Australian Journal of Basic and Applied Sciences, 8(15) Special 2014, Pages: 319-325

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

A Decision Model to Assess Current Methods in Capacity Planning for Semiconductor Industry

Amir Azizi

Faculty of Manufacturing Engineering, Universiti Malaysia Pahang,26600 Pekan, Pahang Darul Makmur, Malaysia

ARTICLE INFO

Article history:
Received 15 September 2014
Accepted 5 October 2014
Available online 25 October 2014

Keywords:
analytic hierarchy process, capacity, decision model, semiconductor, pairwise comparison, uncertainty

ABSTRACT

Background: One of the main challenges of industrial engineering is being able to handle problems that happen in a factory, which consist of many random variables and constraints. Information is typically available with unforeseen uncertainties so that decision making about variables is very complicated. One such problem in high-technology industry like semiconductor that requires high-accuracy decision making in highly dynamic situations is capacity planning. An accurate capacity planning model not only requires correctly calculating decision variables but also requires considering and handling uncertain variables which are unknown like uncertainty in rapid rate of change in technology and products volume and type. The research objectives of this article are (1) to identify capacity planning problems, (2) to determine capacity planning methods, (3) to determine significant criteria for the decision model, (4) to calculate weight distribution of the existing methods with respect to the determined criteria using analytic hierarchy process (AHP), and (5) to conduct a sensitivity analysis to indicate how realistic the final outcome is. The industry chosen for this study is semiconductor wafer fabrication. This study found that the main problems in capacity planning are complex processes, rapid changes in technology and product, long lead time for procurement, cost of tools, uncertain demand, and uncertain capacity. The current methods for capacity planning in this study include spreadsheet, simulation, queuing model, linear programming model, and stochastic model. The criteria that are considered for this study are ability to consider uncertainty, ability to evaluate performance, simplicity of model, and response time of model. The study used questionnaires to identify significant criteria using academic experts' opinions. And also it used questionnaire to determine importance degree of each method for capacity planning using pairwise comparisons through industrial experts. Finally an AHP decision model has been proposed with overall inconsistency of 0.01. It presents that the stochastic method indicated by 33.08% is more suitable than other methods for capacity planning in semiconductor industry.

To Cite This Article: Amir Azizi., A Decision Model to Assess Current Methods in Capacity Planning for Semiconductor Industry. ***Aust. J. Basic & Appl. Sci.,*** *8(15): 319-325, 2014*

INTRODUCTION

This study addresses the capacity planning problems and current capacity planning methods with a focus on the semiconductor wafer fabrication industry. There are many definitions on capacity with different expression, but the concept is completely same. Capacity planning is the process of determining the amount of capacity required to meet changing demands for its products in the future.

Typically, semiconductor manufacturing processes consist four phases, which are wafer fabrication, wafer probe, assembly or packaging, and final testing. Wafer fabrication is the most technologically complex and capital intensive of all four phases (Uzsoy *et al.*, 1992). The planning of capacity especially in high-technology industry like wafer fabrication requires not only substantial investment in purchasing a new tool and machine but also requires an accurate capacity planning model. An accurate capacity planning model not only requires correctly calculating decision variables but also requires considering and handling uncertain variables which are unknown because of rapid rate of change in technology and products. This kind of models can decrease the gap between forecasted demand and production rate.

Corresponding Author: Amir Azizi, Faculty of Manufacturing Engineering,Universiti Malaysia Pahang,26600
Pekan,Pahang Darul Makmur,Malaysia.
Tel: (00609)-424 5845); E-mail: amirazizi@ump.edu.my

Capacity planning problems:

Capacity planning in semiconductor industry can be problematic because of six main reasons that are presented as follows.

1. Complex processes:

The industry presents a highly complex situation in terms of operation involving multiple types of work centers, large and changing varieties of products, sequence dependent setup times, and re-entrant process flow. For example, a wafer may visit the photolithography workstation eight or nine times for fabrication of all circuitry layers.

2. Rapid changes in technology and product:

The rapid rate of technology innovation causes short product lifecycles, low production yield and, often long production lead time, all of which hamper the firm's ability to respond to market changes.

3. Long lead time for procurement:

The lead time for procuring a tool could range anywhere from three months to a year. Thus, planners have to decide on tool procurement based on forecasts for demands for the next year. In a rapidly evolving technology environment, these forecasts could be highly inaccurate.

4. Cost of tools:

The cost of tools has been on the rise as indicated in (Fordyce and Sullivan, 1994). New fabrication may cost at least a billion US dollars and take more than a year to implement. Planners should decide about increasing capacity based on the current demand forecast for the next one or two years.

5. Uncertain demand:

Demands are unpredictable and can be decreased when a manufacturer does not have enough capacity during a period of high demand. Tool procurement is planned so that tools are used intensively while meeting the demand projections. Such a planning approach has often led to either lower utilization of tools (if the actual demand realized is less than projected) or have led to shortages (if actual demands are higher or if the mix changes). To overcome the above problem, the manufacturers are interested in developing a tool procurement policy that hedges against the uncertainty in future demands for various products.

6. Uncertain capacity:

Capacity also can be unpredictable because of random equipment downtime, rework, and scrap. Since product volumes are usually high, the imbalance between demand and capacity materialization always lead to undesirable business performance.

Capacity planning methods:

Many methods and models have been applied to overcome to the mentioned problems in previous section. The methods used for the semiconductor industry are categorized as follows.

1. Spreadsheet:

The spreadsheet is the simplest and most traditional method for planning tool procurement in capacity planning. Typically spreadsheets were employed for strategic capacity planning, for instance, (Witte, 1996) used the spreadsheet via Microsoft Excel for Harris Semiconductor. Typical input for this method includes the tool availability, tool utilization, and process throughput (in wafer starts per hour). Once the input is confirmed, the number of procured tools can be calculated. The needed tools by one process should equal the capacity of the wafer demand needs divided by the capacity of one tool.

2. Simulation method:

It is obvious that simulation can model capacity in a virtual world without actual procurement. Although the simulation model can provide more accurate information than the spreadsheet method, it requires more time to run a model and more information as input, for example, mean time between failures, mean time between repair, and their corresponding probability distributions for each tool group. It also is possible to estimate cycle time using simulation that is not possible with a spreadsheet (Spence and Welter, 1987).

3. Queuing model:

The queuing model is more complex than the simulation and spreadsheet methods. It is not as precise as simulation, but it can estimate performance more quickly. For instance, (Connors *et al*., 1996) developed an open queuing network model for rapid performance analysis of semiconductor manufacturing facilities.

4. Linear programming method:

Linear programming method takes some constraints or assumptions into consideration, which may not be appropriate for the real world because it cannot estimate or calculate uncertainties.

5. Stochastic model:

Compared to the stated methods, this method provides a potential for handling uncertainties or unknown variables. Jayashankar (2000) presented the uncertainty of product demand by a set of demand scenarios with associated probability of occurrence in a stochastic model. Stochastic integer programming is proposed to meet demand uncertainty using a few discrete cases. The objective was to minimize the weighted average of the unmet demand and with respect to capacity constraint (Hood *et al*., 2003; Swaminathan, 2000).

Significant criteria for the decision model:

To evaluate the performance preference of the five capacity planning methods that are mentioned for semiconductor industry in this study, four main criteria are proposed as follows.

1. Ability to consider uncertainty:

In a simple manufacturing environment, the basic problem to be resolved is the effective assignment of resources such as distributing capacities and facilities, and work force and time availabilities to fulfil demand and technological requirements. But these decisions will be complex when a firm deal with several plants, many distribution centres, many regional and local warehouses, and with multistage fabrication, high operation steps, high work centers, re-entrant flow that serve wide market areas affected by huge randomness in the demand pattern. Typically, decisions are made on utilization of regular and overtime workforce, allocation of aggregate capacity resources to product families, accumulation of seasonal inventories, and definition of distribution channels within the consideration of a medium-range time horizon. Capacity decision requires to consider uncertainties and risk attitudes that is one of the newest issues have been interested recently in the decision making process to have a real capacity planning. Recently most researchers and practitioners concentrate on the methods that enable to consider uncertainty.

2. Ability to evaluate performance:

Ability to evaluate any performance related to capacity planning. Such performance key indexes are cycle time and lead time.

3. Simplicity of model:

This criterion is also one of the significant criteria, a model which is simple in terms of calculating is more practical, but typically many mathematical models are complex.

4. Response time of model:

This criterion means how interface is and how easy to work with a model. It is needed to be considered as well to make a model more applicable and useful.

AHP:

The chosen decision making process in this study is complex, involving five capacity planning methods and four criteria. Thus, the problem is a multi-criteria decision problem with different priority levels. Analytical hierarchy process (AHP) is a methodology introduced by Saaty for multiple choice criteria problems. It is an approach to decision making that involves structuring multiple choice criteria into a hierarchy, evaluating the relative importance of these criteria, comparing alternatives for each criterion, and determining an overall ranking of the alternatives (Saaty, 1996). AHP can prioritize multiple alternatives with multiple criteria (Saaty, 1990). The solution steps of decision making in the AHP approach or AHP methodology is described by (Saaty, 1994; 1990). Therefore, this study applied AHP to solve the decision making problem due to identify suitable method for capacity planning problem.

One of the major strengths of AHP is the use of pairwise comparisons to derive accurate ratio scale priorities, instead of using traditional approaches of ‘assigning’ weights. In the pairwise comparison, a judgment expresses the strength of importance or preference of one element over another by an expert decision maker (Saaty, 1986). AHP generates the comparison weight for the decision-maker to predict the outcome of implementation. The AHP provides remarkable versatility and power in structuring and analyzing complex multi attribute decision problems.

Methodology:

The AHP solution process consists of four stages that are described as follows.

1. Determination of the relative importance of the criteria
2. Determination of the relative weight of each alternative with respect to each criteria
3. Determination of the overall priority weight of each alternative
4. Determination of the overall consistency indicator in making pairwise comparisons

Saaty's nine-points scale (Saaty, 1994) was used to determine the efficiency contribution of capacity planning methods through four significant criteria. Judgments in the pairwise comparisons were on a scale from 1–9 (1 = equally, 3 = moderately, 5 = strongly, 7 = very strongly, 9 = extremely). Intermediate values are used where appropriate (2 = equally to moderately, 4 = moderately to strongly, 6 = strongly to very strongly, 8 = very strongly to extremely) that is presented in Table 1 (Saaty, 1980).

Table 1: Degree of preference-Saaty's nine-points scale (Saaty, 1994).

Verbal Judgment of Preference	Equally preferred	Equally to moderately	Moderately preferred	Moderately to strongly	Strongly preferred	Strongly to very strongly	Very strongly preferred	Very strong to extremely	Extremely Preferred
Numerical Rating	1	2	3	4	5	6	7	8	9

Hierarchy Model:

A hierarchy is a tree-like structure that is used to decompose a decision problem. It has a top-down flow, moving from general categories to more specific ones. A hierarchy model for this study is elaborated as presented in Figure 1.

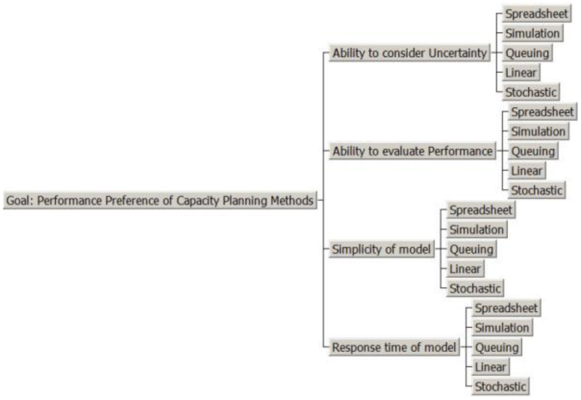

Fig. 1: Hierarchy structure of the decision model**.**

The relative importance degrees among four criteria based on academic experts' opinions are established in Table 2. Where, C1= "ability to consider uncertainty", C2= "ability to evaluate performance", C3= "simplicity of model", and C4=" response time of model".

Table 2: Matrix of paired comparison for criteria.

	C1	C2	C3	C4
C1	1	1	6	5
C2	1	1	5	5
C3	1/6	1/5	1	1/2
C4	1/5	1/5	2	1
Total	2.3666667	2.4	14	11.5

Table 3. presents the relative weight of capacity planning methods as the alternatives through pairwise comparison with respect to "ability to consider uncertainty". Where, A1= "spreadsheet", A2= "simulation method", A3= "queuing method", A4= "Linear model", and A5= Stochastic model"

Table 3: Paired comparison with respect to "ability to consider uncertainty".

	A1	A2	A3	A4	A5
A1	1	1	1	1	1/9
A2	1	1	1	1	1/9
A3	1	1	1	1	1/9
A4	1	1	1	1	1/9
A5	9	9	9	9	1
Total	13	13	13	13	1.444444

Table 4 presents the relative weight of capacity planning methods through pairwise comparison with respect to “ability to evaluate performance”.

Table 4: Paired comparison with respect to “ability to evaluate performance”.

	A1	A2	A3	A4	A5
A1	1	1/9	1/9	1	1
A2	9	1	1	9	9
A3	9	1	1	9	9
A4	1	1/9	1/9	1	1
A5	1	1/9	1/9	1	1
Total	21	2.333333333	2.333333	21	21

Table 5 presents the relative weight of capacity planning methods through pairwise comparison with respect to “simplicity of model”.

Table 5: Paired comparison with respect to “simplicity of model”.

	A1	A2	A3	A4	A5
A1	1	4	9	5	9
A2	1/4	1	5	2	4
A3	1/9	1/5	1	1/4	1/2
A4	1/5	1/2	4	1	2
A5	1/9	1/4	2	1/2	1
Total	1.6722222	5.95	21	8.75	15.5

Table 6 presents the relative weight of capacity planning methods through pairwise comparison with respect to “response time of model”.

Table 6: Paired comparison with respect to “response time of model”.

	A1	A2	A3	A4	A5
A1	1	9	8	7	7
A2	1/9	1	1/2	1/3	1/3
A3	1/8	2	1	1/2	1/2
A4	1/7	3	2	1	1/2
A5	1/7	3	2	2	1
Total	1.5218254	18	13.5	10.83333	9.333333

Results:

The result shows that the most important criterion is “ability to consider uncertainty”, which represents by C1 and indicated by 42% or 0.42. The importance degrees of other criteria are presented in Table 7.

Table 7: Calculation of priority weights of criteria.

Average	Extracted from Table 2
C1	0.422591
C2	0.398782
C3	0.075061
C4	0.103566
Total	1

The priority weights of five capacity planning methods that are spreadsheet, simulation, queuing model, linear programming model, and stochastic model are presented in Table 8.

Table 8: Calculation of priority weights of capacity planning methods.

Average	Extracted from Table 3	Extracted from Table 4	Extracted from Table 5	Extracted from Table 6
A1	0.076923	0.047619	0.563146	0.62917
A2	0.076923	0.428571	0.205332	0.046418
A3	0.076923	0.428571	0.04131	0.07341
A4	0.076923	0.047619	0.125922	0.110913
A5	0.692308	0.047619	0.06429	0.140089
Total	1	1	1	1

Finally, overall weight of the capacity planning methods in synthesis distributive mode is calculated as follows.

A1=Spreadsheet= $(0.076923\times0.422591) + (0.047619\times0.398782) + (0.563146\times0.075061) + (0.62917\times0.103566) = 0.15892$

A2=Simulation= $(0.076923\times0.422591) + (0.428571\times0.398782) + (0.205332\times0.075061) + (0.046418\times0.103566) = 0.22363$

A3=Queuing= $(0.076923 \times 0.422591) + (0.428571 \times 0.398782) + (0.04131 \times 0.075061) + (0.07341 \times 0.103566) = 0.21411$
A4=Linear= $(0.076923 \times 0.422591) + (0.047619 \times 0.398782) + (0.125922 \times 0.075061) + (0.110913 \times 0.103566) = 0.0724$
A5=Stochastic= $(0.692308 \times 0.422591) + (0.047619 \times 0.398782) + (0.06429 \times 0.075061) + (0.140089 \times 0.103566) = 0.33088$

The overall weight of the capacity planning methods presents that stochastic method is more suitable for capacity planning which is indicated by 33% or 0.33. It means that stochastic method can satisfy all the criteria more than other capacity planning methods.

The consistency ratio (C.R.) for a comparison can be calculated to determine the acceptance of the attribute priority weighting above. It is an approximate mathematical indicator, or guide, of the consistency of pairwise comparisons. If it is not greater than 0.1, the consistency is generally quite acceptable for pragmatic purposes as suggested by Saaty (1994, 1996). In this case, the overall C.R value was found to be 0.01.

The results also scrutinize the pairwise comparison between the capacity planning methods as head to head with respect to all four criteria. Figure 2 shows how two alternatives – stochastic and simulation methods are compared to each other against the four criteria. For example, stochastic method is preferred to simulation with respect to "ability to consider uncertainty" since a horizontal bar is displayed towards the left. The overall percentage of this sensitivity comparison is displayed at the bottom of the graph and shows that stochastic model has a better efficiency or a more preference rather than simulation method considering the four significant criteria.

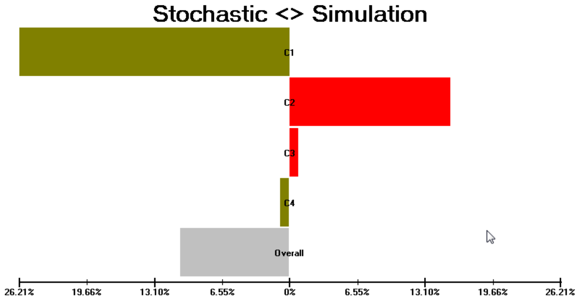

Fig. 2: Weighted head to head between stochastic model and simulation method.

Dynamic sensitivity analysis has been used to dynamically change the priorities of the important criteria to determine how these changes affect the priorities of the capacity planning methods choices. The sensitivity analysis, as shown in Figure 3, presents that simulation method is replaced by stochastic when the importance weight of "ability to consider uncertainty" was decreased by 12.2%, or the importance weight of "ability to evaluate performance" was increased by 13.3%. And the sensitivity analysis presented that spreadsheet is replaced by queuing when the importance weight of "simplicity of model" was changed up by 10.5% or the importance weight of "response time of model" was increased by 9.6%.

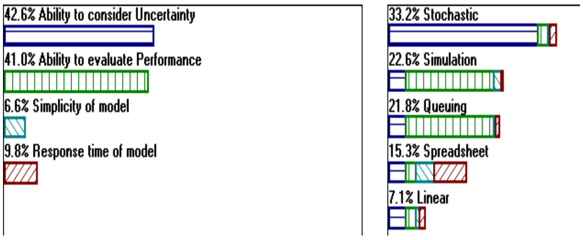

Fig. 3: Dynamic sensitivity of capacity methods.

Conclusion:

This study presented the capacity planning problems, the considerable related criteria, and the existing fundamental methods on capacity planning for semiconductor industry through the current researches and literatures. In conclusion, spreadsheets can solve simply capacity planning, and simulation method can calculate the performance like cycle time. However, both spreadsheets and simulation need trial-and-error runs, which are far from optimal and take long time especially for simulation method if the problem is complex and large. Due to the complicated production process, queuing model is difficult to build. Linear programming method is most commonly used without enough robust. Stochastic programming model is widely used in the manufacturing environment considering uncertainty into account. Consequently, two main methods can be applied to handle uncertainty such as stochastic programming and scenario programming. But since typically determination of uncertainty is done by manager linguistically, the measurement of this determination is vague. Therefore, this study recommends using fuzzy approach to overcome vagueness. Uncertainty can be presented by fuzzy membership functions. The future capacity planning model for complex and dynamic manufacturing environment should allow the planners and managers to more easily identify data issues so that correct planning decision can be generated.

ACKNOWLEDGEMENT

This study is supported by Universiti Malaysia Pahang (UMP). We thank the anonymous referees for valuable comments and suggestions.

REFERENCES

Connors, D.P., G.E. Feigin and D. Yao, 1996. A queueing network model for semiconductor manufacturing. IEEE Trans. on Semiconductor Manufacturing, 9(3): 412-427.

Fordyce, K., G. Sullivan, 1994. A dynamically generated rapid response capacity planning model for semiconductor fabrication facilities. Impact of Emerging Technologies on Computer Science and Operations Research. Kluwer Publishing, Dordrecht, 103-127.

Jayashankar, M.S., 2000. Theory and Methodology Tool capacity planning for semiconductor fabrication facilities under demand uncertainty, European Journal of Operational Research, 120: 545-558.

Hood, S.J., S. Bermon and F. Barahona, 2003. Capacity Planning Under Demand Uncertainty for Semiconductor Manufacturing. IEEE Transactions on Semiconductor Manufacturing, 16(2): 273 - 280.

Saaty, T.L., 1980. The Analytic Hierarchy Process. New York, NY: McGraw-Hill.

Saaty, T.L., 1986. Exploring optimization through Hierarchies and ratio scales. Socio-Econ. Plann. Sci, 20(6): 355-360.

Saaty, T.L., 1990. Multicriteria Decision Making - The Analytic Hierarchy Process, AHP Series, McGraw Hill, New York, NY.

Saaty, T.L., 1994. The Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process. AHP Series, RWS Publication, Pittsburgh, PA. 527.

Saaty, T.L., 1996. Multicriteria Decision Making. RWS Publications, PA.

Spence, A.M. and D.J. Welter, 1987. Capacity Planning of a Photolithography Work Cell in a Wafer Manufacturing Line. Proceedings of the IEEE Conference on Robotics and Automation, 702-708.

Swaminathan, J.M, 2000. Tool capacity planning for semiconductor fabrication facilities under demand uncertainty. European Journal of Operational Research, 120: 545-558.

Uzsoy, R., C. Lee and L.A. Martin-Vega, 1992. A review of production planning and scheduling models in the semiconductor industry, Part-I: System characteristics. Performance evaluation and production planning. IIE transactions 24(4): 47-61.

Witte, J.D., 1996. Using Static Capacity Modeling Techniques in Semiconductor Manufacturing. IEEE/SEMl Advanced Semiconductor Manufacturing Conference.