Semiconductor:
To Build or To Buy?

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Project Title: **Semiconductor: To Build or To Buy ?**
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Table of Contents:

I. Introduction

As we are moving into the fourth industrial revolution, we are dependent on an increasing number of technologies that are quickly changing the way humans create, exchange, and distribute value (Klaus Schwab, 2018). As semiconductors is a crucial electronic component of all these technologies, (Allied Components International, 2016), the demand for semiconductor is growing rapidly[1] (Thomas Alsop, 2021).

To keep up with the rising demand, a company's decision whether to outsource their manufacturing process or build their own fab becomes more significant due to the higher opportunity cost incurred. Thus, the company should consider various factors including cost, confidentiality leakage, reliability of the supply chain and degree of autonomy of production & differentiation.

II. Factors of Consideration

1. Capital Investment

In decision making, the preliminary factor is cost. It is important to weigh the differences in cost of building its own fab and outsourcing their manufacturing process to limit the input cost, thus, increasing the revenue.

a. *Cost in Building Fab*

The cost to build a semiconductor wafer fabrication plant increased over the years, from 2–3 billion US dollars in 2004, up to 20 billion in 2020 (Table 1).

Year	Cost (US$ billion)
2004	2-3
2011	3-4
2020	7-20

Table 1: Cost of building a semiconductor fab over the year

It is indubitable that building a fab is a lucrative investment, yet, with delayed returns. 12 to 24 months is needed to build a shell of a fab and install the required tools, and another 12 to 18 months to ramp-up to full capacity. Should demand fall, or costs exceed expectations, the returns could be much lower than expected (McKinsey & Company, 2020)

1 Demand for semiconductor is growing rapidly# from $299b in 2012 to $466b in 2020 (Thomas Alsop, 2021)

Furthermore, semiconductor fabrications generally require retooling every few years. In 2007, Intel Corp invested $1.5 billion to retool a factory[2]. The cost of developing the latest technologies is exorbitant. Companies are expected to keep spending a substantial amount for R&D, for instance, designing a 5 nm chip costs $540 million from validation to IP qualification, higher than $300 million required for a 7 nm chip, and higher than the $175 million required to design a 10 nm chip and (Fig 1).

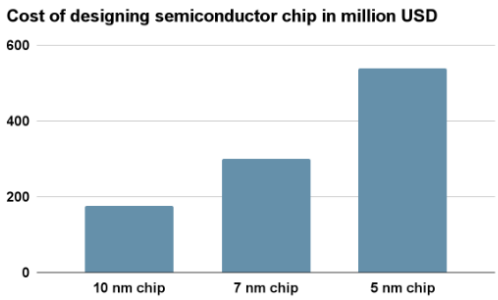

Fig 1: *Cost of designing semiconductor chips*

Between 2010 and 2018, the U.S. semiconductor manufacturing industry's domestic expenditures for new plants and equipment ranged from $11 billion to $22 billion (United States Census Bureau, 2017).

b. Cost in Outsourcing

In response to higher costs, semiconductor companies resorted to fabless strategies by outsourcing a large fraction of their production. Today, these fabless companies generate one-third of industry revenue (Jeff Thurk, 2019), providing cost-advantages in this fabless strategy.

Firstly, outsourcing fabrication avoids billions of dollars of capital investment to build a fabrication facility and hence, to reach the break-even point and start creating profit in a much shorter period of time.

Secondly, outsourcing, often from overseas (Table 2), enables them to lower input costs as they pool production with other fabless companies in third-party foundries; and allows them to take advantage of lower foreign wages and weaker environmental standards.

[2] Fab11X, in Rio Rancho, New Mexico, which would start to make chips with cutting-edge 45-nanometer-wide transistors in the second half of 2008

Fabless Production Market Share by Country

YEAR	CHINA	JAPAN	KOREA	SINGAPORE	TAIWAN	USA	OTHER
2004	11.07	6.07	5.78	14.56	45.42	3.75	13.35
2005	2.47	4.89	2.47	6.04	69.06	2.66	12.41
2006	2.36	7.37	5.58	13.35	57.26	3.54	10.54
2007	6.38	2.95	3.18	18.74	57.81	2.19	8.75
2008	6.44	6.42	4.69	14.97	57.90	2.00	7.58
2009	6.87	6.82	2.22	9.49	64.83	4.30	5.47
2010	7.42	11.73	3.42	6.90	58.75	7.16	4.62
2011	13.84	8.02	4.44	4.05	59.07	6.48	4.10
2012	4.99	4.01	7.43	3.19	68.53	4.45	7.40
2013	5.97	14.45	5.70	2.83	62.91	3.74	4.40
2014	9.30	24.09	5.97	5.26	46.31	4.14	4.93
Total	7.17	8.38	4.71	8.70	59.38	4.13	7.53

Notes: Author's calculation based on GSA wafer pricing survey (2004-2015). Statistics reflect the share of wafers produced by third-party fabrication facilities in a given year. "Other" includes Europe and other countries with small market shares (e.g., India, Israel).

Table 2: *Increasing outsourcing from overseas; Taiwan is seen to account for approximately 59% of all outsourced wafers produced, followed by Singapore with approximately 9%*

Outsourcing has resulted in an overall net reduction of capital expenditures in the industry, from an average of approximately 27% of the revenue (from 1996 to 2001) to approximately 20% of the revenue (from 2002 to 2009) (McKinsey on Semiconductors, 2011). Hence, outsourcing reduces the input costs of business.

2. Confidentiality

Possible leakage of confidential information is another factor to be considered. It is essential to ensure that the third parties who have access to confidential information are protecting that information from disclosure and misuse, to prevent the loss of market share of the technological companies.

a. Case Study

In a case study of L.M.Ericsson[3] 2002, Gosta Lemne stated "***we have to do it ourselves [internally] because the typical DSPs on the external markets are like an estate wagon with a powerful engine ….But if we know the algorithms well enough, we may very well be able to come up with more optimized task-specific designs. We do not want to make those designs available to our customers by sharing the knowledge through our suppliers***". This shows if there is no guarantee that the outsourcing service will keep the designs in confidence, there is a likelihood of leakage of business secrets to the competitors (Elena Bundaleska, 2013).

This is especially true in the semiconductor industry. Customers have a wide range of choices in the market filled with various types of conductors. The upper edge gained by

[3] **Telefonaktiebolaget LM Ericsson** (lit. *Telephone Stock Company of LM Ericsson*), commonly known as **Ericsson**, is a Swedish multinational networking and telecommunications company headquartered in Stockholm. The company sells infrastructure, software, and services in information and communications technology for telecommunications service providers and enterprises, including, among others, 3G, 4G, and 5G equipment, and Internet Protocol (IP) and optical transport systems

a secret adjustment for product optimization can bring profits to the company. However, outsourcing would potentially expose that upper edge, if the outsourcing manufacturer cannot guarantee confidentiality (Christine Harland, Louise Knight, and Richard Lamming, 2005). In outsourcing, it is difficult to ensure information protection by service providers, who may not be bound by the same laws and regulations as their clients. Such protection is often to prevent competitors from stealing customers, and more importantly, to increase the reliability of that firm in the eyes of investors (Axelrod, 1983).

Meanwhile, in-house fabrication would ensure a higher level of confidentiality. SLIC-chips[4] were relatively standardized and manufactured in large volumes, which was suitable for outsourcing, yet, Ericsson kept the design algorithms secret by manufacturing these components in-house (Lemne, 2002). It was also stated in this case that ***"Many suppliers would like to be involved in the design and manufacturing of most important chips to get a glimpse of our algorithms for Radio Base Station (RBS), but we do not want to risk sharing our crown jewels with our competitors through the suppliers"***. Thus, building their own fab would be a better choice in terms of confidentiality, which may help to potentially differentiate their products in the market.

b. Overcoming Confidentiality Limitations

However, this can be overcome by legal terms for any breach of non-public information protection, especially for fraudulent endeavors[5]. Such legal contracts are to protect sensitive information or databases. As such, the concern of confidentiality is more ensured in outsourcing[6].

Hence, with this agreement in place, firms can minimize the chance of leakage of confidential information in considering outsourcing over building in. However, results may not be certain.

3. Reliability on the Supply Chain and the Degree of Autonomy of Production & Differentiation

a. Capacity Decision especially under Uncertainties of Demand & Supply

The semiconductor industry is a productive but volatile industry (Tan & Mathews, 2010) with uncertain emergence of demand. From Fig. 2, over time, the demand (for each type of semiconductors) is generally increasing yet the variance of demand should not be ignored.

[4] An SLIC, also known as a subscriber line interface card, is a modular electronic circuit that interfaces with a telecommunications network. It is used to convert analog voice communications to digital, and vice versa.

[5] Non-Disclosure Agreement is a legally binding contract between the provider and recipient of confidential material, knowledge or information. It is an undertaking not to disclose such confidential information covered under the agreement (Singapore Legal Advice, 2020).

[6] Legal actions can be taken if the confidentiality of the information about the product is compromised, thus prompting the service to promote a strategy to keep the details secret among its employees (Dickson, 2019)

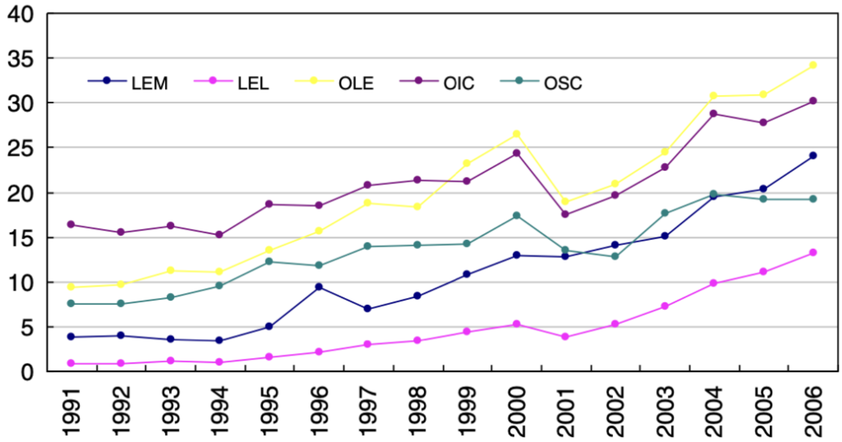

***Fig 2:** Worldwide demand of microchips by product segments[7] (Source, Int.J.Production Economics, 2007)*

The variance in microchip sales proved exactly the same assumption. Fig. 3 showing that the trend of sales before 1995 was predictable yet the industry seemed to enter an area of great volatility after 1995.

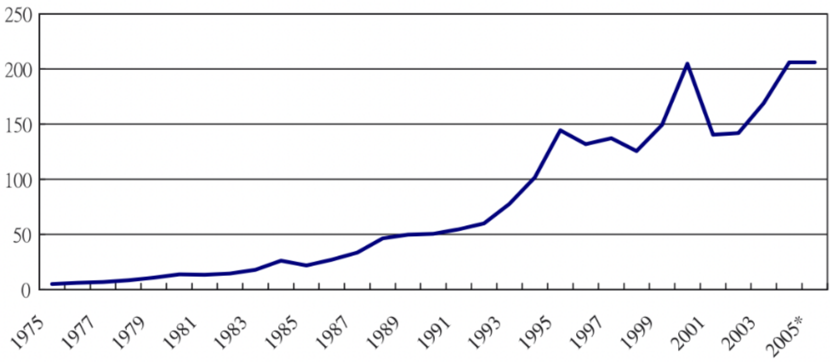

***Fig 3:** Global sales of Microchips (in $ billion), from 1975 to 2005*

Similarly, in Fig. 4, the volatility in global sales of semiconductors is observed from 2017 up to now, despite an obvious growth in sales.

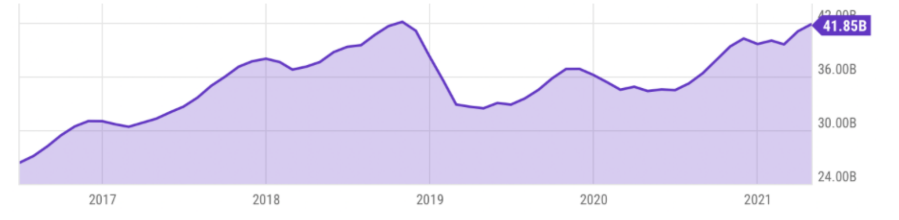

***Fig 4:** Global sale of semiconductors from 2017 to 2021 (Source: Y Chart 2021)*

Yet, the production and manufacturing of semiconductors — whether it is in-house or outsourced — need to meet the capacity requirement despite this uncertainty of demand and sales.

On one hand, due to the constraints of order flexibility and dependence on various legal clauses of rolling-horizon flexibility contracts[7] between the suppliers of semiconductors and the tech companies (Knoblich et al 2014), outsourcing production is equivalent to being reliable on an inflexible supply chain. As a result, the companies are unable to increase the production of certain tech products by much due to the inability to increase the imports of semiconductors, hurting the revenue stream of the companies should the demand be on the rise.

On the other hand, executing in-house manufacturing allows companies to improve on manufacturing yield themselves with the implications of scientific and industrial procedures (N.Kumar et al, 2006; S.-C.Hsu, C.-F. Chien, 2006). Consequently, companies would be less dependent on the supply chain of semiconductors, thus, being able to increase the outputs of products due to the autonomy in increasing the production of semiconductors, contributing to the rise of revenue of companies.

Therefore, it is imperative for companies to consider capacity planning under demand variance as a factor in the decision whether to outsource production or to build a new fab.

The trade-off between building a new fab and outsourcing production is analysed using a programming model[8] (A.P Rastogi et al, 2011) to provide numerical studies and conditions for decision-framework.

Variance in demand[9] is studied by investigating the correlation of demands[10] of 2 products from 2 families produced in the same company. The uncertain demand is parameterised (Meixell & Wu, 2001) by its deviation from the mean and the correlation between the demands of the two product families.

The study found that when demands of 2 products are negatively correlated (r = - 0.4) (Fig. 5). The decision to build a new fab to meet the expected demand is recommended when the deviation in demand from the forecast is 20% or less.

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[7] Rolling-horizon flexibility contracts are legal means to coordinate demand and supply under uncertain emergent demand to support them in their emergent markets (Knoblich et al, 2014)

[8] Stochastic Integer Mixed Programming is used to handle demand uncertainty to make dynamic decision based on realisation of demand (A.P Rastogi et al, 2011)

[9] By including various parameters, costs objectives & constraints in the 2 stages (A.P Rastogi et al, 2011)

[10] The relationship between the demand of two products is presented by the assumption that the demand for one product increases when it reaches a peak in demand and once a new product is introduced, the demand for current product declines.

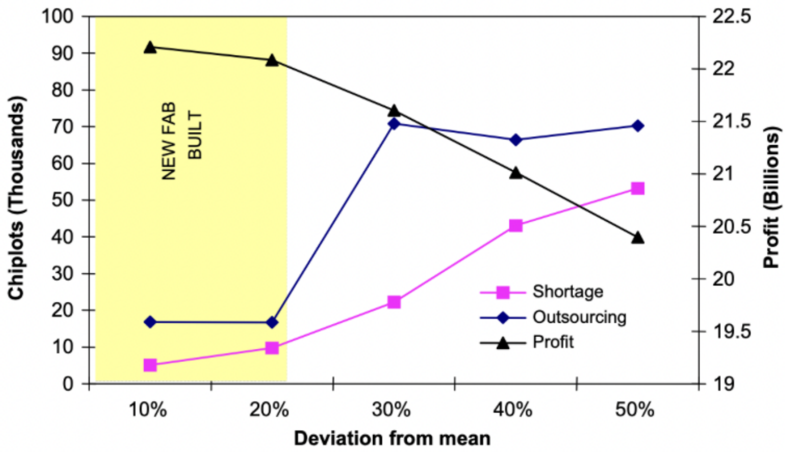

Fig 5: *Negative Correlation of demands(r = -0.4)*

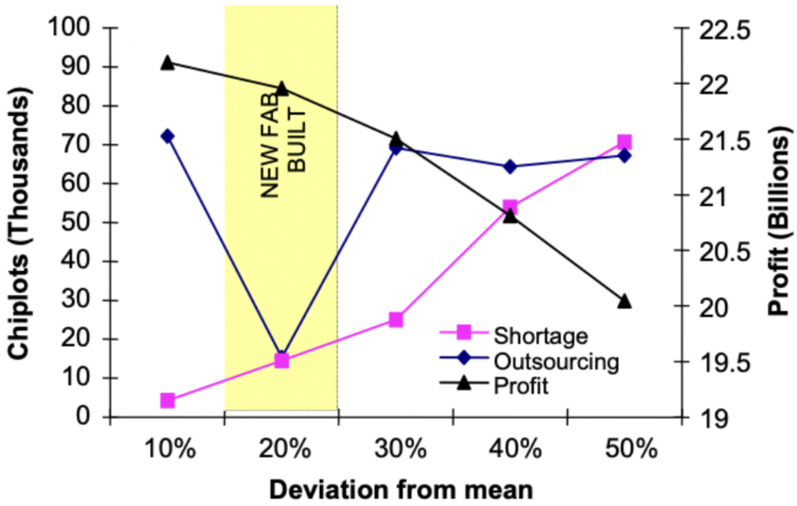

Fig 6. *Zero Correlation of demands(r = 0)*

When the demand is non-related to each other (r = 0, Fig 6) meaning the demand of one product does not affect that of the other. The decision to build a new fab is only recommendable as it is profitable when the deviation from the demand is 20%.

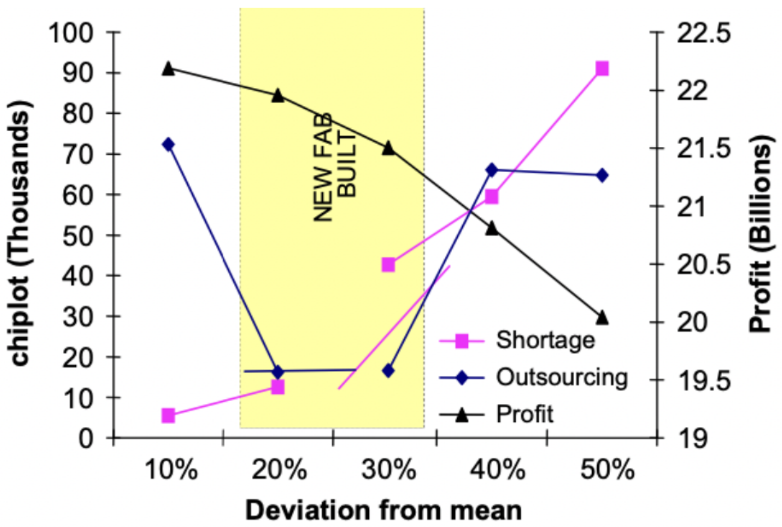

Fig 7.Positive correlation of demand (r=0.4)

As the demand for products is positively correlated (r = 0.4), the company should build in when the deviation in demand is about 20% to 30% from the mean.

Therefore, the company should consider the uncertainty of demand, determined by the correlation of demand and deviation from the mean, to decide whether building a new fab or outsourcing production would be more profitable.

b. Key Value Proposition: Potential to Differentiate

When analysing the decision for outsourcing, it is tied to the risk of not differentiating products enough compared to building fab for internal manufacture (H. Glimstedt et al, 2010).

From the case study of L.M. Ericsson, the decision to buy from external sources or to make internally is based on the specific product's market share and potential for product differentiation (Lemme, 2009).

For example, with the introduction of new technology, the RBS needed to do more complex tasks[11]. At the same time, as Texas Instruments[12] wanted to make digital signal processors[13] more powerful; they introduced a new innovative function. Yet, Ericsson found that this architecture was not well fitted into the RBS's main function. By developing a unique RBS chip specifically adapted to specific tasks of RBS internally, Ericsson differentiated their RBS's from the competition.

Compared to in-house internal manufacturing, outsourcing was considered more suitable for large market share, thus, was more suitable for the supply of standardised

[11] The high advance of technology then was not really addressed and discovered by the 3G algorithms in the late 1990s (H.Glimstedt et al, 2010)

[12] **Texas Instruments Incorporated** (**TI**) is an American technology company headquartered in Dallas, Texas, that designs and manufactures semiconductors and various integrated circuits, which it sells to electronics designers and manufacturers globally.[6] It is one of the top 10 semiconductor companies worldwide based on sales volume (Wikipedia, 2021)

[13] TI started to develop in the late 1970s

commercial chips. In other words, outsourcing inherents a lower potential to differentiate a product in the market.

Thus, based on the key value proposition of the products that the company is aiming to bring to the market, the company can decide between internally manufacture semiconductors or outsource the production

III. Conclusion

Ultimately, the decision to outsource or build their own fab relies on many factors but these three, in particular, are of utmost significance: cost; confidentiality; and reliability of the supply chain and the degree of autonomy of production. This is where different circumstances — their method of resource allocation, the culture of the company, and the risk level the company is able to bear play— play a significant role. For the best decision to be made, a company must consider all factors carefully and objectively assess them for both the short term and the long term.

IV. Reference

1.Chou, Y.-C., Cheng, C.-T., Yang, F.-C., & Liang, Y.-Y. (2007). *Evaluating alternative capacity strategies in semiconductor manufacturing under uncertain demand and price scenarios. International Journal of Production Economics, 105(2), 591–606*
2. Elena Bundaleska, Makedona Dimitrova, Vlado Navmoski (2013). *Outsourcing, can we go wrong?*. University American College Skopje, Republic of Macedonia
3. McKinsey on Semiconductors (2011). *McKinsey & Company*
https://www.mckinsey.com/~/media/mckinsey/dotcom/client_service/semiconductors/pdfs/mosc_1_revised.ashx
4. Congressional Research Service (2020). *Semiconductors: U.S. Industry, Global Competition, and Federal Policy*.https://fas.org/sgp/crs/misc/R46581.pdf
5. McKinsey & Company (2020). *Semiconductor design and manufacturing: Achieving leading-edge capabilities.*
https://www.mckinsey.com/industries/advanced-electronics/our-insights/semiconductor-design-and-manufacturing-achieving-leading-edge-capabilities#
6. United States Census Bureau (2017). https://www.census.gov/programs-surveys/asm/data/tables.html
7. Jeff Thurk (2019). *Outsourcing, Firm Innovation, and Industry Dynamics in the Production of Semiconductors*. Yale University
8. Semiconductor Industry Association (2016). *Beyond Borders. The Global Semiconductor Value Chain.*
https://www.semiconductors.org/wp-content/uploads/2018/06/SIA-Beyond-Borders-Report-FINAL-June-7.pdf
9. ExtremeTech Staff (2007). *Intel to Retool N.M. Fab for 45-nm Chips*
https://www.extremetech.com/extreme/77768-intel-to-retool-nm-fab-for-45nm-chips
10. Computer Hope (2017) SLIC https://www.computerhope.com/jargon/s/slic
11. Henrik Glimstedt, Donald Bratt and Magnus P. Karlssony (2010). *The decision to make or buy a critical technology: semiconductors at Ericsson, 1980-2012. Industrial and Corporate Change, Volume 19, Number 2, pp. 431–464*. doi:10.1093/icc/dtq011
12. Y-Char (2021), *Worldwide Semiconductor Sales (2021).* https://ycharts.com/indicators/worldwide_semiconductor_sales
13. Macher, J. T. (2006). *Technological Development and the Boundaries of the Firm: A Knowledge-Based Examination in Semiconductor Manufacturing. Management Science, 52(6), 826–843.*doi:10.1287/mnsc.1060.0511
14. Rastogi, A. P., Fowler, J. W., Matthew Carlyle, W., Araz, O. M., Maltz, A., & Büke, B. (2011). *Supply network capacity planning for semiconductor manufacturing with uncertain demand and correlation in demand considerations. International Journal of Production Economics, 134(2), 322–332.* doi:10.1016/j.ijpe.2009.11.006
15. Malli Mohan and Karthikeyan (2010), Outsourcing trends in Semiconductor Industry. Massachusetts Institute of Technology. Engineering Systems Division.
16. Wally Rhines, Chapter 8 - Value Through differentiation in Semiconductor Business
https://semiwiki.com/wally-rhines/274559-chapter-8-value-through-differentiation-in-semiconductor-businesses/
17. Cunningham, S. P., Spanos, C. J., & Voros, K. (1995). *Semiconductor yield improvement: results and best practices. IEEE Transactions on Semiconductor Manufacturing, 8(2), 103–109.*doi:10.1109/66.382273
18. Knoblich, K., Heavey, C., Williams, P., Quantitative Analysis of Semiconductor Supply Chain Contracts with Order Flexibility under Demand Uncertainty: A Case Study, Computers & Industrial Engineering (2015)
19. Mohan, Karthikeyan. (2011). *Outsourcing trends in Semiconductor industry.*
20. Syed Alam, James Wildenburgh, Vanessa Naik. IS YOUR MANUFACTURING SOURCING STRATEGY ERODING COMPETITIVENESS?. Accenture Strategy.
21. Wu, JZ., Chien, CF. Modeling strategic semiconductor assembly outsourcing decisions based on empirical settings. OR Spectrum 30, 401–430 (2008).
22. Lin, Y.-T., Lin, C.-L., Yu, H.-C., & Tzeng, G.-H. (2010). A novel hybrid MCDM approach for outsourcing vendor selection: A case study for a semiconductor company in Taiwan. Expert Systems with Applications, 37(7), 4796–4804.doi:10.1016/j.eswa.2009.12.036
23. Hsu, S.-C., & Chien, C.-F. (2007). Hybrid data mining approach for pattern extraction from wafer bin map to improve yield in semiconductor manufacturing. International Journal of Production Economics, 107(1), 88–103. doi:10.1016/j.ijpe.2006.05.015
24. Jo, H.-J., Connerton, T., & Kim, H.-J. (2019). Dynamic Outsourcing Development for Sustainable Competitive Advantage in a High-Tech Backend Semiconductor Equipment Firm. Sustainability, 12(1), 155. doi:10.3390/su12010155
25. Kumar, N., Kennedy, K., Gildersleeve, K., Abelson, R., Mastrangelo, C. M., & Montgomery, D. C. (2006). A review of yield modelling techniques for semiconductor manufacturing. International Journal of Production Research, 44(23), 5019–5036.doi:10.1080/00207540600596874