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Capacity Planning Model for Manufacturing Organizations using AHP

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***Abstract* — In today's competitive era, the main aim of the manufacturing organization is to deliver products to customer on time with better quality and at lower cost than the competitors. Many organizations have their manufacturing facility located at different geographical locations to gain advantages like lower wages, better infrastructure facilities, better government policies, availability of local customers and market etc. In a make-to-customer order manufacturing organizations, management need to take in consideration mix of different qualitative and quantitative factors while making decision of allocation of manufacturing facility for new customer order. In this paper, a decision making model is proposed to select one manufacturing facility for manufacturing organizations having more than one manufacturing facilities in order to utilize capacity and distribute load uniformly among all manufacturing facilities. Analytical Hierarchy Processing is used as a multi-criteria decision making tool while developing the business model. In this paper, tool manufacturing industry is taken as a reference for development of the model and case study of Engineered Tooling Solutions of Larsen and Toubro is taken to study results obtained from the model. The results shows that by use of the model manufacturing capacity utilization and manufacturing load is uniform among all manufacturing facilities which leads to better overall capacity planning of organization. Due to us of model lead time of tool manufacturing is reduced which increased percentage of On Time Delivery of tools to customers.**

Keywords—AHP, Capacity Planning, Decision Criterions

INTRODUCTION

Some firms fulfill customer orders through finished goods inventories are Make-to-Stock (MTS) firms while some start working only after customer order is received are Make-to-Order (MTO) firms [1]. The tool manufacturing organization is a make-to-customer order kind of manufacturing facility where tools are manufactured for customers only after order is received. The most important aspect in the make-to-order is the effective and efficient utilization of available capacity to meet customer demands since unused capacity is considered as loss of revenue for organization [1]. In the manufacturing there are two kinds of manufacturing processes Bottleneck process and Non-bottleneck process. The detection of bottleneck process is necessary to make planning and scheduling of manufacturing processes [2]. Capacity planning determines resource requirements to fulfil customer demands and there are three levels of capacity planning: Long term, Medium term, and Short term [1]. . In this paper, the model is developed by focusing mainly on medium term planning of resource capacity, where manufacturing plan for four to five months is done. Bottleneck detection in manufacturing process is necessary to improve manufacturing efficiency and improve capacity utilization [3]. In tooling industry different kind of tools are manufactured like Press Tools, Molds, Die Casting Dies, and Fixtures etc. based on requirement of customer or characteristics of component. The tool manufacturing organization is a flow-shop kind of production system which has multiple processing stages each having different type of operation [4]. The capacity decisions should be made simultaneously to increase capacity utilization and reduce total system cost [4]. Multi Criteria Decision Analysis techniques have seen incredible use in decision making process in different variety of application areas as new methods getting developed and old methods are improving over several decades· [5]. Some commonly used Multi Criteria Decision Analysis techniques are Analytical Hierarchy Processing, Fuzzy Set Theory, Case based reasoning, Goal Programming, Technique for Order of Preference by Similarity to Ideal Solution etc. [5]. In resource management problems, performance type problems, planning problems AHP is found to be suitable decision making technique [5]. AHP is taken as a decision making tool in the development of capacity planning model for this paper. Analytical Hierarchy Processing is a multi-criteria decision making tool used in variety of decision making processes developed by Satty [6]. The Analytical Hierarchy Processing is a theory of measurement through pairwise comparisons and relies on judgement of experts to derive priority scales [7]. In public administration sectors, customer service industries, manufacturing and automobile industries, military and political applications, sports sector etc. Analytical Hierarchy Processing is used for the decision making [7]. The AHP attracted so many researchers because of its nice mathematical properties of the method and data required for the process is rather easy to obtain [8]. The steps involved in AHP problem solving method are: Define the Problem, Build the Decision Hierarchy, Construct pairwise comparison matrices, Use priorities obtained to weigh the priorities in immediately below level and go on till priorities for bottom level is achieved [7].

Model for Capacity Planning

L&T ETS has three different tool manufacturing facilities to manufacture all kind of tools located at Mumbai, Ahmednagar, and vadodara. Mumbai manufacturing facility is oldest manufacturing facility having more experienced resources while Vadodara being the latest started two years ago. The main processes involved in tool manufacturing are: Design, Machining, and Assembly. In machining again there are three major activities: Milling, Spark Erosion, and Wire Erosion. The main goal of the model is to capacity planning at each tool manufacturing facility for uniform load distribution among them to increase effective utilization of resources at each location which will reduce lead time and delays in tool delivery. For a new tool order received from customer to decide manufacturing facility which will result in optimum capacity utilization among all manufacturing facilities. The AHP Hierarchy for the model is as shown in Figure.1 below:

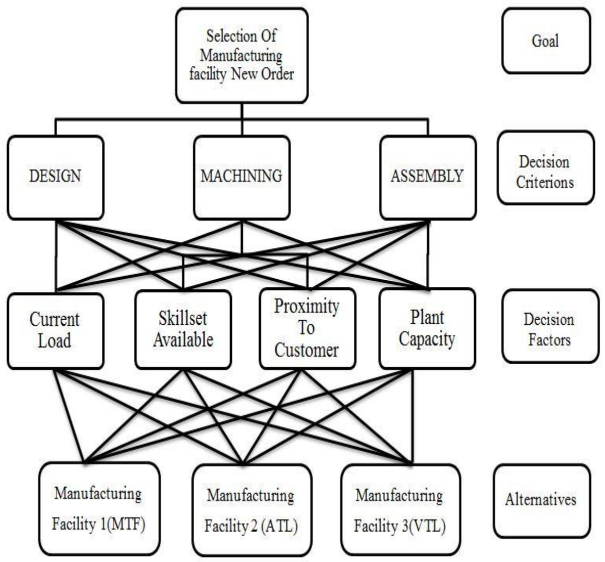

Figure 1 AHP Hierarchy of model

The figure 1 shows that, the goal or aim of the model is to select manufacturing facility for the new customer order based on the current situation present at each manufacturing facility. The current scenario for each manufacturing facility is studied based on three decision criterions: Design, Machining, and Assembly as these are the critical activities in the tool manufacturing process. For the evaluation and comparison of the alternatives decision criterions are further evaluated based on the four decision factors: Current Load, Skillset Available, Proximity to Customer, Plant Capacity. The reasons for taking these four as decision factors are:

Current Load: Current load gives, out of total manufacturing capacity how much capacity is currently engaged to manufacture orders already in WIP. This is determined based on average time taken by each process and the number of tools currently in that process. Current load directly affects the lead time for the customer delivery which in turn affect planned cost.

Skillset Available: In Make to Order organizations the customized products need to be manufactured based on customer requirements for which skillful resources are needed. Skillset available factor will evaluate the manufacturing facilities based on experience, technology, quality of work etc. Skillset available factor reduces percentage of rejection of manufactured components during inspection reduces rework activities results in reduction of lead time and cost.

Proximity to Customer: Proximity to Customer factor evaluates the ease with which the customer can be accessible for the manufacturing facility. The inputs, feedback and approvals from customer are required during different stage of product manufacturing. It is important to consider this factor during manufacturing facility selection.

Plant Capacity: Plant capacity will give the annual manufacturing capacity of different processes of manufacturing facility. Plant capacity is necessary to carry out capacity planning of manufacturing facilities and it is considered for selection of manufacturing facility. The decision factors need to be selected for the capacity planning model changes based on the nature of organization, products that organization manufactures etc.

AHP Methodology

AHP methodology follows following major steps: Problem definition, pair wise comparison of alternatives, sensitivity analysis and final rankings of alternatives. Pairwise comparison matrix of alternatives for each decision factor of decision making criteria is constructed. Then, decision factors are compared pairwise with each other to get the score of each factor for that particular decision criterion. Higher the score for factor higher is the importance in decision making for the particular decision criteria. In pairwise comparison we compare alternatives on the scale which was developed by Satty from 1 to 9. The scale used is as shown in table below:

Table 1 Priority Scale of AHP

Intensity of Importance	Definition	Explanation
1	Equal Importance	Both alternatives contribute equally
3	Moderate Importance	One alternative contribute moderately more than other
5	Strong Importance	Judgement is strongly in favor of one alternative than other
7	Very Strong Importance	Judgement is very strongly in favor of one alternative than other
9	Extreme Importance	One alternative is extremely important than other alternative in highest possible order
2,4,6,8 are used to intermediate expression of alternative comparisons		

The pairwise comparison matrix samples that will be used for comparison of decision factors are as shown below:

Table 2 Sample Comparison Matrix of Decision Factors

Skillset Available			
	Plant A	Plant B	Plant C
Plant A	1.00	0.50	1.00
Plant B	2.00	1.00	2.00
Plant C	1.00	0.50	1.00
Col.Tot	4.00	2.00	4.00

Proximity To Customer			
	Plant A	Plant B	Plant C
Plant A	1.00	0.20	3.00
Plant B	5.00	1.00	7.00
Plant C	0.33	0.14	1.00
Col.Tot	6.33	1.34	11.00

The weightages given to the alternatives of the decision factors for particular decision criterions are of dynamic nature. Each decision factor are given weightages for a particular decision criteria based on present situation and will change based on change in the scenario.For example,The weightages for current load will change dynamically based on the load on process for that particular alternative. The weightages for skillset available will change based on the type of product customer want to manufacture. To calculate vector weight of alternative for each decision factor divide each column element with respective column total and then take the average of row elements.

In this way, vector weights for each alternative of decision factors are obtained. Then we have to carry out the sensitivity analysis to confirm weightages assigned to alternatives are correct. To perform sensitivity analysis two factors are needed Consistency Index (CI) and Random Index (RI). The ratio of these two factors is called as Consistency Ratio (CR).

$$CR = \frac{CI}{RI}$$

Consistency Index (CI) is given by:

$$CI = \frac{\lambda max - N}{N - 1}$$

λmax is calculated by matrix multiplication of vector weight matrix and pairwise comparison matrix. Dividing the respective element of resulting matrix with vector weight matrix we get three new vectors. By taking average of these three elements we get value of λmax. N is the number of available alternatives. Putting these values in equation we get CI value. RI value will be obtained from the RI scale given by Satty based on number of alternatives for the comparison. The table of RI values as shown in table below:

Table 3 RI Scale

No.Of Alternatives (N)	Relativity Index (RI)
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45

By putting calculated CI and RI values in the equation of CR, value of CR will be obtained. If value of obtained CR is less than 0.1 then weightages given to the alternatives are consistent but if CR is greater than 0.1 then we have to change weightages of alternatives to obtained CR less than 0.1.

The vector weightages of decision factors are calculated based on their importance in the decision making process of Design, Machining and Assembly decision criterions. For Design criteria importance of decision factors are in the order of skillset available, Proximity to Customer, Current Load, and Plant Capacity. For Design of product skillful and experienced human resource, availability of required softwares is primary requirement hence Skillset Available takes upper rank than other decision factors. During design of product customer is required at various design phase to approve design and changes if any done in design, so Proximity to Customer comes at second rank then comes Current Load and Plant Capacity. For machining criteria importance of decision factors are in the order of Current Load, Skillset Available, Proximity to Customer, Plant capacity. For machining Current Load is prime important as queue of products to be machined increases the WIP levels increases which can result in delays in tool delivery. Also for machining the capability and specifications of available machines, technical advancement of machines is also important factor which covered in skillset available factor so it takes importance rank below Current load. For assembly the skills of die maker are important hence skillset available has prime importance in decision making. Then current load comes as it may cause delay in deliverables. So, by considering these criterions the vector weightages assigned to decision factors of decision making criterions are as shown in table below.

Table 4 Vector Weightages of decision factors

	Design	Machining	Assembly
Current Load	0.122	0.558	0.558
Skillset Available	0.263	0.263	0.263
Proximity to Customer	0.558	0.122	0.122
Plant Capacity	0.057	0.057	0.057

To get the rankings of the alternative for decision making criterions we will multiply the vector weight of alternatives of decision factors with vector weight of decision factors of that decision making criteria. As a result, we will get the final weight of the alternatives for decision criteria as shown below.

C.L	0.56
P.T.C	0.12
S.R	0.26
P.C	0.06

M A T R I X M U L

	C.L	P.T.C	S.R	P.C
Plant A	0.33	0.72	0.63	0.26
Plant B	0.14	0.19	0.26	0.63
Plant C	0.52	0.08	0.11	0.11

Table 5 Alternative Rankings of Decision Criterions

		Ranking
Plant A	0.248	3
Plant B	0.360	2
Plant C	0.392	1

In this way the ranks for all the decision making criterions viz. for Design, Machining and Assembly is obtained.

RESULTS

To get results for selection of manufacturing facility for new customer order one dashboard is prepared as shown in figure 2.

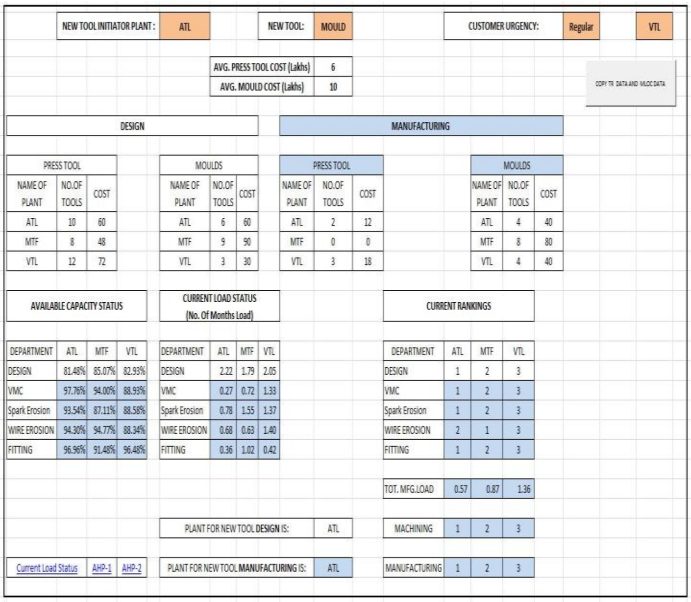

Figure. 2 Dashboard for Model

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The dashboard will show current load at all manufacturing facilities also number of products allocated for manufacturing at each manufacturing facility. The rank of all decision criterions of each manufacturing facility are also shown in dashboard. The different inputs need to be entered by user at the beginning of evaluation and based on inputs entered , manufacturing facility for new order is decided. For our case the input required are customer location, type of product and customer urgency for the product. After entering the inputs the model will give us Design location and Manufacturing location for new order by evaluating using AHP. The inputs required may vary based on type of organisation, products, customers etc. The results obtained by implementation of model shows that, capacity utilization and distribution of manufacturing load is uniform among all manufacturing facilities.

CONCLUSION

Due to the use of model, manufacturing load and capacity utilization is uniform among all the manufacturing facilities which results in better planning of manufacturing processes. Waiting time to perform any manufacturing process is reduced while product manufacturing as dashboard shows current load status so processes can be planned accordingly. The rework and rejection of products reduced during manufacturing results in improved quality of manufactured product and improved overall performance of the manufacturing facility. The bottlenecks in the manufacturing procees are detected at early stages of manufacturing which helps planning team to plan manufacturing activities accordingly which will not result in any bottleneck. Due to improved and effective planning of capacity utilization of resources the On Time Delivery percentage of products to customer increases which improves performance and trust level of customer towards organisation. Due to uniform load distribution among all manufacturing facilities excessive pressure of achieving targets is reduced for a particular plant which helps to improve morale and positive attitude among human resources. The lead time for product manufacturing is reduced due to impact of all the above outcomes. The reduction in lead time leads to reduction in overall cost of manufacturing. These all are the positive outcomes obtained by the use of model.

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