costs. Inventory models for different types of inventories are also analyzed in this project. In the design phase, simulation models are built for the inventory and the production process. The results of these simulation process are verified to check the ability of the design to meet the process goals in the span of 300 days.

## **Acknowledgement:**

I would like to express my deepest gratitude and appreciation to all those who provided me the wonderful opportunity to do this project. Firstly, I am very thankful to Dr. Baruch Saeed, who is my project advisor, for suggesting and encouraging me to take up this project at Spartan Superway. I also want to thank him for his guidance, encouragement and excellent suggestions that have contributed immensely to develop my idea on the project.

A special gratitude I give to the Spartan Superway Project coordinators Ron Swenson, Buff Furman and Eric Hagstrom for giving me an opportunity to do this project for their team. Furthermore, I am also thankful to them for providing me resources, guidance and support for the completion of this project. Lastly, I would thank my family and friends for giving me constant support through the duration of the project,

## Chapter 1: DEFINE

The goals of this first phase of the DMADV Methodology are to identify the purpose of the project, to identify and then set realistic and measurable goals as seen from the perspectives of the project, to create the schedule and guideline for the review and to identify potential risks.

### Problem Statement:

Spartan Superway is an interdisciplinary project at San Jose State University whose main goal is to build a sustainable personnel mobility system for Silicon Valley. It consists of a pod car moving along the guideway. These pod cars utilize solar energy through solar cells to power along the guideway. This project focusses mainly on the manufacturing of the steel columns which support this guideway structure. Here the Spartan Superway is trying to decide between the two guideway column designs according to their manufacturing costs and feasibility of the supply chain design.

The two steel pole designs are:

- 1) Beamway Columns
- 2) Milotek Columns

## Mission Statement:

The main goal of this project is to build a supply chain model for the manufacturing of the Beamway columns from the product design. This consists of determining of different manufacturing techniques used to produce these beamway steel columns and conducting a discrete event simulation for manufacturing process of this design. The other main objective is run a cost a cost analysis of the two designs and determine the most feasible and cost effective among the two. This consists of estimating manufacturing costs of the two designs through ABC cost modeling and concluding which would cost the least if manufactured.

## Project Charter:

**Background:** Spartan Superway aims to design a sustainable personnel mobility system for Silicon Valley using renewable resources. This mobility system consists of a pod car which moves along a guideway using Solar Energy. This project focuses mainly on the columns that support the guideway. There are two different types of columns designs which can be implemented, they are:

- Beamway Columns
- Milotek Columns

**Purpose:** The main purpose of this project is to construct a supply chain network design for the Guide way columns. The other aim is to run a cost analysis to determine the Manufacturing costs for different column designs and do a comparison to determine a cost effective design.

**Scope:** This project is expected to determine cost effective and quality driven approaches to construct the supply chain network for the Guide way columns. The main focus areas include:

- Research on the procurement of raw materials for the two guideway column designs from different suppliers.
- Analyze different manufacturing techniques which can be used for the assembly and fabrication of the guideway columns. Determine the best and cost effective methods.
- Calculate the manufacturing costs of Beamway columns and Milotek Columns. Compare the two designs and determine which cost the least.

**Deliverables:**

- Project Duration: - 2 months
- Estimation of the Manufacturing Costs for Guideway Columns (Milotek and Beamway)
- Determine the Least Costing Design
- DMADV approach is used to determine the most suitable and cost effective strategies.

**Measurable:**

- Cost Estimation in Dollars
- Estimation of Manufacturing time in minutes.

**Resources:**

- Project carried out by Harshavardhana Reddy
- Spartan Superway Management team: Ron Swenson, Buff Furman, Eric Hagstrom
- Advisor at San Jose State University: Professor Baruch Saeed



## Introduction:

The supply chain of the manufacturing of steel columns can be structured into many different elements. In the following pages the relationship between these elements is established. The main elements of this supply chain structure which are discussed in detail in this project are Suppliers, manufacturing and Storage (Inventory). The steel sheets for both the columns designs can be procured by steel suppliers from different locations. The procurement costs related to these activities play a vital role in estimating the manufacturing costs per steel columns. This chain is generally characterized by the forward flow of this raw material and backward flow of information namely in this case the quoted price from different supplier. This material flow and information flow is established in the following pages of this document. The next element in this supply chain structure is the manufacturing of these steel columns. The complexity in the design for the milotek columns makes it more difficult to manufacture than the Beamway columns. The forward flow of materials in this supply chain element is the processed steel columns through different machines and the backward flow of information are the process times, utilization, Work in process (WIP), productive hours, labor costs, setup costs, setup times and setup costs. The elements of this manufacturing information flow are calculated and also collected from the simulated results in the later part of this project. The last element of the supply chain structure that we will look into in this project is Storage. This storage element consists of steel sheet inventory and finished steel column inventory. The forward material flow in this element is further divided into two parts. The first part is the flow of steel sheets from the supplier to the warehouse where it is held until required for production. Optimum inventory levels that trade off both the holding costs and purchasing costs are determined theoretically in the following pages. Constant demand rate is assumed for the steel sheets so to satisfy the production demand which in turn satisfies the customer demand. Hence Economic order quantity is calculated to replenish the inventory when the inventory level is zero. For

the simplicity of the inventory modeling, planned storage is now allowed and reorder points can be equal to the lead time demand. The lead time to replenish the inventory given by the supplier in this case is estimated to about 1 week. The second part of the material flow is the flow of finished steel columns from the last workstation to the warehouse where it is stored until it is shipped to the guideway construction site. The Economic Production Quantity model can be used in this project to establish the optimum inventory levels for these finished steel columns and constant customer demand is assumed. Scenarios with different inventory levels can be simulated to obtain the optimal inventory level that minimizes the amount of inventory lost and number of times the inventory is not met the demand. The backward flow of the information in this storage element consists of holding costs, ordering costs, setup costs, eoq, epq, re-order point, cycle time, target stock of inventory, amount lost and customers lost. These parameters are to established in the later part of this project research.

### **SIPOC Analysis:**

SIPOC Analysis is used to identify all relevant elements of particular project before the work begins. It helps to define a complex project that may not be well scoped and would be typically employed at the Define Phase of the DMADV methodology.

Here the SIPOC analysis is used to study the supply chain of the Beamway column design, Beamway columns would be made of Low Carbon Steel and sheet metal will be used to manufacture these columns.

Low carbon Sheet metal distributors and Manufacturing Equipment distributors were identified as Suppliers.

Machines and equipment required for manufacturing, Sheet Metal plates were identified as Inputs for the Manufacturing process.

The manufacturing process which turns raw sheet metal into galvanized steel pole is mentioned below in different steps.

The finished products from the different process steps are identified as outputs.

Suppliers	Input	Process	Output	Customers
Sheet Metal Suppliers	Sheet Steel Square Plates	Sheet metal is shipped to the production facility	Flattened Sheet metal	Cutting Team
De-coiler Manufacturing	De-coiling Machines	A shear cutter cuts the sheets into appropriate sizes.	Sheet Metal with Appropriate Size	Bending team
Cutting Department	Press Brakes	Bending machine called the Press Brake is used to bend the flat steel into Multi round poles..	Multi Sided Round Poles	Welding team
Bending Machine	Measuring Devices	Hydraulic rollers apply pressure and the pole is welded.	Welded Steel Poles	Inspection Team
	Shear Cutter	Then a square plate is welded to the bottom of the pole.	Pole with a base plate	Spartan Superway

Gauge Suppliers	FCT devices	Inspection is done for identifying defects.	Inspected poles	
		Galvanizing is done.	Galvanized Poles	

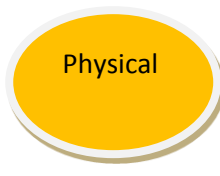
*Table 1 – SIPOC analysis*

The steel sheets which are going to be used to manufacture these steel columns are procured from different suppliers. The Beamway columns which are made of low carbon steel get the sheets from one of the two suppliers located here in the Bay Area. The steel sheets and square plates are transferred to the production facility warehouse and these are identified as inputs to the production process. Then this rolled sheet metal is transferred to the de-coiler machine and the output is Flattened sheet metal. Then this sheet metal can be transferred to cutting team who can be identified as customers who receive these sheets. Then with the help of shear cutter and laser cutter the flattened steel sheet (which is the input to this process) can be cut into appropriate sizes. Then the sheet metal with appropriate dimensions is transferred to the bending team who can be identified as customers for this particular process. The press brake is used to bend the sheet into a cylindrical column using measuring devices to measure the angle at each bend. These multisided round columns (output) are then transferred to the customers who are in this case the welding team. Then these multisided round columns are then welded at the edges using seam welding techniques. The welded round metal columns are then transferred to the inspection team (customers) where they can be inspected for possible defects using FCT devices as inputs and gauge suppliers.

## **VOC (VOICE OF CUSTOMERS):**

The Voice of Customers (VOC) is a product development technique that produces a detailed set of customer wants and needs which are organized into hierarchical structure, and then prioritized in terms of relative importance. Here this strategy provides key inputs for the setting of appropriate detail specification for these new product column designs.

The Customers were identified from the SIPOC Methodology. Interviews were conducted with the Spartan Superway Design and Management team. Customer Specific needs required for the manufacturing of these new column designs were obtained from these interviews. Steel pole manufacturing process was analyzed and the end customer needs were identified from these process. These customer needs were divided into separate categories based on the type of value they add to manufacturing of new steel designs design and they are listed below.



Steel Poles should have low  
Overall costs

Low labor costs

Should have low handling  
costs

Low shipping costs

Low storage costs

Pole should not vary in dimensions

Tight tolerance

Poles should be light

Steel Pole geometry should not  
Vary with seasons

Corrosion protected

Low carbon steel

Stenex 700 steel

Recycled steel

Strong concrete

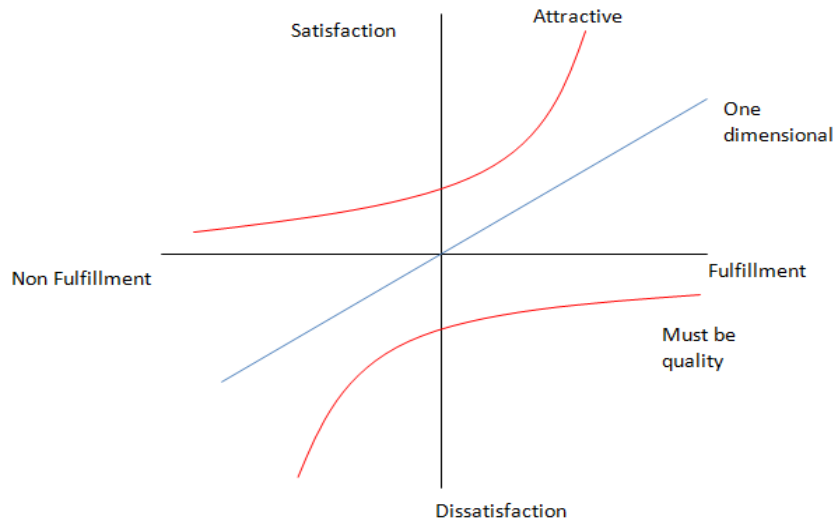
The next step of this VOC is to arrange these above customer needs into hierarchy of primary, secondary and tertiary needs. This can be paired with the Kano Analysis to go more into detail the expectations of the customers.

## **KANO Analysis:**

As mentioned above the KANO Analysis categorizes customer requirement into the following categories:

1. **Must be (Primary needs):** Expected features for these column designs. If these needs are not fulfilled it will lead to dissatisfaction of the customer and if fulfilled it will not lead to satisfaction. They are listed in the table below.
2. **One Dimensional (Secondary needs):** The more of these needs are met more the customers would be satisfied. They increase or decrease satisfaction. In this case most of the customer needs are one dimensional.
3. **Attractive (Tertiary needs):** These are unexpected needs. If fulfilled it will lead to high satisfaction of the customers but if the needs are not fulfilled it will not lead to dissatisfaction. They are listed below in the table.

## KANO Model



*Figure 1-Kano Satisfaction model (Source 10)*

## Kawakita Jiro (KJ) Analysis:

KJ analysis allows to quickly reach a consensus on priorities of subjective and qualitative data. In this analysis the above mentioned customer needs can be categorized into different groups based on the difficulty in manufacturing these columns designs. All the needs can then be identified whether they are NEW, UNIQUE, STANDARD or DIFFICULT.

Customer Need Statement	KJ Analysis	Kano Analysis
1)Poles should not vary in dimension	S	Must be



2)Poles should be lightweight	S	One Dimensional
3)Steel Poles geometry should not vary with seasons	U	One Dimensional
4)Poles should be corrosion protected	U	Must Be
5)Poles should be stiffer	S	One Dimensional
6)Low Labor costs	S	One Dimensional
7)Poles can be made of Recycled steel	U	Attractive

8)Poles can handle heavy load	D	One Dimensional	S-
9)Concrete in the Milotek columns should be strong.	D	One Dimensional	
10) Poles should have tight tolerances	S	Must Be	

**Standard, D-Difficult. U-Unique**

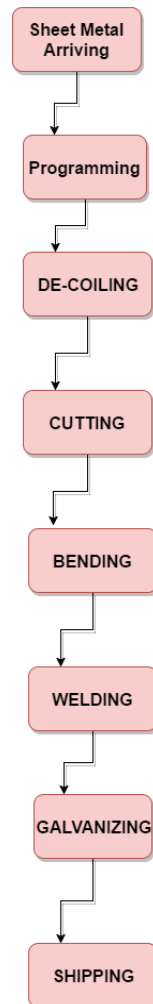
*Table 2 – KJ and KANO Analysis*

The poles should not vary in dimensions is identified as a must be customer needs in kano analysis. The poles should be fabricated according to standard dimensions for each pole. If the dimensions vary from pole to pole, this will cause problems when attaching them to the guideways. This customer need can be met by using standard techniques which is identified in KJ Analysis. The poles should be lightweight is identified as one dimensional customer needs. The weight of the poles can cause some problems in erecting and transportation but not meeting this need will not stop the process like the dimension needs. The KJ analysis identifies meeting this need as not difficult. The corrosion protected needs can be identified as Must be needs in the KANO Analysis. The poles must be corrosion protected for longer durability and to eliminate rust and this need makes use of unique methods like galvanizing, coating, enameling and copper plating. Low labor costs are a desired customer need; hence it is one dimensional. The methods which can be used to reduce the labor costs are not difficult to implement.

## Chapter 2: Measure Phase

The Measure Phase is the second phase of the DMADV Methodology and it focusses on the recording and collection of the data that could be relevant to the Critical to Quality (CTQ) measures that were identified during the define phase. The data which would be collected during the measure phase is vital to the process and it would be used to move the rest of the methodology forward.

**Understanding the Workflow:** Before calculating the manufacturing costs of the column, we have to understand the work flow for these columns. Here is the typical work flow for Steel column manufacturing (Common for Both).



*Figure 2-Process Flowchart*

*De-Coiling: Rolled sheet metals can be flattened using the De-Coiler.*

- **Cutting:** Laser cutting can be used to obtain precise measurements on the cuts and it saves time.
- **Bending:** Press brake can be used to bend the metal into cylindrical shape.
- **Programming:** If solid work model is provided, programming time is saved.
- **Welding:** Seam welding can be used to join the ends of the cylindrical sheet. MIG or TIG Seam Welding can be used.
- **Galvanizing:** The finished and Inspected columns can then be dipped in Sulfuric Acid and Molten Zinc.
- **Shipping:** More packaging time would be needed if cosmetics are important.

### **Cost Estimation:**

The key components of Steel Column Production quote are material, labor, services and overhead. The costs can be transferred among categories depending on the cost, quality and lead time targets required for the production process. Cost estimation would be focal point for design and manufacturing strategies and will be an important agenda for business and technical decision. In this case the cost estimation

strategy is primarily based on the comparison analysis of the new column designs with the similar products that have been manufactured previously in order to analyze the similarities in the new ones. The costs in the flowing sections are rough estimates of the actual costs.

**Materials:** The materials included in this category are raw materials like sheet metal plates which can be flattened using the De-Coiler. The other raw materials also include purchased materials such as bolts, nuts, gaskets and other components purchased along the sheet metal which is shipped to the production facility. Some raw materials might require packaging and the materials section would include packaging material in the overhead costs category. Welding machine tooling, cutting machine tooling, press brake tolling and some of the general production supplies such as machine oils, machine coolant, boards could be overhead costs. Other costs could include some of the hidden material costs like in-bound shipping costs. These costs can be included in the quoting the price of the material. Galvanizing agents Sulphur acid and Molten Zinc can also have categorized into overhead material costs.

### **Steel Costs:**

**Beamway Columns:** The Beamway columns can be made of low carbon steel like ASTM A-36 steel or Cold Rolled Steel. Sheet Metal of thickness of .6 mm and 9.12 m in length can be used for this purpose. The Quoted price for A-36 carbon steel from two different steel suppliers based in the Silicon Valley is given below.

Supplier 1: Price for Steel Sheet of dimensions 70\*300 inches and weight 319 lbs.: \$489/sheet

Shipping Costs: \$8/sheet

Supplier 2: Price of Steel Sheet of dimensions 70\*300 inches and weight 330 lbs.: \$523/sheet

Shipping Costs: \$10/sheet

**Milotek Columns:** The Milotek Columns can be made of made Cold Forming steel like Domex 700 W. Sheet metal thickness of thickness 3mm and 8m in length can be used for this purpose. The Quoted price for Domex Steel from a supplier based in Iowa is given below:

Domex Steel Supplier: Price of Steel Sheet of dimensions 50\*315 inches (w\*l) and weight 400 lbs.: \$584.32/sheet

**Labor:** The direct labor costs are the total costs of manufacturing laborers who work directly on the steel columns being manufactured. Indirect labor would be the cost assigned to run the business. The direct labor costs were estimated for each involved in both the steel column manufacturing designs.

**Direct Labor costs:**

1. **Programming Labor Costs:** The sheet metal parts should be programmed for machines running in the shop by CNC programming. Important variables in estimating these variable costs would be part complexity and que time.

Typical wages for a CNC Machine Programmer: \$29.42/hr

Work hours: .2/unit

2. **Cutting Labor Costs:** Laser cutting can be used to cut the sheet metal into precise measurements. The Laser cutting eliminates the machine setup time. The laser cutting is the method is a choice for a high-mix production and it should be low-volume. The CNC programming costs for the Laser machine is already included in Programming costs

Cutting Operator Wages: \$15.54

Work Hours for Milotek: .10/unit

Work hours for Beamway: .20/unit

3. **Welding Labor Costs:** Seam Welding techniques like Tungsten Inert Gas Welding (TIG) and Metal Inert Gas can be used for this process. In welding the manufacturing process times can be governed by the fabricator skills and not machine speed.

Typical Welding wages: \$20.66/hr

Work Hours for Milotek: .35/unit

Work Hours for Beamway: .25/unit

4. **Bending Labor Costs:** Bending is done on a press brake and it presses the sheet on a marked line in a pre-programmed angle. The pre-programmed angle is set by the operator by looking at the design. These machine operators will look at the blueprints, path of the cut in the sheet metal and material feed, setting up of machines and they would perform periodic check on the output.

Press Operator Wages: \$17.48/hr

Work Hours for Beamway Columns: .10/unit

Work Hours for Milotek columns: .15/unit

5. **Galvanizing and Concrete Filling Labor Costs:** The Steel columns with the welded base plate in the bottom will be now shipped to the Galvanizing plant where they dipped in wash tanks containing molten zinc. Concrete is filled in the milotek columns to make them look sturdy.

Galvanizing Labor wages: \$18.8/hr

Concrete Filling Labor wages: \$13.81/hr

Galvanizing Labor hours: .30/unit

Concrete Labor hours: .10/unit

**Overhead Costs:** Overhead manufacturing costs are costs that are estimated other than direct labor and direct material costs. These costs are called indirect costs because they do not add value directly to the



production of the steel columns like the other costs. There are two types of overhead costs, Fixed and Variable overhead costs. Variable costs depend on amount of columns being produced. Here in this case only fixed costs are estimated because we are in initial design stage and there is no production.

Mortgage/Rent:	\$ 223500/yr.
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Machine Depreciation costs	\$ 4791.73/yr.
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(Taking the Initial costs of Press Brake,  
TIG Welding, Laser Cutter  
and De-Coiler is taken  
into consideration)

Average Electricity costs (Industrial)	\$ 22000/yr.
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Management (Supervisor salary)	\$74136/yr
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## Chapter 3: Analyze

At this stage, the proposed product designs or manufacturing process are analyzed to identify whether there are better ways in achieving the results. Areas that need improvement in product design or manufacturing processes of making these products are determined. Here in this project the parameters which were collected in the measure phase are studied in detail in the analyze phase.

### Supply chain Operations Reference model (SCOR):

The SCOR model is a supply chain frame work, linking the business processes, practices, performance metrics, supply chain practices and people skills into a unified structure. It increases the speed of an organizations system implementation, it supports learning goals of an organization and also helps in improving the inventory. The SCOR model links the process elements, best practices and the features linked to the supply chain execution in a unique framework. This framework focusses on the framework involved not the people who perform these activities. In this project, the SCOR model is conceptualized as a hierarchical framework with different levels of element.

The Level 1 elements involved in this process are:

- 1) **Plan:** Demand and Supply Chain Planning are included in this step. In this case there is a requirement of 600 Steel columns of either of the designs to be manufactured in order to build a test track. This could be the demand and duration would be 6 months assuming constant demand every month.

- 2) **Source:** This step would describe the sourcing framework and material acquisition. It explains how to manage inventory levels, the network of the supplier, supplier performance and agreement with the supplier. In this project, the activities involved in procurement of low carbon steel for the Beamway columns and Domex Steel for Milotek columns come under this sourcing frame work. The activities might include, getting a quote from the supplier, handling the supplier payments and time and duration of the raw material transfer.
- 3) **Make:** This step includes all the manufacturing processes like which are involved in making the steel columns like cutting, bending, galvanizing and welding. It identifies whether the manufacturing is make to order or make to stock. It also involves maintenance of machines to ensure the production is running smoothly without bottlenecks due machine breakdown. Facility maintenance through lean techniques like 5s is also included.
- 4) **Deliver:** This step includes the processes that would provide the finished products or services to meet the forecasted or actual demand and it typically includes the transportation management, order management and distribution management. Delivery activities of these steel columns consists of processing customer quotes and inquiries, receiving and entering the customer orders from the guideway team, holding of the finished column inventory in the warehouse for specific orders and scheduling of delivery is done, select transportation carrier based on the shipping rates, material moving by the carrier to the guideway construction site.

5) **Return:** This process describes the activities related with the reverse flow of goods from the customers. The return activities typically include the identification of reason for the return, the scheduling of the return, transportation and preparing receipts for these return goods. The defective steel columns are returned to the source which in this case is production facility. The source or make activities are then initiated by these defective steel columns return. Deliver return activities include authorizing the defective steel column return, managing the return inventory and receiving and verification of these defective steel columns.

The above mentioned core processes can be further divided into elements on the second level of the Supply Chain Operations Reference Model. The elements are:

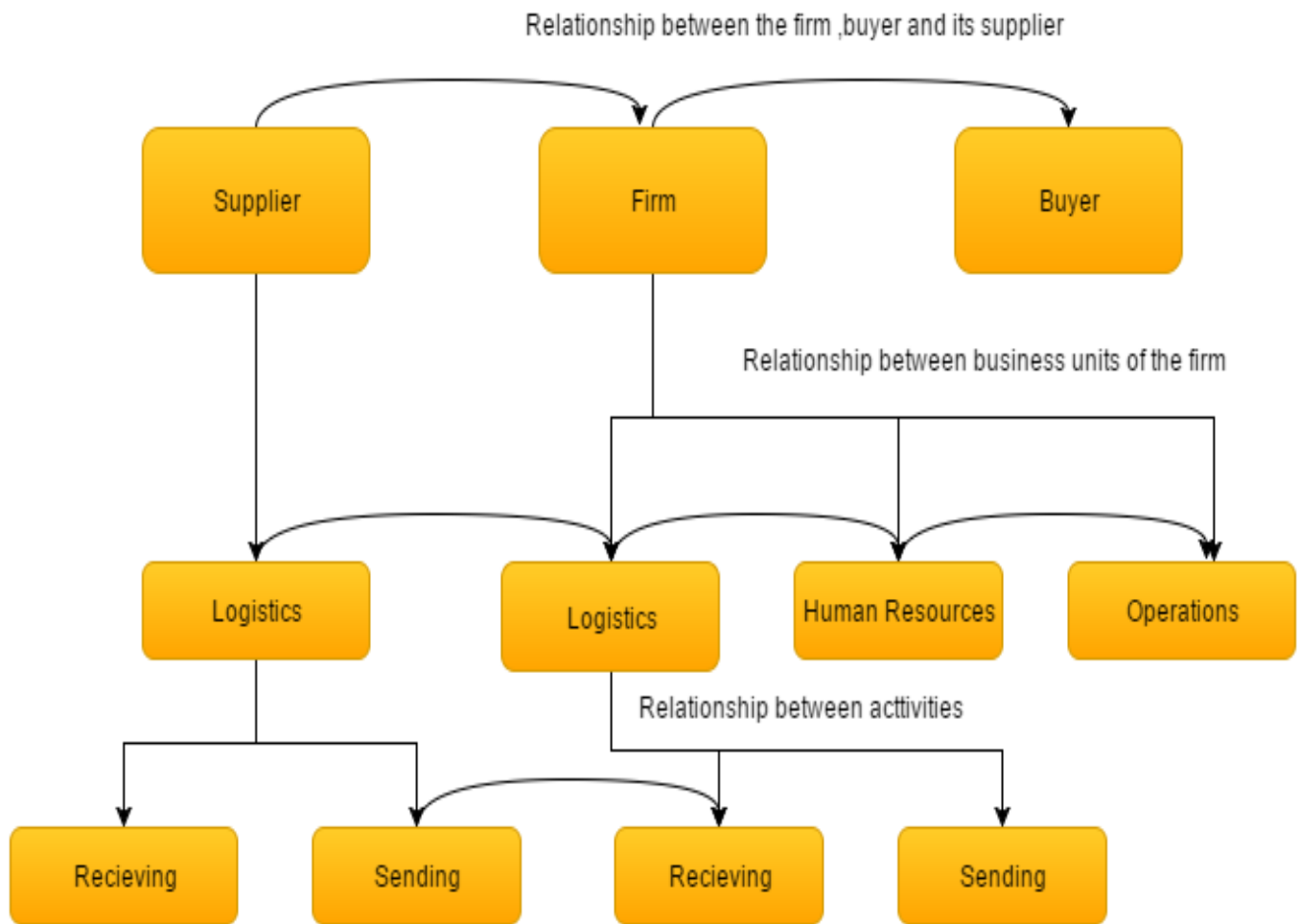
**Make to Stock:** This refers to production based on demand forecasts and accurate forecasts would prevent inventory loss and prevent opportunity loss due to stock outs. This can be regarded as the push type system. Here in the manufacturing of steel columns we can use exponential smoothing method for forecasting the demand for manufacturing the columns to construct the test track. The production quantities should match the forecasted demand.

**Make to order:** This refers to production due to incoming customer order. Its starts only after the customer orders are released. This is regarded as pull type system because the materials are pulled downstream as the customer orders are placed. In this case, the manufacturing of columns can be regarded as make to order environment when there is a small change in the design of the track and expansion is required thus needing more columns to support the guideways. Here these columns are produced based on the requirement and not at constant rate to fulfill the demand forecasts.

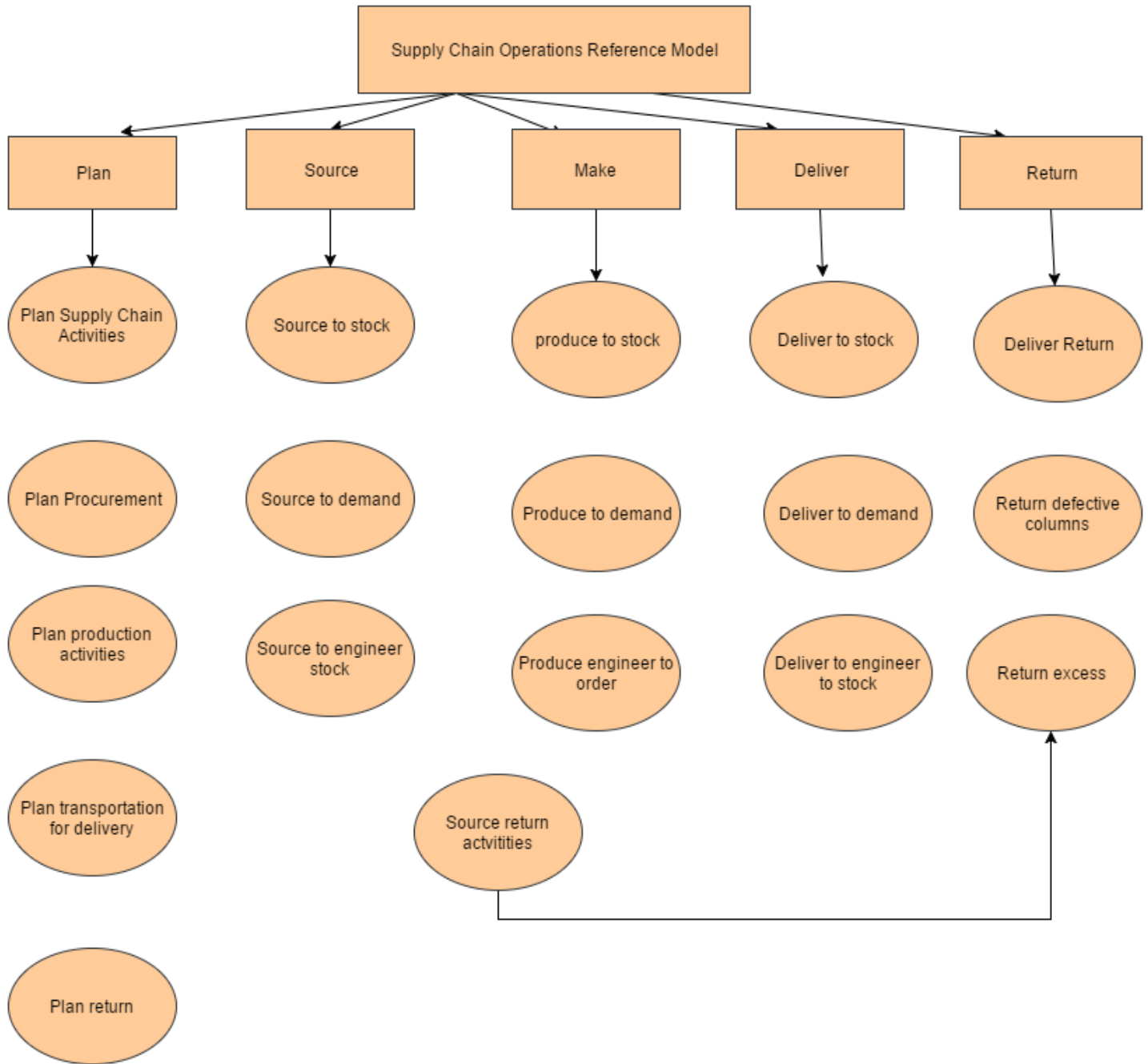
**Engineer to order:** As the name suggests the products are engineered or made based on the specifications of the customer order. It is similar to make to order but here the manufacturing depends on very specific customer requirements. If the designs of the steel columns change overtime, the manufacturing facility should be flexible to manufacture the new columns designs to expand the guideway network.

The third Level of the SCOR model consists of elements of particular manufacturing processes. These elements define fundamental process parts of the above mentioned process levels and inputs and outputs. In order get a clear idea, one of the level two process elements such as Source to stock products is broken down into several sub-elements. The source to stock in the manufacturing of steel columns is broken down into four sub-elements:

- Schedule raw material delivery (steel in this case) from the supplier.
- Receive steel sheets
- Assay the steel sheets
- Transport the steel sheets to the facility through the supplier, own or third party logistics.
- Make a payment to the supplier.



*Figure 3-The relationship activities between different departments in the supply chain as defined by Porter (1985)*



*Figure 4-General SCOR Hierarchical Model (Source 4)*

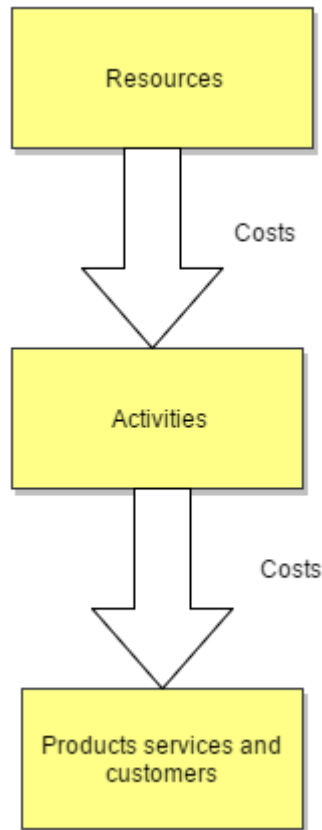
## Activity Based Cost Modeling (ABC):

The main principle of this model is a common definition of the cost drivers and manufacturing activities in order to determine the cost effective consequences of any manufacturing reconfiguration (Dekker and van Goor, 2000). This Activity Based Costing information is used for pre-development or design phase budgeting purposes. This allows a determination of the manufacturing costs during the product development and the evaluation of the raw material suppliers (Moller and Moller, 2002). The cost drivers as defined by the ABC technique can be used to optimize the complex process which cannot be done all at once. This technique is used to make a comprehensive evaluation of every level of manufacturing process supply chain allowing the distributing costs and profits equally along this supply chain network. The above mentioned SCOR model identified the main management processes, manufacturing elements or activities and lower level sub-elements that mainly drive these costs. A typical supply chain cost model will involve:

- A list of supply chain partners and most common activities shared by these partners.
- Resources and cost drivers for each activity
- Each Manufacturing activity information
- Each Manufacturing Cost information

In this project, the manufacturing activities which are involved in producing the steel columns and cost drivers related to each of the manufacturing activities is identified. The implementation of this ABC technique across the supply chain network would create an agile supply chain that responds to just in time (make to order) manufacturing processes if there are any changes in the dynamic production.





*Figure 5-Elements of Cost Assignment based on ABC (Source 8)*

The table in the next page lists different manufacturing activities and their sub-activities and these activities can be measured by cost drivers which are also listed along with the unit level. The cost driver can be described as unit of measure selected to represent the volume of an activity. Cost drivers can be further divided into primary and secondary drivers. The primary drivers can be described as the initial cause of the main manufacturing activities that require the resources like machines, equipment for the machines, material moving equipment, production laborers and the production facility. The secondary drivers can be described as causes of the manufacturing sub-activities. These sub activities can be defined as activities that support the main manufacturing actives. For Example, in the bending process, the press brake bends the steel sheet into cylindrical column and this would be a main activity. After

bending the steel sheet to particular angle, the press brake operator measures for correct angle using a measuring device and then proceeds to bending further and this can be identified as the sub-activity.

Activity	Cost Driver	Unit Level
Procurement of Steel	Number of purchase orders	Part or Batch Level
Manufacturing Machine Set-up	Setup time ore number of setups required to process the part	Batch level
Transportation	Weight of the steel in pounds	Part or batch level.
Production	Number of production hours or orders	Part or batch level
Inventory control	Number of parts in the inventory or administrative hrs.	Part or batch
Receiving the raw material from the steel supplier	Number of purchase orders	Part or Batch level
Engineering (Make to order or engineering to order)	Number of engineering specific orders	Part or Batch level
Inspection of the steel sheets after receiving from the supplier	Number of inspections or inspection time	Part or Batch level.
Material handling during delivery	Number of customer orders	Part or batch level

*Table 3 – Activities and Cost Driver*

Once the manufacturing activities are identified, the manufacturing costs with each activity with the number of number of steel columns as the outcome. Total cost per activity can be calculated when we identify all the costs associated with these activities. The estimated cost per activity is given by following simple formula:

$$C/A = H * W + M + E + S \dots (1)$$

Where C/A=Cost per Activity

H=Labor Hours

W= Wages per labor hour

M=Material costs for the materials used in the activity

E= Equipment costs

S=Subcontracting costs

***Table 4 - Activities and Costs***

Activities	Type of Activity(SCOR)	Cost Drivers	Type of product design	
			Beamway	Milotek
Programming	Plan Activity	Number of hours take for the activity	.2	.3
		Wages for CNC programmer	\$29.42/hr.	\$29.24/hr.

		Total labor costs for this activity.	\$5.884	\$8.820
Cutting	Make Activity	Number of hours taken by the activity	.10	.20
		Wages for Cutting Operator	\$15.54/hr.	\$15.54/hr.
		Total Cost	\$2.33	\$2.33
Welding	Make Activity	Number of hours taken by the activity	.35	.25
		Wages for the cutting operator	\$20.66/hr.	\$20.66/hr.
		Total Cost	\$6.19	\$4,12
Bending	Make Activity	Number of hours taken by the activity	.10	.15
		Wages for the press brake operator	\$17.48/hr.	\$17.48/hr.
		Total Cost	\$1.17	\$2.66
Galvanizing	Make Activity	Number of hours taken by the activity	.30	
		Wages	\$18.80/hr	
		Total Cost	\$5.64	
Concrete Filling	Make Activity	Number of hours taken by the activity		.1

		Wages		\$13.81/hr.
		Total Cost		\$1.381

***Table 5 – Direct Material Costs***

Type of Column Design		Direct material cost per steel sheet
Beamways(Low Carbon)	Supplier 1	\$497.38
	Supplier 2	\$523.43
Milotek (Domex Steel)		\$584.35

***Table 6-Overhead for both columns***

Mortgage/Rent	\$223500/yr.
Depreciation of machines	\$4791.73/yr.
Estimated Electricity	\$2200/yr.
Management(Supervisors )	\$74136/yr
Total overhead costs per steel column	$304627.73/1000 = \$ 304.62$

*Table 7 - Total manufacturing costs*

Type of Costs	Costs for different types of column designs	
	Beamway	Milotek
Total Direct Labor Costs per unit	\$21.56	\$20.98
Total Direct Material Costs per unit	\$497.38	\$584.35
Total Overhead costs per unit	\$304.62	\$304.62
Total estimated cost per unit	\$823.56	\$909.95

### **Inventory cost models:**

Inventory refers to the idle products or material that could be held by the firm for use in the future. Items that could be carried in the inventory are raw materials for the products, purchased products, sub-assemblies, finished products, work-in-process (wip) and engineering supplies. Inventory plays an essential role for any organization but the costs or expenses associated with financing and maintaining the inventories is very important part of business costs. Two important aspects of any inventory cost modeling that we should learn about is

- Quantity of parts that should be ordered when the inventory is replenished
- The cycle time at which the inventory should be replenished.

In this project, the inventory modeling was done for production of steel columns for Beamways. Here there are two types of inventory that we looking into, they are:

- The raw materials used for the production of the steel columns which are steel sheets which are stored in the warehouse until they enter production.
- The finished the steel column which could be stored in the warehouse until shipped to the test track.

The modeling for raw material inventory can be done by a modeling technique called Economic Order quantity model or EOQ model in short. This is deterministic continuous review model, here we assume that the demand is known and its constant. The finished steel column inventories are modeled by Economic Production Quantity Model. This model is the extension of EOQ Model; this model assumes that the company will produces its quantity to be shipped.

### **Economic Order Quantity Model:**

The EOQ Model is a deterministic continuous review model. It is applicable when the demand of an item is constant and when the entire quantity which is ordered arrives at one point of the time. In this project the raw materials for Beamway Steel Column production is modeled according the EOQ model.

Some general assumptions of this model are as follows:

- A known constant demand rate of 80 sheets per month
- The order quantity (Q) needed to replenish inventory arrives all at one time when inventory levels
- Planned Storage are not allowed.

The costs associated with this model are ordering costs for this inventory and holding costs. These costs are briefly explained below:

1. **Holding Costs:** These costs are linked with maintaining or carrying a given a level of the inventory and these costs depend on the size of the inventory. While calculating costs we should consider the interest costs that exists for the invested capital tied up in the inventory. The cost of this capital is usually explained in the percentage of the amount which can be invested. In the previous section it was mentioned that the cost of one sheet metal quoted by the supplier 1 (we chose this because of the cheaper cost) is **\$497.39** and this also includes the shipping costs. The holding costs can be calculated by estimating a percentage for this value of this inventory. Here, we assume that holding cost be 5% of cost of one sheet metal.
2. **Ordering Costs:** These costs are considered as fixed costs and does not vary with order of the quantity This costs are related to the purchasing activities of the firm like processing the order, invoice verification, receiving, making a payment etc. In this case, purchasing of steel sheets from different suppliers can be carried out by a purchasing agent. Typical hourly salary for a purchasing agent in the state of California is **\$32/hr.** and we assume that other overhead costs related to purchasing can add up to about **10\$.**

Other Terminology related to this model are the cycle time and re-order point.

- **Cycle Time:** The cycle time is the period between the orders and this answers to frequency of the orders place. It is given by this formulae:  **$300 (Q^*)/D$**  where, D=Demand and  $Q^*$ =Optimal order quantity. For this case we assume there is 300 working days in the year.
- **Re-Order Point:** The re-order point is the inventory level at which a new order of steel sheets is placed. This is associated with the lead time demand. In this case we assume that supplier 1 will need **1 week** lead time on any order placed by the steel column production facility. The re-order point can be calculated by using this formula:  **$r=dm$**  where, d=demand per week, m=lead time for new order for sheet metal in weeks.



We assume,  $D = 80$  sheets/month or 960 sheets/year (Demand)

Holding cost  $C_h = 5\%$  of \$497.39 = \$ 24.8695 (Annually)

Ordering Costs  $C_0 = \$42.36$

Optimal Order Quantity  $Q^* = \sqrt{2DC_0/C_h} = \mathbf{58 \text{ steel sheets}}$

Hence the optimal order quantity for the raw sheet metal that the production facility should get from the supplier so to minimize the holding costs and ordering costs is **58 sheets**.

Cycle time =  $300 Q^*/D = 18$  days

Re-order point  $r = dm = 20$  sheets.

### **Economic Production Quantity Model (EPQ):**

The EPQ Model is used to model finished product inventories which are ready to be shipped to different customers. The finished steel columns can be stored in a warehouse until they are shipped to the guideway construction site. The costs related to holding this inventory in the warehouse can be the holding costs. The holding cost in this case is assumed to be 20 % of the value of inventory which can be the cost of one beamway column which was calculated in the previous section. The setup costs of all the machines involved in the manufacturing process such press brake, laser cutter, de-coiler and welding machine is estimated to be around \$8000 annually. The calculations are very similar to that of a EOQ Model.

Assume,  $D = 80$  steel columns / month or 960 steel columns /year

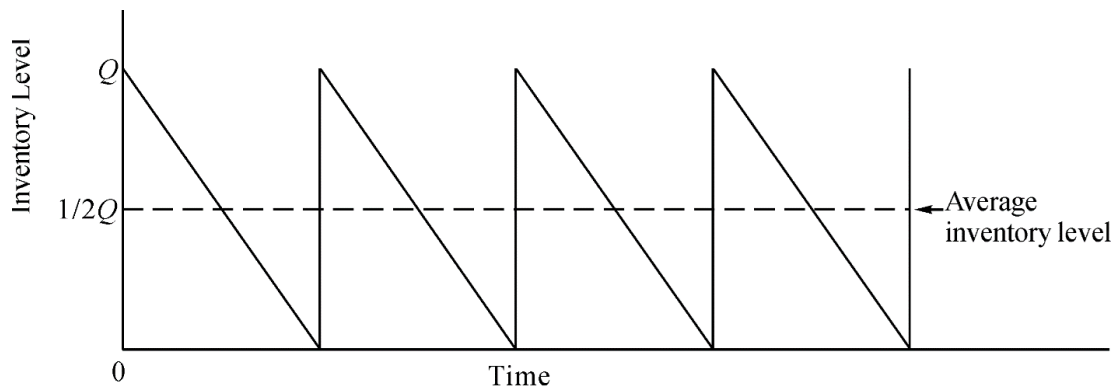
Annual Capacity,  $p = 1000$  steel columns (Assumed from estimating production times)

Holding Cost,  $C_h = 18\%$  of \$ 823.56 (Estimated rate per steel column) = \$ 148.24

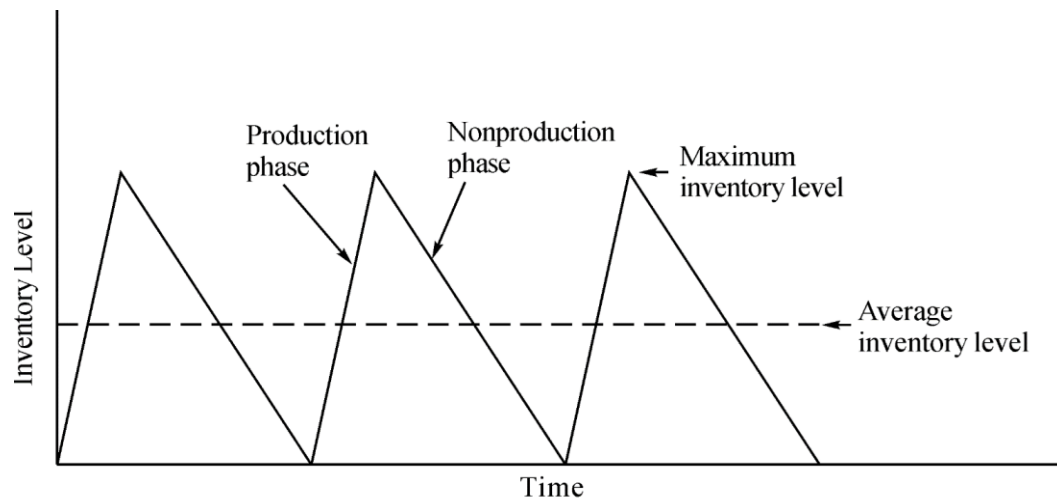
Optimal Order Quantity ,  $Q^* = \sqrt{\frac{2DC_0}{(1-D/P)C_h}} = 25$  steel columns (Also referred as Production Lot

Size)

Re-Order Point,  $r = dm = 18$  columns.



*Figure 6-Inventory pattern for the EOQ Model(Source 6)*



**Figure 7-Inventory Pattern for the economic production quantity model(Source 6)**

## Chapter 4: Design

Once the Analyze phase is completed, the next phase in the DMADV methodology is the Design phase. The objective of this phase is to implement all the items which were discussed in the Define, Measure and Analyze phase into detail sign.

In this project Simulation of the production inventory model and the entire manufacturing process model was done.

Simulation: Simulation is the imitation of the operation of a real-world process or system over time.

Here, the simulation was done by using discrete event simulation software like ARENA Supply Chain Simulation.

### Production Inventory Model Simulation:

Simulation is done for production inventory models which we discussed in the analyze phase. The parameters which were calculated using the Economic Order Quantity model (EPQ) are used as inputs for this simulation model. These parameters are input as variables into arena to build this model. The parameters are:

- Batch Size
- Target Stock
- Demand
- Re-order point

The other variables which we newly added to the model are as follows:

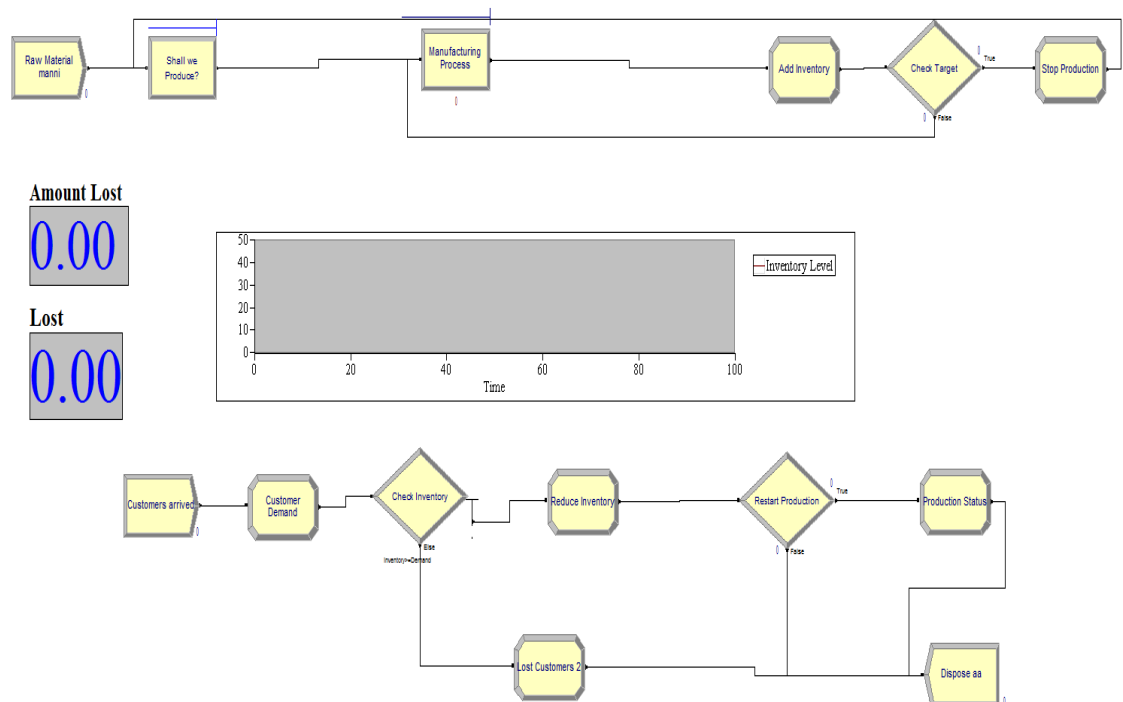
- **Lost or Customers Lost:** As the name suggests this variable represents the number of customers lost when demand is not met. In this case this simply represents the number of times over the span of 300 days (Run-time in arena) the inventory is not met the demand. A logic like  $\text{inventory} \geq \text{demand}$  is given in the Decide Module in arena. This logic separates the inventories that have met the demand with those which have not.
- **Amount Lost:** Amount lost is number of products present in the inventory when it does not meet the demand.

According the model when this happens the production is restarted and more steel columns are produced to fill in the inventory. This is initiated by a Hold function and here a binary number is attached to the production using Scan for condition logic and this assigns whether to start the production or not

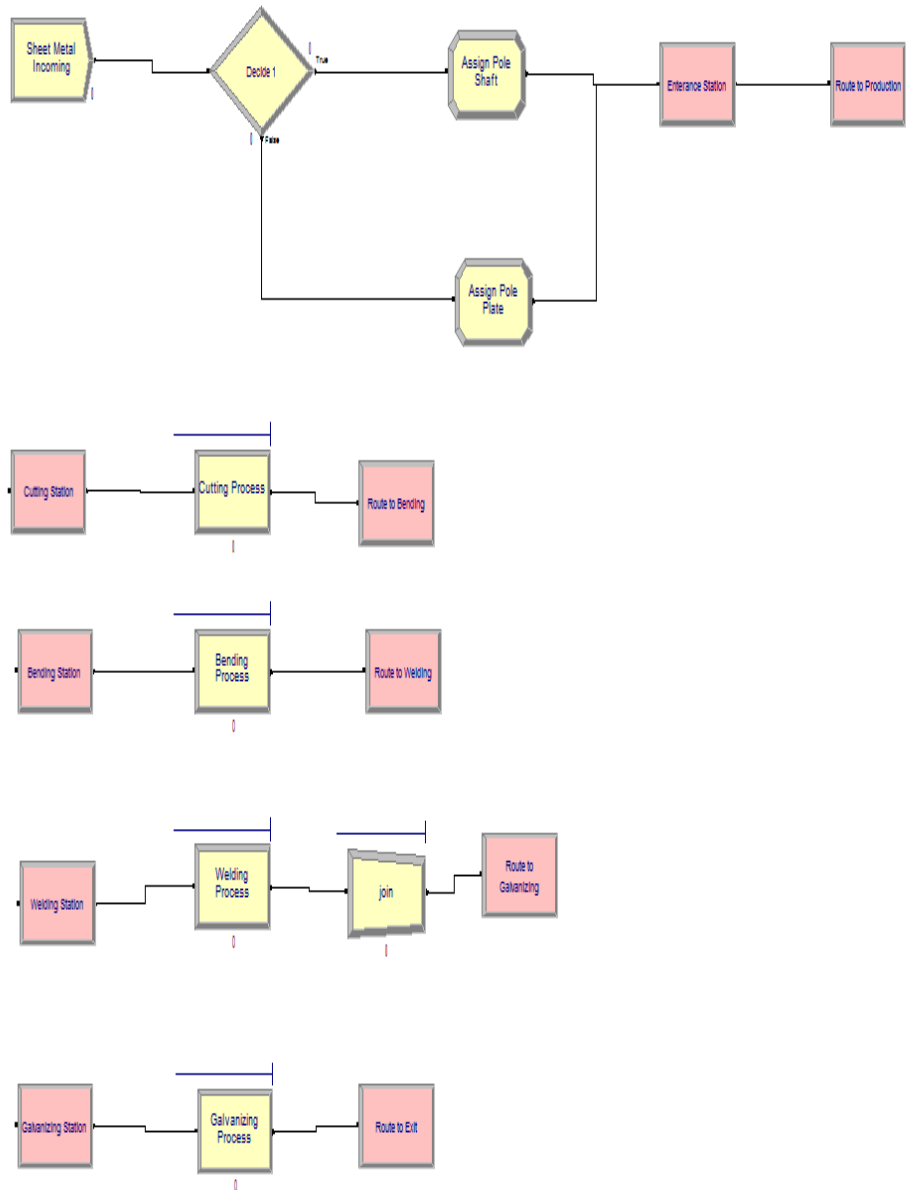
Check target module is a decision model which checks if the inventory is more than target stock if not it sends the entity back to the manufacturing process. The replication length is 300 days and this is when the simulation is stopped. This length represents the number of working days of the year where the production is taking place, Uniform distribution is used for the customer arrival and the customer demand.

The manufacturing process is also simulated by using ARENA the software. The simulation is done for processing two products. One product is cylindrical steel shaft and other is the square base plate used at the bottom of this steel shaft. The decide module separates the steel entity incoming into two separate products by giving a logic called condition by chance (50%). The production times which were mentioned earlier in the analyze phase are input to

the different types of process modules according to respective processes. The sequencing of the two parts is done by entering process route for each part in the sequence spread sheet and assigning their sequence as attribute for each part respectively. The steel shaft takes a sequence of cutting, bending, welding and galvanizing and the base plate takes a sequence of cutting and welding. The batch function is used to join the two parts after the welding process module.



**Figure 8-Production Inventory Simulation**

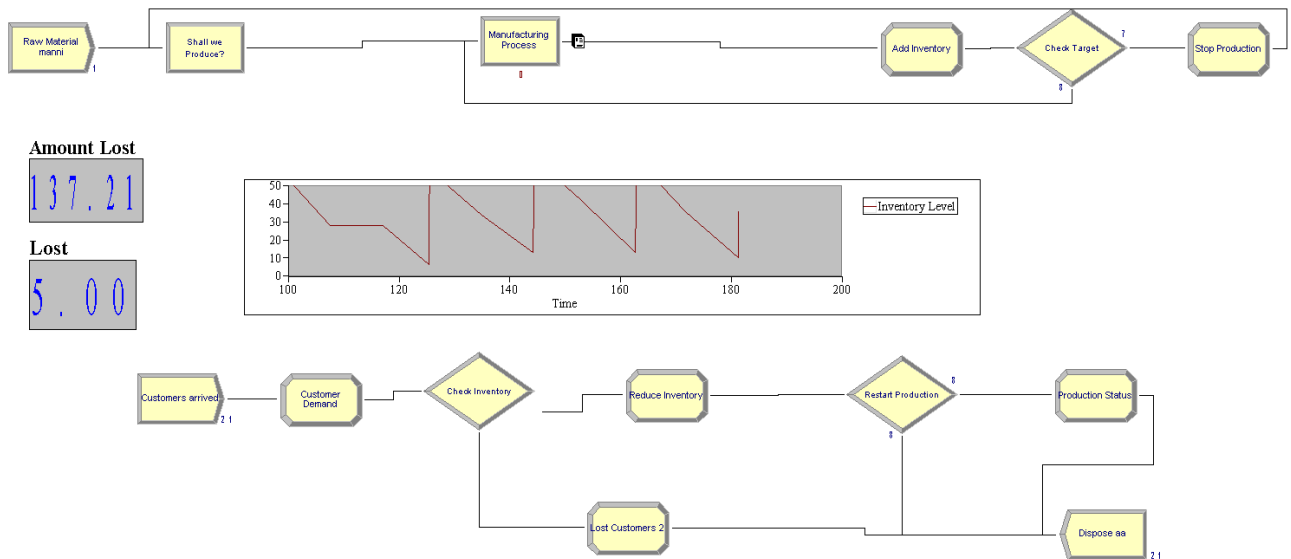


*Figure 9-Manufacturing Process Simulation*

## Chapter 5: Verify

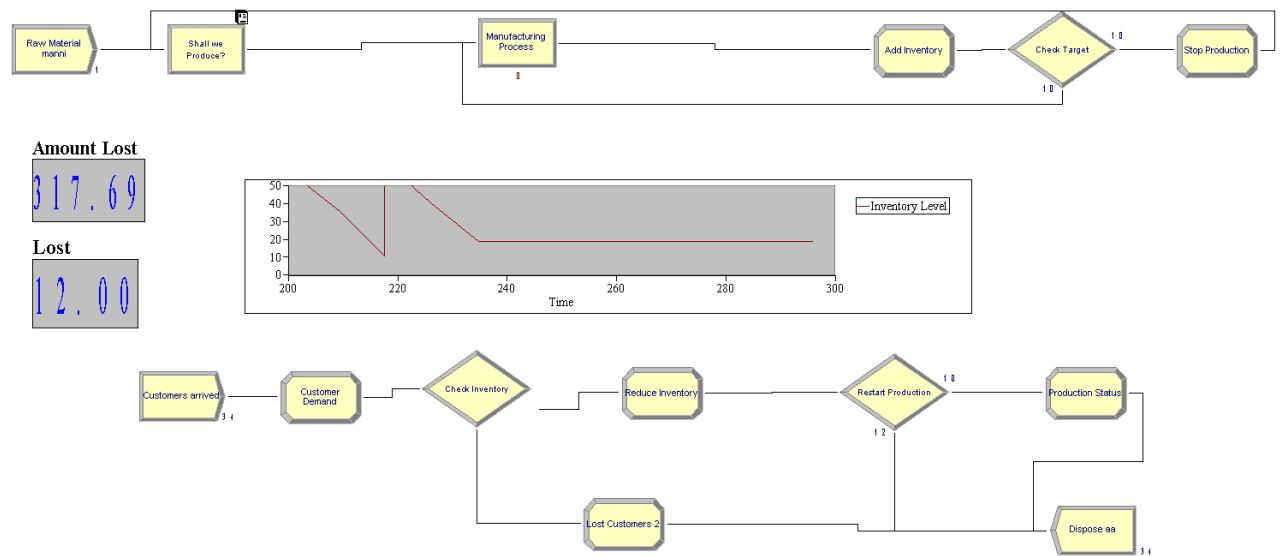
The simulation model that was designed in the last phase is made to run in verify phase and results from this simulation run is analyzed. In this phase the performance of the design phase and its ability to meet the target needs could be verified.

The production inventory simulation is run:



*Figure 10-Simulation Model Still Running*

In the above figure, we can see that graph showing inventory level nearly emulates the graph showing the inventory pattern of the Economic Production Quantity Inventory Model.



*Figure 11- At the end of the simulation run*

From the figure, the final results on the amount lost and lost is shown. Lost variable represents the number of times during the production run the inventory is less than required demand and this case its 12 times. The amount lost represents the number of parts in the inventory that are present when it does not meet demand, here the amount lost adds up to a total of 317.69 parts. Two different scenarios are run by changing the variables like Batch Size, Reorder Point and Target Stock. The scenario results are given below.

Scenario	Batch Size	Reorder Point	Target Stock	Amount Lost	Lost
1	26	18	50	317.69	12
2	29	20	60	113.41	7
3	31	25	65	326.51	13

*Table 8 – Sensitivity Analysis*

From the above table we can conclude that the scenario 2 with batch size of 29 is the best because the variable Lost is the lowest in that scenario.



The results of the manufacturing process simulation are attached in the next five pages. By looking at the simulation results:

- The throughput after completing the simulation run is 720.
- The average Work in Progress(WIP) is 2.8583
- By analyzing the queue time, we can conclude that the welding process has the highest average Queue time which is 3.123
- In the resource utilization section, the welding machine has the highest utilization rate.
- Total number seized is the same in Welding and Cutting which is 720 parts.

## Conclusion

The DMADV Methodology used in this project helped to satisfy all the goals mentioned in the project charter. In the define phase the manufacturing process elements were identified by SIPOC analysis, KJ and Kano analysis were done and the voice of customer was converted into critical to quality measures by using these techniques. The estimated manufacturing costs were collected in the measure phase and the steel column process flow was analyzed. In the Analyze phase through the Supply Chain Operations Reference model (SCOR) the different types manufacturing activities were identified and these activities were input to the Activity Based Cost Modeling (ABC). Through this ABC analysis, manufacturing costs of one unit of beamway column which is \$823.56 and Milotek column which is \$909.95 were calculated. The total inventory costs for holding the finished goods inventory for EOQ of 26 columns is estimated to be \$153.16 per column and \$194.46 per column. The transportation costs for raw material of the Beamway columns is estimated to \$10 per column and that for Milotek column is estimated as \$14 per column.

Type of Costs	Beamway Column	Milotek Column
Manufacturing Cost	\$823.56/column	\$909.95/column
Transportation Cost	\$10/column	\$14/column
Inventory Costs	\$153.16/column	\$194.46/column
Total Cost	\$986.72/column	1118.41/column

By comparing both the costs, the beamway columns were identified as less expensive to make and store. Inventory costs models for raw material and production inventories were analyzed. The optimal order quantities from the supplier and the production batch sizes were calculated. In the Design Phase, simulation models were built for the production inventory and the steel pole production process. From

the inventory models, the number of times the production did not meet the inventory was identified and different scenarios were run with changing some variables like batch size and the best scenario which gave the lowest lost customer value was identified. The production process simulation gave results for throughput, queue times, work in process (WIP) and machine utilization. Hence from the brief explanation in the above paragraph about the results established in this project, it can be concluded that the project achieves mainly in establishing a blueprint for the production process for both the steel column designs and outline for their supply chain network specifically for the beamway columns.

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Unnamed Project

Replications: 1

Time Units: Hours

Key Performance Indicators

System	Average
Number Out	720

## Unnamed Project

Replications: 1 Time Units: Hours

## Entity

### Time

VA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.6572	0.012162096	0.4500	0.8500

NVA Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00

Wait Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	4.1066	0.648961619	0.00	12.8644

Transfer Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00

Other Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	0.00	0.000000000	0.00	0.00

Total Time	Average	Half Width	Minimum Value	Maximum Value
Entity 1	4.7638	0.647911576	0.4500	13.3144

### Other

Number In	Value
Entity 1	720.00

Number Out	Value
Entity 1	720.00

WIP	Average	Half Width	Minimum Value	Maximum Value
Entity 1	2.8583	1.19707	0.00	39.0000

**Unnamed Project**

Replications: 1 Time Units: Hours

**Queue****Time**

## Waiting Time

	Average	Half Width	Minimum Value	Maximum Value
Bending Process.Queue	0.00	0.000000000	0.00	0.00
Cutting Process.Queue	0.9836	0.085556198	0.00	3.0144
Galvanizing Process.Queue	0.00	0.000000000	0.00	0.00
Welding Process.Queue	3.1230	0.598789401	0.00	9.8500

**Other**

## Number Waiting

	Average	Half Width	Minimum Value	Maximum Value
Bending Process.Queue	0.00	(Insufficient)	0.00	0.00
Cutting Process.Queue	0.5902	(Correlated)	0.00	31.0000
Galvanizing Process.Queue	0.00	(Insufficient)	0.00	0.00
Welding Process.Queue	1.8738	0.882017929	0.00	29.0000

## Unnamed Project

Replications: 1 Time Units: Hours

## Resource

### Usage

#### Instantaneous Utilization

	Average	Half Width	Minimum Value	Maximum Value
Molten Zinc Tank	0.0932	(Correlated)	0.00	1.0000
Plasma Arc Welder	0.2100	(Insufficient)	0.00	1.0000
Press Brake	0.03108333	(Correlated)	0.00	1.0000
Shear Cutter	0.06000000	(Insufficient)	0.00	1.0000

#### Number Busy

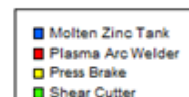
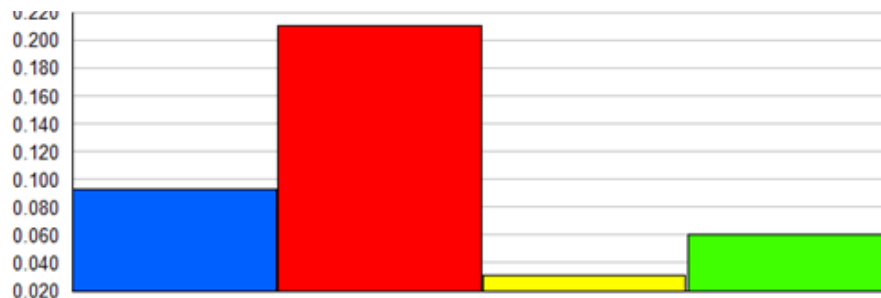
	Average	Half Width	Minimum Value	Maximum Value
Molten Zinc Tank	0.0932	(Correlated)	0.00	1.0000
Plasma Arc Welder	0.2100	(Insufficient)	0.00	1.0000
Press Brake	0.03108333	(Correlated)	0.00	1.0000
Shear Cutter	0.06000000	(Insufficient)	0.00	1.0000

#### Number Scheduled

	Average	Half Width	Minimum Value	Maximum Value
Molten Zinc Tank	1.0000	(Insufficient)	1.0000	1.0000
Plasma Arc Welder	1.0000	(Insufficient)	1.0000	1.0000
Press Brake	1.0000	(Insufficient)	1.0000	1.0000
Shear Cutter	1.0000	(Insufficient)	1.0000	1.0000

#### Scheduled Utilization

	Value
Molten Zinc Tank	0.0932
Plasma Arc Welder	0.2100
Press Brake	0.03108333
Shear Cutter	0.06000000





Unnamed Project

Replications: 1      Time Units: Hours

Resource

Usage

Total Number Seized      Value

Molten Zinc Tank	373.00
Plasma Arc Welder	720.00
Press Brake	373.00
Shear Cutter	720.00

