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Cost Planning and Target Setting
na Infineon Technologies AG

LGEI

Porto, 2003

University of Porto
Engineering Faculty

Management and Industrial Engineering

Curricular Internship

in

Infineon Technologies AG

Curricular Internship

Management and Industrial Engineering
2001/2002

Cost Planning and Target Setting

The REFERENCE FAB Model

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Munich

October 2002

Foreword

This report concludes a six-month internship in Industrial Management and Engineering in the Memory Products/ Business Administration/ Production Planning and Controlling/ Backend department (MP BA PPC BE) of Infineon Technologies AG. This department is situated in Munich, Germany, and belongs to Infineon's central headquarters.

The target readers of this report are both University teachers and Infineon staff members. Therefore, in order to assure confidentiality and to use the report outside of Infineon, fictional data will be used when necessary, and more detailed information will be left out. More specific documentation is available at Infineon for its staff members, namely those who will proceed with the work carried out in this internship.

At the beginning, the objective of the internship was to simplify and update a model called "Reference Fab". This model is used by the head office for:

- cost and efficiency planning and target setting for the Backend sites, and
- benchmarking the sites internally (which is the key for continuous improvement).

As this work developed, a problem in the model was identified: so far it had ignored the fact that the Dresden Backend develops more engineering activities, which implies more cost and resource usage per unit produced in contrast to the other Infineon sites which concentrate mostly on production activities. The reporting and planning system did not take this into account in a quantitative way. Although everybody understood why the reported costs were so high at Dresden, it was not possible to identify which cost component was due to the site's "special mission" and what component should be attributed to other reasons, in particular to inefficiency. Once this problem was identified a project was set up in order to quantify the different cost components and to support planning and target setting for the engineering activities.

The update of the "Reference Fab" was concluded in time to set the next business year cost targets for the Backend sites. These targets were accepted by the sites after the usual negotiation.

A proposal for reporting and planning the engineering activities at Dresden was developed. That site accepted the overall concept, and full identification of the engineering projects was achieved.

Acknowledgements

My special thanks to Claudio Fernandes for proposing this internship, facilitating it and giving constant support to it.

I also thank my supervisor at the University of Porto, Prof. Rui Guimarães, for his support and advice.

In addition I would like to thank everyone whom I worked with at Infineon Technologies, who directly or indirectly made this work possible. My special thanks to Sven Starke, who gave me support in the final part of my work and on my visit to Dresden.

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1 Introduction

1.1 Objectives of the Internship

The first objective of the internship was to update and review a model called "Reference Fab". This model is used by Infineon Technologies to set cost targets for the Backend sites and to benchmark the sites internally, in order to find opportunities for improvement and to set Best Practices. The overall objective was to simplify the model so as to shorten the planning process; specifically, the simplified model was intended to produce new planning targets by the end of the planning period. This was achieved by the end of July. Meanwhile, the Key Performance Indicators used to benchmark the sites internally were properly documented.

After the review of the "Reference Fab" model began, a mismatch between the model assumptions and reality in one of the sites was detected. This site, located in Dresden, does not have the same mission as all the others. Its aim is not only to manufacture low cost products but also to develop new products, to perform engineering activities in order to develop new processes and to support the two Frontend sites which are also located in Dresden. These additional activities imply higher costs than those associated with only mass volume production. Although this problem had been acknowledged, no targets had been proposed for the planning and costing of engineering activities. What part of the overall cost was due to the site's "special mission" and what part was the result of inefficiencies could not be identified.

The objective of the second part of the internship was to solve this problem. The engineering activities needed to be described in a way that would make it possible to calculate the costs incurred by them. The result would then be integrated into the existing tools in order to validate the model with past information and, if possible, to plan the costs and efficiencies for the next business year. As this project was only begun in the last part of the internship not all of its objectives were achieved. However, a new model was proposed for, and accepted by, the Dresden site. This model included the definition of all the engineering activities so as to be able to compute their associated costs.

1.2 Structure of the Report

Following the brief introduction, a description of Infineon Technologies, AG will be given.

The Memory Products market will be presented in chapter 3.

Chapter 4 addresses the Planning and Target Setting method used by Infineon.

Chapter 5 analyses the Backend Production, and the different steps involved in transforming a chip into a memory module are identified.

In the following chapter a model used for Volume Normalisation is discussed, and an explanation is given on how the different products are normalised into a single entity in order to simplify all cost calculations. This explanation is needed in order to fully understand the cost models.

Chapter 7 includes a description of the Reference Fab Model, together with an explanation of the Key Performance Indicators which are the basis for the cost target setting and benchmarking. This chapter concludes with the results achieved in the initial target setting exercise carried out with the improved Reference Fab Tool.

In chapter 8, the cost structure of the Backend operations is analysed, and some comparisons between the sites are presented.

The following chapter includes some comments on several specific problems which occurred during the Reference Fab update, as well as on how they were dealt with and solved.

Problems concerning the engineering activities are discussed in chapter 10. This chapter includes the definition of the problem, the proposal of a solution, and closes with the conclusions and recommendations on this proposal.

The report ends with a final conclusion on the work carried out and of the internship experience.

2 Infineon Technologies AG

Comprised of all of Siemens' semiconductor activities, Infineon Technologies AG[1] was founded on April 1st 1999 and it soon became one of the ten largest semiconductor manufacturers in the world and number two in Europe. It has 16 manufacturing sites and 29 research and development locations in Asia, Europe and the USA, and it employs approximately 30 000 people[1][2]. Infineon Technologies is listed on the DAX Index on the Frankfurt Stock Exchange and on the New York Stock Exchange with the ticker "IFX".

Based in Munich, Germany, it operates in several business areas, such as:

- Wireless Communications: Broadband and Carrier Access, MAN, WAN & LAN, High Speed Line Cards for Metro Access and Optical Networks
- Wireless Solutions: Cellular Phones, Cordless Phones, Wireless Local Area Networks, Mobile Applications and Systems
- Security and Chip Card ICs: Identification, Network Security (Telecom/ Banking/ Health), Biometric Systems, IP Security, Logistics
- Automotive & Industrial: Car Electronics (Engine Management, Airbags, ABS, Infotainment Telematics), Industrial Drives, Power Supplies and Distribution
- Memory Products: PC and Notebooks, PC-upgrades, Workstations, Servers, Communication Equipment, Computer Peripherals

The semiconductor market has had greater average growth rate compared to the pharmaceutical, electrical and chemical industries, which can be seen in the Exhibit 1:

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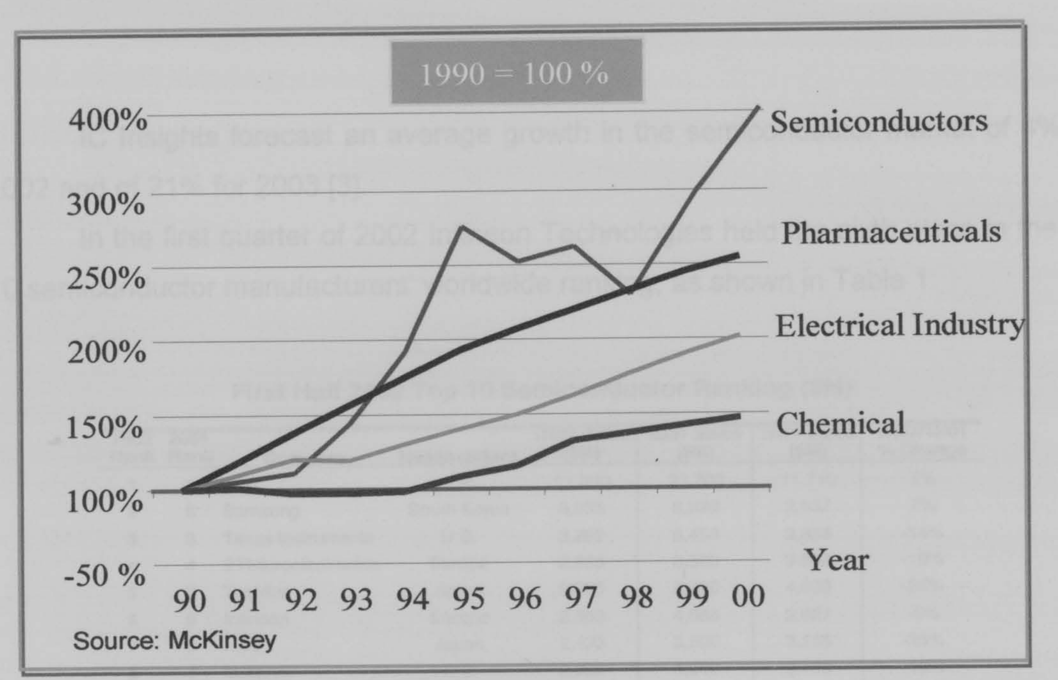
[1] From now on Infineon Technologies AG will be shortened to Infineon.

[2] [1] indicates reference number 1 (see p.80)



Source: McKinsey

Exhibit 1 - Growth of Semiconductors, Pharmaceuticals, Electrical and Chemical Industries [2]

Apart from this significant growth, the semiconductor market can be characterised as one subject to considerable fluctuations, seeing a decrease of 32% during 2001, the greatest downturn in the history of semiconductors (see Exhibit 2).

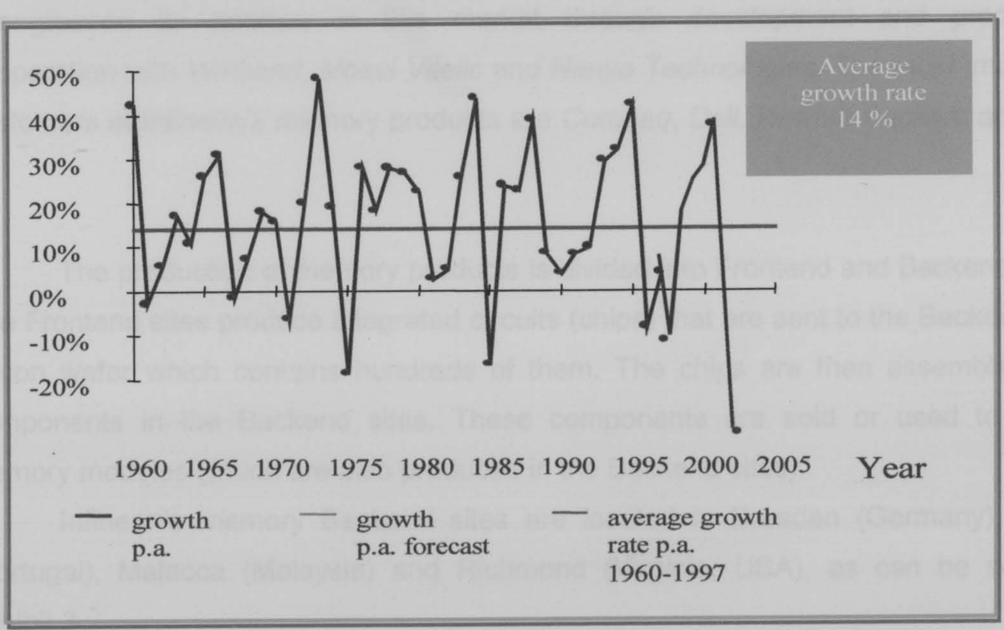


Exhibit 2 - Semiconductor growth since 1960 [2]

IC Insights forecast an average growth in the semiconductor market of 4% for 2002 and of 21% for 2003 [3].

In the first quarter of 2002 Infineon Technologies held the sixth place in the top 10 semiconductor manufacturers' worldwide ranking, as shown in Table 1:

First Half 2002 Top 10 Semiconductor Ranking ($M)

1H02 Rank	2001 Rank	Company	Headquarters	1H02 Sales ($M)	2001 Sales ($M)	1H01 Sales ($M)	1H02/1H01 % Change
1	1	Intel	U.S.	11,800	23,700	11,710	1%
2	5	Samsung	South Korea	3,885	6,320	3,637	7%
3	3	Texas Instruments	U.S.	3,282	6,450	3,833	-14%
4	4	STMicroelectronics	Europe	2,885	6,360	3,508	-18%
5	2	Toshiba	Japan	2,875	6,780	4,030	-29%
6	9	Infineon	Europe	2,503	4,560	2,627	-5%
7	6	NEC	Japan	2,435	5,500	3,265	-25%
8	7	Motorola	U.S.	2,309	4,940	2,733	-16%
9	15	TSMC	Taiwan	2,303	3,705	1,995	15%
10	10	Philips	Europe	2,153	4,410	2,557	-16%
–	–	Total	–	36,430	72,725	39,895	-9%

Source: IC Insights

Table 1 – Top 10 Semiconductor Ranking [3]

In the memory market, Infineon has been a know-how leader in performance DRAM's and specialty memory products (e.g. for networks, servers, routers, mobile-RAM and graphics) and it has been the leader in 300mm wafer production. It has strengthened its position in this market through development and production cooperation with *Winbond*, *Mosel Vitelic* and *Nanya Technologies*. The most important customers of Infineon's memory products are *Compaq*, *Dell*, *Hewlett Packard* and *IBM* [1].

The production of memory products is divided into Frontend and Backend sites. The Frontend sites produce integrated circuits (chips) that are sent to the Backend in a silicon wafer which contains hundreds of them. The chips are then assembled into components in the Backend sites. These components are sold or used to make memory modules (which are also produced in the Backend sites).

Infineon's memory Backend sites are located in Dresden (Germany), Porto (Portugal), Malacca (Malaysia) and Richmond (Virginia, USA), as can be seen in Exhibit 3.

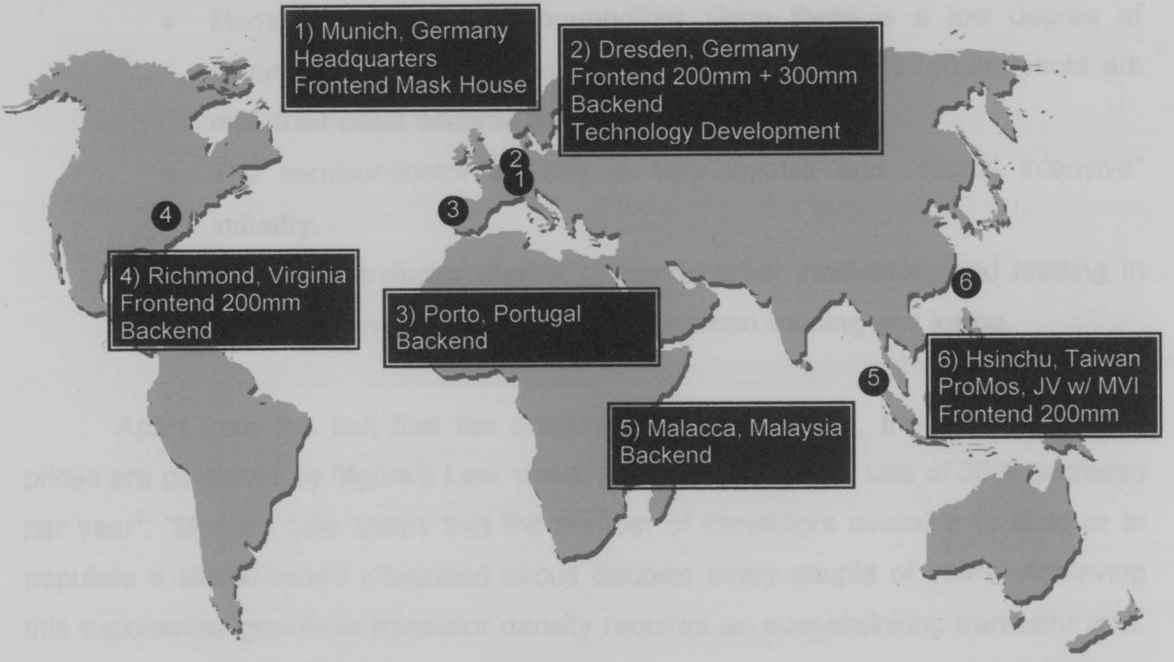


Exhibit 3 – Infineon Memory Sites

3 Memory Products

The focus of competitive semiconductor manufacturers is technology development in the Frontend sites and reducing mass production costs in the Backend sites. The reasons for that are:

- Memory products are commodities since there is a low degree of differentiation among them. Once their basic quality requirements are met, their costs become critic.
- The semiconductor industry is very volatile and “capital intensive” industry.
- The semiconductor market demands great innovation, and leading in this area can make the difference between winning and losing.

Apart from the fact that the products are commodities, the memory market prices are governed by Moore’s Law, which predicts an average rate of 30% decrease per year[3]. “Moore's Law states that the number of transistors available to build or to populate a silicon-based integrated circuit doubles every couple of years. Achieving this exponential growth in transistor density requires an ever-shrinking transistor size. In turn, this steady reduction results in the decreased cost and in the increased performance of silicon-based devices built with these smaller transistors” [4].

Each year, in order to keep up with Moore’s law, the semiconductor production costs have to decrease more than their prices. In order to achieve this reduction, the main objective of semiconductor industries is to increase the quantity produced through mass volume production; but this increase is limited to market demand. This results in reducing the number of semiconductor companies in the market, some through mergers, and others by their departure from the market. This is even greater when prices decrease by more than the effect of Moore’s law. This can be seen in the Exhibit 4.

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[3] in their “Price/bit“.

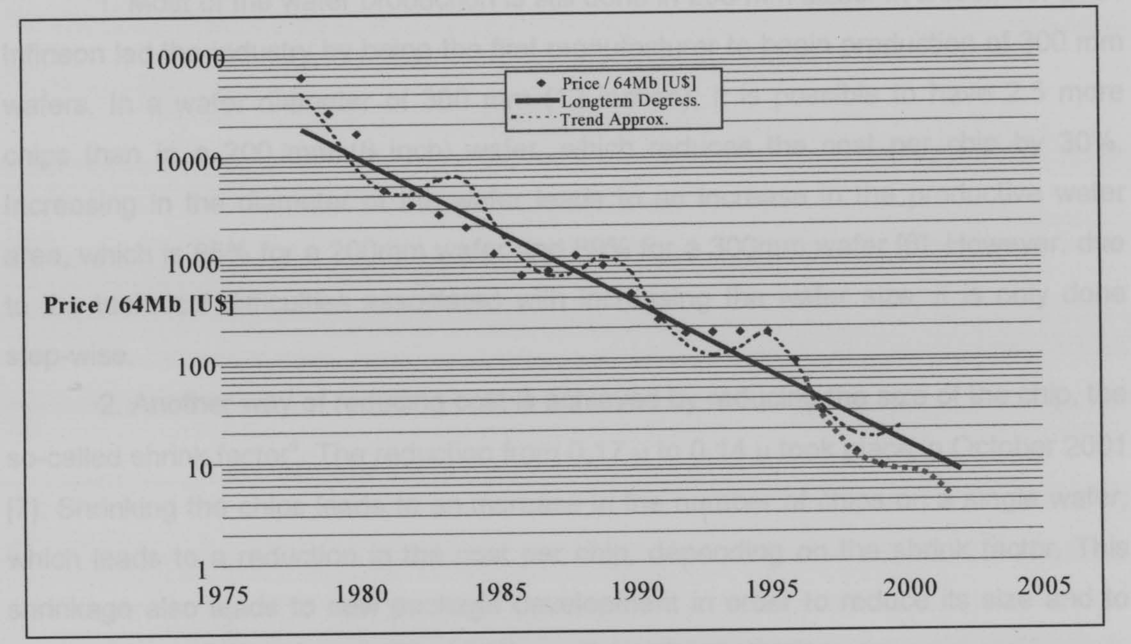

Exhibit 4 – Moore's Law effect on memory prices

Since the "boom" in the memory and chip market in October 1999, prices have greatly decreased. In this market environment, cost reduction beyond the demands of Moore's law is imperative to the memory product industry.

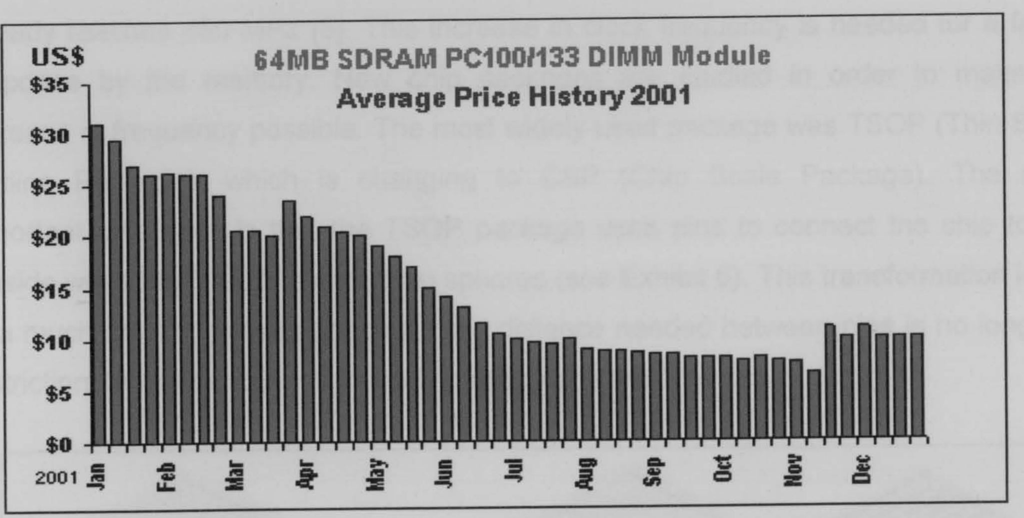

Exhibit 5 – Memory Modules Average price in 2001 [5]

The evolution in the memory products and their price is affected by:

1. the transition to bigger wafers,
2. the reduction in the size of memory chips,
3. the production of higher capacity memories, and
4. the increase in memory module clock frequencies.

1. Most of the wafer production is still done in 200 mm sizes. In December 2001 Infineon led the industry by being the first manufacturer to begin production of 300 mm wafers. In a wafer diameter of 300 mm (12 inches), it is possible to have 2.5 more chips than in a 200 mm (8 inch) wafer, which reduces the cost per chip by 30%. Increasing in the diameter of the wafer leads to an increase in the productive wafer area, which is 85% for a 200mm wafer and 89% for a 300mm wafer [6]. However, due to the technical difficulties associated with increasing the wafer size, it is only done step-wise.

2. Another way of reducing cost is achieved by reducing the size of the chip, the so-called shrink factor[4]. The reduction from 0.17 μ to 0.14 μ took place in October 2001 [7]. Shrinking the chips leads to an increase in the number of chips on a single wafer, which leads to a reduction in the cost per chip, depending on the shrink factor. This shrinkage also leads to new package development in order to reduce its size and to create the possibility of producing smaller and smaller memories.

3. The demand for memory is always in the direction of higher capacity units, mainly due to more demanding software applications. 512 Mbit[5] generation memory chips from Infineon were announced in October 2001 [7].

4. The clock frequency of most memory modules is 133 MHz but Graphic RAM already reaches 450 MHz [8]. This increase in clock frequency is needed for a faster response by the memory. New chip packages are studied in order to make the increase in frequency possible. The most widely used package was TSOP (Thin Small Outline Package), which is changing to CSP (Chip Scale Package). The most important difference is that the TSOP package uses pins to connect the chip to the outside while the CSP one uses little spheres (see Exhibit 6). This transformation leads to a much smaller package because the distance needed between pins is no longer a restriction. In CSP packages the only restriction is the chip size.

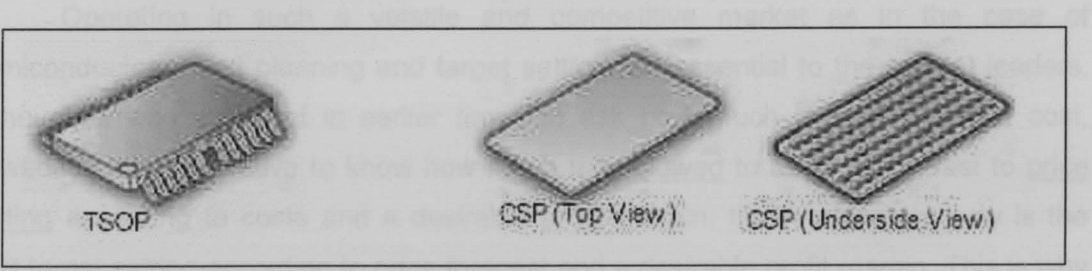

Exhibit 6 - TSOP vs. CSP Package [9]

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[4] The process of shrinking decreases the main elements, the distance between them and consequently the memory cell size.

[5] Mbit is the measurement of chip capacity, while MB (MByte) is the capacity measurement for modules. One Byte corresponds to eight bits.

4 Cost Target Management

"Cost target Management" appeared in Japanese companies in the 1960s, originating from the American idea of "Value Engineering". The technique of "Value Engineering" was created by American engineers of *GE - General Electric* during World War II, and was defined by the search for new materials which would be more accessible and cheaper than those used until then. After the war ended they noticed that these new materials could be used to make the final products cheaper without lowering the consumers' satisfaction level.

After their defeat in the war, the Japanese adopted several techniques from the Americans, "Value Engineering" being one of them. But they developed further this technique by joining the marketing and planning professionals with production, building multidisciplinary teams and originating "Target Costing", which is a more flexible technique for planning and reducing costs. *Toyota* was the first Japanese company to use the Target Costing and several others followed, such as *NEC*, *Sony*, *Nissan* and *Sharp*. The rest of the world began to use it only after the 80's, starting with American and German companies.

The objectives of Target Costing are:

- To calculate the allowable cost given a certain price and a desirable profit.
- To reduce the cost of the products without reducing their quality.
- To see the whole value chain and not only the production.
- To work in all the departments of the company towards the same objective, which is improvement.

Operating in such a volatile and competitive market as in the case of semiconductors, cost planning and target setting are essential to the market leaders. Although it was sufficient in earlier times to ask how much a product would cost, nowadays it is imperative to know how much it is allowed to cost. In contrast to price setting according to costs and a desirable profit margin, the requirement now is the cost target setting according to price forecast and a desirable profit margin. This is why cost target setting holds such importance for companies like Infineon. This is the reason why it becomes the company's driving force towards cost improvement. Unlike traditional cost management systems which have a largely internal focus, target cost management is outwardly focused and market driven. In particular, target cost management recognises that the customer comes first.

Targets must be considered achievable although they may not be easy to achieve, and must be accepted by the sites in order to reach their goal. They must lead to the motivation of the employees in the direction of improvement.

The planning period is long and the planning method repetitive, due to changes that often occur in the premises initially set. Starting from Infineon strategy, the Memory Products' strategy is defined. One of the relevant inputs is the market share that Infineon wants to achieve in the coming years. The demand is analysed by the marketing department, and volumes for the Frontend and Backend are planned. As the Backend volumes depend on the Frontend ones, any change in the latter will affect the Backend planning. After the volumes are defined for each site, the major investment needed is calculated. This is done top-down by the headquarters' planning department. Top-down costs are calculated and scenarios studied. These scenarios bring about reformulations in the strategy, volume and investment planning. After a version of the production volumes is released, top-down targets are calculated and announced to the sites, where bottom-up planning is done. The sites and the headquarters discuss these targets and plans in a workshop, improvement projects are set and initial targets are agreed on. Following the workshop, the sites' plans are redefined and, after discussions, the final targets' version is set. Closing the gap between the cost target and the plan is very important and drives the search for improvement projects.

Finally, incentives for reaching the targets are established. This overall flow of the planning process just described is shown in Exhibit 7.

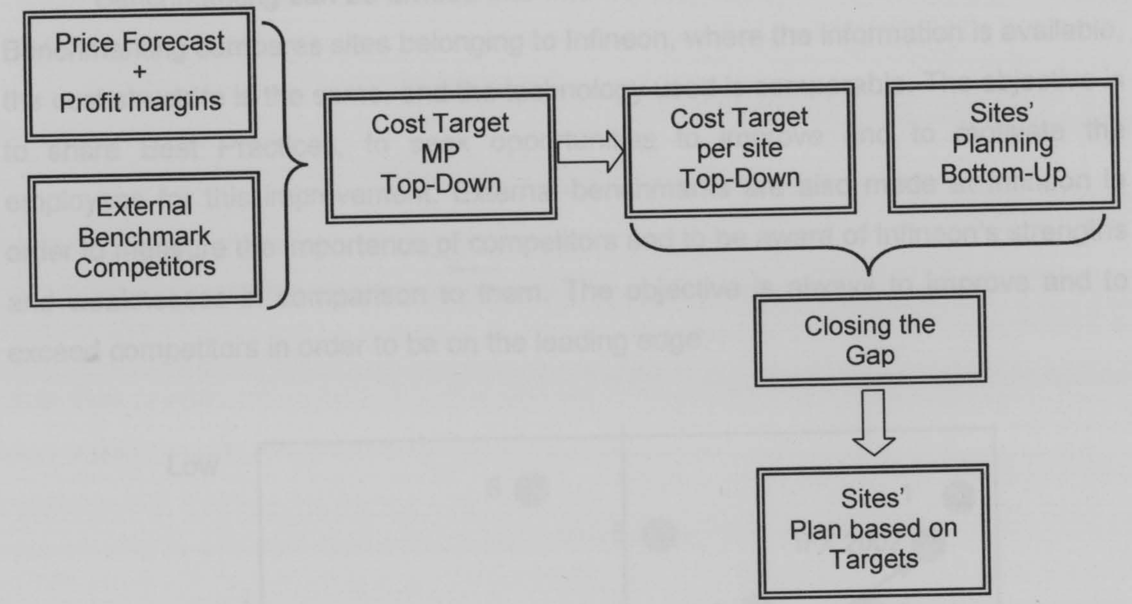

Exhibit 7 - Target Setting and Planning Flow in Infineon MP

In order to support this process there are several models and tools, including those for volume calculation and aggregation, cost calculation and financial consolidation and controlling. One of these models is the "Reference Fab" one, whose aim is essentially target setting and cost benchmarking.

The original meaning of benchmark is "A surveyor's mark made on a stationary object of previously determined position and elevation and used as a reference point in tidal observations and surveys" [10]. Its meaning from the management point of view is not far from the original one. The "benchmark" is a cost or a specific practice which will be used as a reference.

Benchmarking is understood in Economics as the professional comparison between two organisational units with the goal of developing their own capabilities and therefore improving their competitive ability. It is a future-oriented management instrument that permits identifying weaknesses in a company and implementing measures in order to progress. Sometimes it is seen as an instrument to copy the processes of other companies, but benchmarking is much more than copying; it enables analysis of the better processes and a way to implement these in different environments. Accordingly, Infineon's objective is to benchmark in order to become *the benchmark*!

Benchmarking can be divided into Internal and External Benchmarking. Internal Benchmarking compares sites belonging to Infineon, where the information is available, the cost structure is the same, and the technology used is comparable. The objective is to share Best Practices, to seek opportunities to improve and to motivate the employees for this improvement. External benchmarks are also made at Infineon in order to measure the importance of competitors and to be aware of Infineon's strengths and weaknesses in comparison to them. The objective is always to improve and to exceed competitors in order to be on the leading edge.

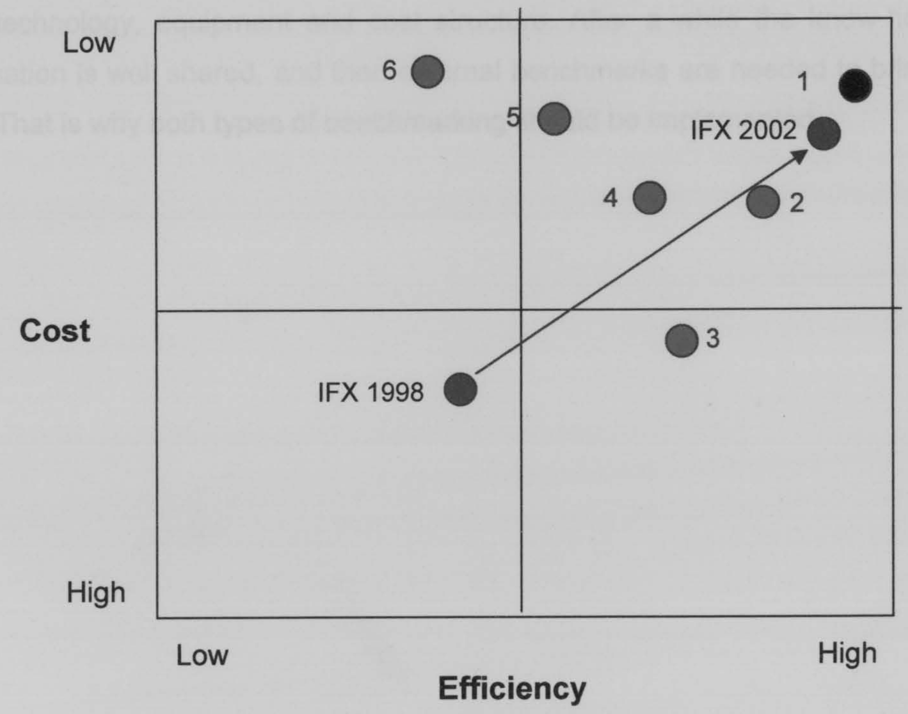

Exhibit 8 - Infineon MP BE vs. its competitors

Exhibit 8 shows the result of several external benchmarks. In terms of cost and efficiency, Infineon has one major competitor, as can be seen. Having this information, the direction to follow is to observe and give attention to all movements that the competitor number 1 makes. Although the other competitors are behind Infineon in terms of cost and efficiency, it must be not assumed that a benchmark with them is not worthwhile. It can happen that they have different technology, for example, but in those cases care must be taken in order to learn more from the benchmarking partners than to teach and to show them Infineon's best practices.

Indicators have to be chosen in order to achieve comparability when measuring performance. Depending on the information acquired, this measuring can be done in two ways: quantitatively or qualitatively.

In the environment of this work and in the following pages of this report, mention of Benchmarking means, mostly, Internal Benchmarking. The Reference Fab is used for quantitative internal Benchmarking of MP BE's fabrication sites and its main focus is cost and resource usage efficiency. The main advantage of the internal benchmarks is that they provide good accuracy and comparability because the sites have almost the same technology, equipment and cost structure. After a while the know-how in the organisation is well shared, and then external benchmarks are needed to bring in new ideas. That is why both types of benchmarking should be implemented.

5 Backend Manufacturing

The production of chips and modules is done in “clean rooms”. These rooms have to be free of dust and static electricity and have different levels of “cleaning”, depending on the part under production. Component manufacturing is done in a 10k room, while module manufacturing is in a 100k room. This indicator for “cleanness” calculates the maximum number of dust particles, greater than one micron in size, permitted in a cubic foot of clean room space. For this purpose, operators are garbed with special suits, called “bunny suits”, which cover them from head to toe, and the air is continuously filtered and re-circulated.

While the Frontend manufacturing has a complex production process, the Backend production is almost linear; therefore the complexity arises in the product and not in the process.

5.1 Components

The production process of memory components is divided into three areas: Pre-Assembly, Assembly and Test.

In Pre-Assembly the wafers coming from the Frontend are transformed into single chips. This is done beginning with the **Laminate** process where the wafer is protected with tape in order to be ground (**Grinding** process), which means reducing its height. After grinding, the protection tape is taken off (**Peeling** process). Then, in the **Mounting** process, the wafers are protected with tape and fixed in frames in order to be diced (**Dicing** process), which is the process through which the chips are singularised. After the Dicing process, the wafers have to be **Visually Inspected**, which is done with the use of microscopes. Now the good chips[6] are ready to be assembled.

The Assembly begins with the **Die-Bonding** process, in which the chips are attached to the “Lead frames” using an adhesive tape. This method is called Lead on Chip (LOC). After this, the **Wire-Bonding** process follows, when the chip is electrically connected to the lead frame using absolute clean gold wire.

From here on the processes until the end of Assembly are called End-of-Line, beginning with the **Moulding** process, where the chips are covered with mould compound, formed into the required shape using pressure and temperature. This

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[6] The good chips are identified in the wafer map, which is defined in the Frontend.

protection of the chip has to dry during the **Post Mould Cure** process for about six hours in a 180° oven. The rest of the mould compound and the connection between the pins from the component must be taken off in the **Dedam-Dejunk** process. After this step, the components go to the **Deflash and Plating** process, where the components are cleaned and the pins are coated with a tin and lead solder alloy (SnPb) to assure better solder-ability and higher protection against environmental conditions. In the end of the Assembly, in the **Trim & Form** process the components are singularised and the pins are formed according to the final structure.

The Burn-In and Test assures that the components not only function but also will not become damaged in a short period. After some studies, it was concluded that the components fail in the beginning of life ("infant mortality") and after the forecast life span. To avoid early failure after the component reaches the consumer it is exposed to certain stresses by temperature and programmable voltage supplies in the **Burn-In** ovens in order to simulate the required life-time. For this action, the components are loaded (**Burn-In Load**) from trays to Burn-In Boards and in the end unloaded (**Burn-In Unload**). After the Burn-In, the remaining good components are tested at a wide range of temperatures to ensure conformance to specifications in the **Test** process.

Finally the components are marked with the Infineon logo and identification, scanned in order to see that the pins are not deformed, and packed into tape or trays according to customer specifications. This final process step is called the **Mark, Scan & Pack** process. These components reaching the end of these processes are sold or used in the production of memory modules.

The overall production process which has been described is illustrated in Exhibit 9:

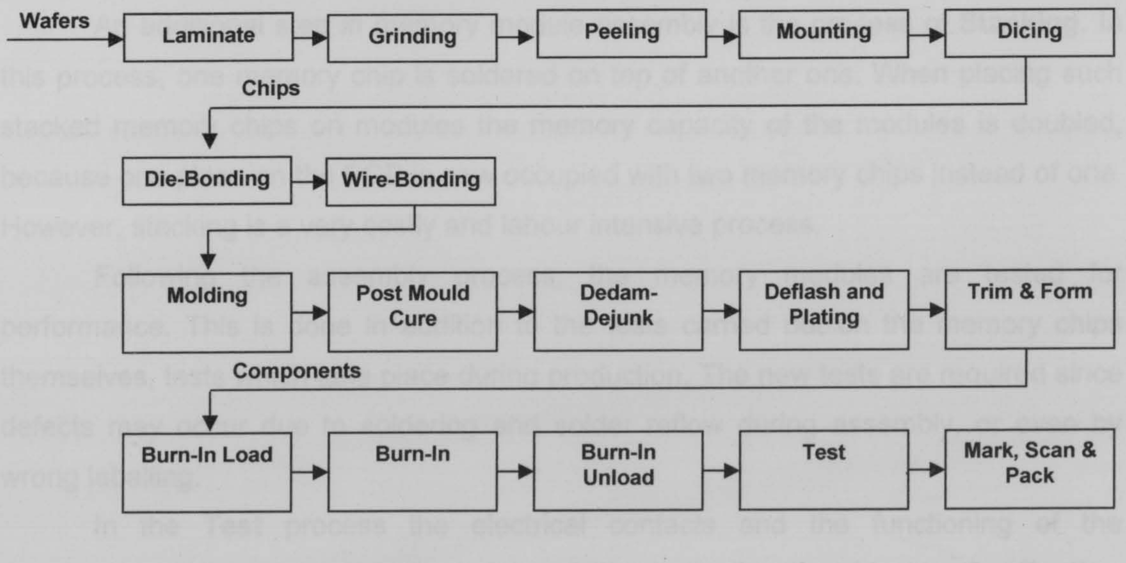

Exhibit 9 - Component Production Flowchart

5.2 Modules

Memory chips provide the memory capacity of the module. Depending on the chip organisation inside the memory chips and the number of chips, a module can provide more (or less) memory capacity. The customers usually buy the components and then produce the modules. Due to the increasing number of chip generations and to the risks associated to storing the components, especially because of their price volatility, customer demand has increasingly changed from components to ready-assembled modules. This has made module manufacturing progressively more important to semiconductor manufacturers.

The production of memory modules is divided into Assembly and Test.

The assembly is done on so-called SMT lines (Surface Mount Technology) and is fully automated. Therefore, before beginning production, lot groups have to be combined appropriately for the type of modules to be assembled. In the auto line, solder paste is first printed onto the PCB's (Printed Circuit Boards) where components are going to be mounted. This is the **Solder Paste Printing** process. Then the components are placed, but still not firmly attached, on the PCB. The attachment is done in the **Solder Reflow** process, where the solder is melted to form a solder joint that electrically and mechanically bonds the components to the surface of the board. With all components attached to the module, the panels are separated by cutting them into individual modules. This process is also called **De-panelling**. This can be done in automatic or manual machines. Then, the modules are inspected optically and, when accurately assembled, a module label is attached. Afterwards, the modules are sent to module testing.

An additional step in memory module assembly is the process of **Stacking**. In this process, one memory chip is soldered on top of another one. When placing such stacked memory chips on modules the memory capacity of the modules is doubled, because one place on the PCB is now occupied with two memory chips instead of one. However, stacking is a very costly and labour intensive process.

Following the assembly process, the memory modules are tested for performance. This is done in addition to the tests carried out on the memory chips themselves, tests which take place during production. The new tests are required since defects may occur due to soldering and solder reflow during assembly, or even by wrong labelling.

In the **Test** process the electrical contacts and the functioning of the components of the modules are tested. In addition to the functional test an **Application Test** is done. Here, a percentage of the production lot is tested for performance in different system boards, also known as motherboards. At the customers' demand, some modules have to have another application test with cycles of hot and cold testing, which is done in ovens. However this is not the standard process.

After passing the tests, the memory modules undergo a **Visual Inspection**. The ones that pass in the visual inspection are packed into blister trays. The trays are put into cardboard boxes that are marked and labelled according to their contents. After that, the boxes are shipped to customers.

Although the goal in memory module production is to reach 100% yield, failures may occur during manufacturing, especially with increasing production speeds and decreasing component sizes. With the advancing technology and increasing complexity of the products, the value of each memory module is escalating, making "scrap" modules very expensive. To save production costs and to avoid "scrap", reworking and repairing defective or wrongly assembled modules is important. The **Rework** is done after inspection, where failures are detected. Rework is a manual process, done at a workbench, where faulty components are removed from the module and replaced. If a module is reworked after being tested, the module has to undergo the test again.

The steps involved in manufacturing memory modules are summarised in Exhibit 10.

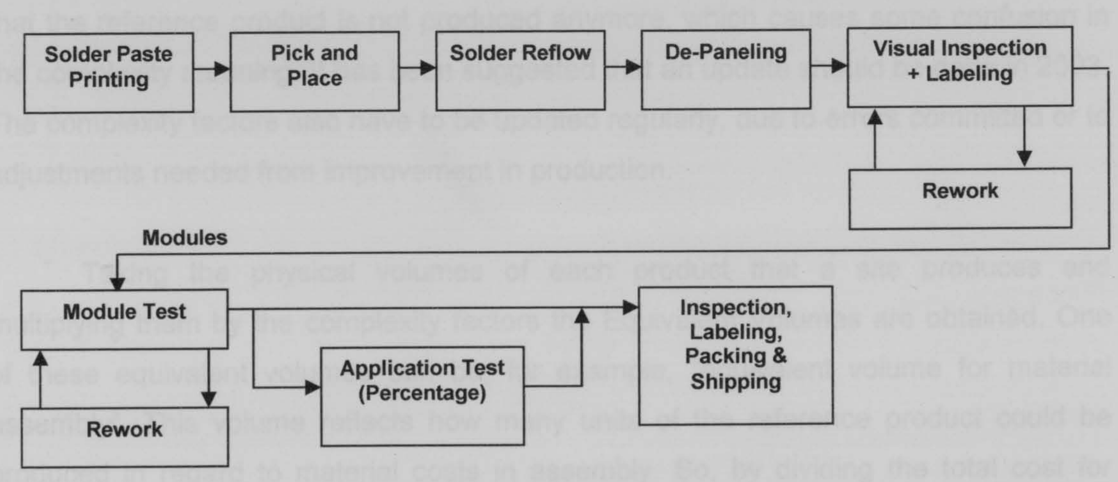

Exhibit 10 - Memory Module Production Flowchart

6 Volume Normalisation and Cost Complexity Factors

Volume normalisation is necessary in order to simplify the cost calculation for each product. The goal is to normalise all products to one reference product, and to have all models and tools use this product for cost calculations.

Using a reference product as a basis, the model calculates complexity factors which reflect the cost complexity between the reference product and the product in question, and, finally, normalises the volume. The main meaning of the complexity factors is: how many units of the reference product could be produced for the cost of producing one unit of product "x". So, the reference product has the complexity of 1, more complex products have a factor greater than 1 and less complex products have a factor less than 1.

These complexity factors are calculated for all products, components and modules, for the three main cost categories (Capital, Material and Personnel) and for each area (assembly and test). Therefore, for each component or module six complexity factors are calculated. For this calculation a reference component and a reference module is used. These reference products are previously defined and have to be updated from time to time in order not to lose meaning, because it can happen that the reference product is not produced anymore, which causes some confusion in the complexity meaning. It has been suggested that an update should be done in 2003. The complexity factors also have to be updated regularly, due to errors committed or to adjustments needed from improvement in production.

Taking the physical volumes of each product that a site produces and multiplying them by the complexity factors the Equivalent Volumes are obtained. One of these equivalent volumes can be, for example, "equivalent volume for material assembly". This volume reflects how many units of the reference product could be produced in regard to material costs in assembly. So, by dividing the total cost for material in assembly by this volume, the cost per piece (in the reference product) is obtained. After having this method applied to all types of costs, the total cost per piece can be obtained as illustrated in Exhibit 11.

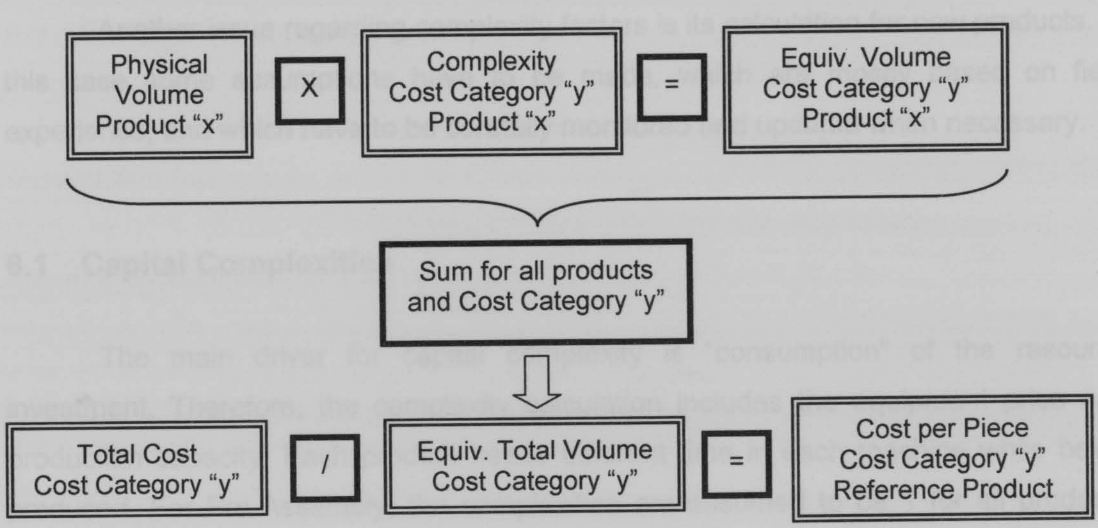

Exhibit 11 - Volume Normalisation and Calculation of Equiv. Cost per Piece

The description of the products has to consider the level of detail required. For components it must describe the package type (TSOP, BGA), the generation (memory capacity in Mbit), the technology (SDR, DDR, etc.), the shrink factor (0.14, 0.17, etc.) and the organisation (*4, *8 or *16). For modules, it must describe the generation and the technology of the chips, the module organisation (depth and width of the memory - 16M*8, 32M*4, etc.), the module type (unbuffered, registered, etc.), whether it is customized (for which customer) or standardized, and whether it is stacked or not.

Complexity factors are not static values. They change over time due to the ramp-up of new products, their life-cycle, improvement in equipment capacities, changes in price of materials, etc. Thus, they have to be updated regularly in order to have accurate costs per piece. But with the updating of complexities, the improvements done in production are reflected in these changes and not in the cost per piece. This is a problem, because management does not look at complexities in detail, but to the trend of the cost per piece. This caused a lot of discussion regarding the updating of complexities, and during this planning period it was decided to freeze complexities for a certain time and to update them in determined time frames. With this procedure the trend of the cost per piece can be identified and people will not lose track of changes done while updating the complexities.

Another issue regarding complexity factors is its calculation for new products. In this case some assumptions have to be made, which are mostly based on field experience, and which have to be carefully monitored and updated when necessary.

6.1 Capital Complexities

The main driver for capital complexity is "consumption" of the resource investment. Therefore, the complexity calculation includes the equipment price and production capacity. Each product needs different time in each machine while being produced. For Pre-Assembly, the complexities are assumed to be 1 for all products because the process is the same for all at the wafer level. For Assembly, Burn-In Load/ Unload and Mark-Scan & Pack, the products are differentiated by their package type. For Burn-In and Test the generation, the organisation and the shrink factor of each product must be taken into consideration.

For simplification, the Building and Facilities (B&F) costs use the same complexities calculated for the Equipment, because it is assumed that the time needed for production, influencing equipment capacities, reflects the B&F costs also.

6.2 Material Complexities

The Bill of Materials (BOM), which lists the consumption quantities of each material for all products, and the material prices give the material cost for all products. By dividing this cost by that of the Reference Product, the material complexities can be calculated. These are the complexities for Material in Production. For Other Material in Production the same complexities are used, since the most important materials are the driver for the material cost and therefore the simplification is acceptable. For Pre-Assembly all materials are assumed to have the same complexity, 1, since it is done on a wafer level and the wafer price is not considered. For Utilities and Maintenance material costs the Capital complexities are used, since their driver is not the material consumption but the equipment "usage".

6.3 Personnel Complexities

Personnel costs are scaled with two main drivers: the number of equipment needed and the volume produced. It can be assumed that the personnel complexities increase with capital complexities, but not in a directly proportional manner. The following formula was adopted to express the personnel complexity:

$$\boxed{\text{PER COMPX} = \sqrt{(1 + \text{CAP COMPX})/2}}$$

Another, and perhaps more accurate possibility, would be the calculation of the F1 Times, which are the times needed to produce one product. This approach would, however, need too much effort, especially in the updating of the complexities. Nonetheless, in a meeting held in July 2002 with the objective of updating the personnel complexities for a new product, it was concluded that the formula based on the experience used till now is accurate when compared to the values reached by the site in question. It was necessary to update the complexity for this new product because an estimated one had been used due to the lack of experience and historical data. This update showed that the estimated complexity was much lower than the real one.

6.4 Overhead Complexities

Overhead costs are allocated to each product by value added during its production. First each type of cost (Capital, Material and Personnel) for the Reference Product is multiplied by the complexity for each cost category of the product in question ("x"). This total cost for product "x" is divided by the Reference Product total cost for these categories. In this way a total cost complexity is achieved, which is used to allocate Overhead costs to each product.

7 Reference Fab Model

7.1 Introduction

Due to great volatility in conjunction with lower prices in the memory market, it is essential to plan and target costs for all sites. It is also important to internally benchmark the sites with each other in order to focus on best practices and continuous improvement. For these reasons a model called "Reference Fab" was built in 1997. This model uses a virtual site, the "Reference Fabrication Site", in order to compare costs and efficiencies with the real sites and to compare them with each other. Therefore the term "Reference Fab" refers to the model, the software tool that implements the model and the virtual fabrication site included in the model.

The target setting, benchmarking and controlling is achieved by making use of a set of unified parameters that reflect the costs and efficiencies of the sites, which are the "Key Performance Indicators" (KPI's).

As the production sites are different from each other, for each of them the model must include different volume capacities and factor costs, such as the salaries. This variability creates complexity in the cost calculation, which has to be overcome by the Reference Fab model.

Consequently, the main objectives of this model are:

- to be a cost model that describes and benchmarks the BE sites,
- to include the implementation of top-down target setting,
- to be capable of scenario calculation,
- to build a unified cost structure that is comparable for all BE sites,
- to be of use in external benchmarking processes, and
- to ensure an overall efficiency optimisation throughout the MP BE production sites.

Updating the model and the tool requires a simplification of the model in order to calculate the targets in a simpler way. This ensures understanding by the users of the model and of its results.

7.2 Key Performance Indicators

The definition for an indicator is: "Any of various statistical values that together provide an indication of the condition or direction of the economy" [10]. In this case the object of study is not an economy but rather one company or a part of it.

Indicators are particularly suitable for preparing decisions and for examining the effects of some decisions. They should summarize large quantity of information collected by a company and in this case, they are regarded as tools for planning, target setting and controlling. The use of indicators is essential for systematic optimisation since "what can be measured, can also be improved" [11].

The indicators used in order to target and plan costs have to describe the cost structure of the sites. Production costs are important in order to calculate the cost per unit produced. In the Reference Fab model, costs are categorised according to the consumption of production factors. These categories are Capital, Material, Personnel and Overhead. Overhead costs include the overhead elements of Capital, Material and Personnel. The structure is shown in Exhibit 12:

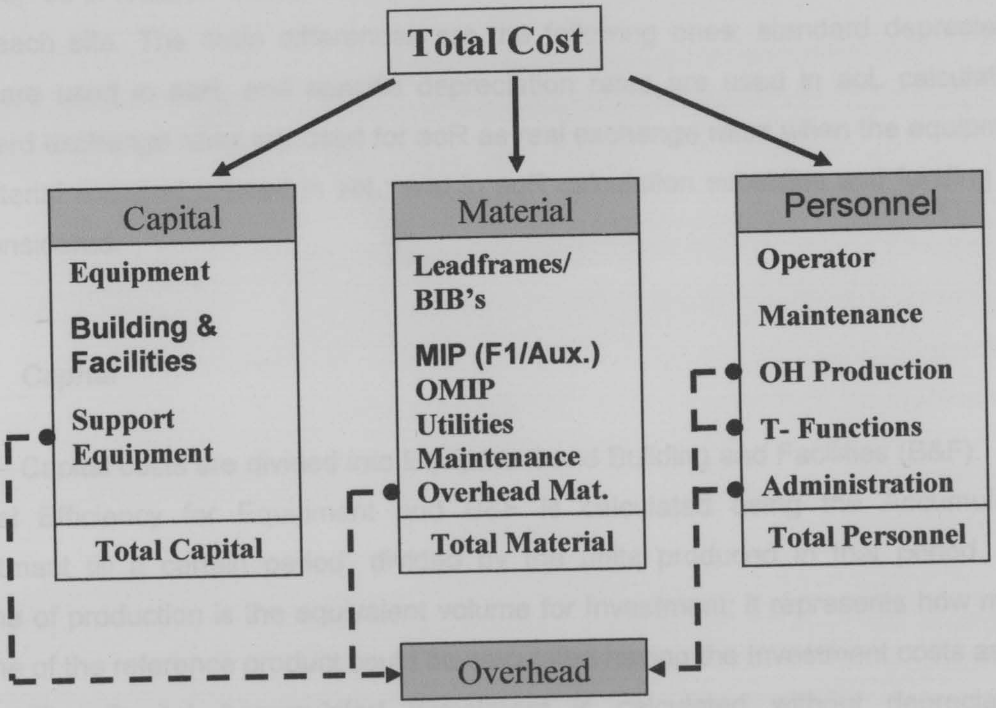

Exhibit 12 - Cost definition in the Reference Fab

Using the categories described in Exhibit 12, performance indicators (KPI's) are defined.

While getting acquainted with the Reference Fab and the other models for cost calculation, the objective was to document the KPI's. After carrying out this documentation effort, the understanding of KPI's greatly increased.

The objective of the KPI's is to calculate and benchmark the resource utilisation per unit produced. In order to ensure comparability, a Reference Product is used and the costs of producing other products are "transformed" to the equivalent volumes with the help of complexity factors (as explained in chapter 6). These equivalent volumes indicate how much volume of the reference product could be produced with the product mix used. The equivalent volumes are calculated for each of the cost categories, Capital, Material and Personnel. All costs are calculated in Euro.

The efficiencies are obtained by dividing the resources or costs involved by the equivalent volume achieved. An increase in the efficiency value means a less efficient process.

This calculation of costs and resources uses the method "as of reference" (aoR), which was determined in order to ensure the comparability of costs. The other method, "as of location" (aoL), uses the realistic assumptions and costs which originate from each site. The main differences are the following ones: standard depreciation rates are used in aoR, and specific depreciation rates are used in aoL calculation; standard exchange rates are used for aoR as real exchange rates when the equipment or material acquired is used in aoL; and in aoR calculation subsidies and funding are not considered.

7.2.1 Capital

Capital costs are divided into Equipment and Building and Facilities (B&F). The Capital Efficiency for Equipment and B&F is calculated using the Accumulated Investment till a certain period[7] divided by the units produced in that period. The volume of production is the equivalent volume for Investment; it represents how much volume of the reference product could be calculated having the Investment costs as the basis. The Capital Accumulated Investment is calculated without depreciation, subsidies and funding, in order to be comparable to other sites, because these factors distort the real meaning of efficiency.

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[7] The period can be a week, a month or a year. In the following equations the most common one, i.e. the month, will be used.

The Capital Efficiency is measured in Euro per equivalent pieces produced per week, and is computed according to the following expression:

$$\text{CAP Efficiency [EUR/eq. pcs. opw]} = \sum\nolimits_{\text{all categories}} \left(\frac{\text{Cum Invest aoR [Mio EUR]}}{\text{Equiv VOL Invest [eq. kpcs]}} \right) * \text{n.weeks} * 1000$$

The capital cost used for cost per piece is calculated using the consumption of invested capital, which is calculated using the depreciation of the capital. Depreciation cost is calculated using a never-ending depreciation and a normalised depreciation rate. This method of calculation is used in order not to benefit some sites that already have depreciated equipment.

7.2.2 Material

Material costs include all kinds of material costs needed for production. This category is subdivided into Material in Production (MIP), Utilities, Maintenance and Other Material in Production (OMIP).

The allocation to the categories had to be redefined during the planning period because it was realized that the sites were not using the same allocation. Most of them were not aware of the definition agreed on in April 2000, and others had to align the allocation with the Frontend sites, which was the case of Richmond and Dresden. These sites share the facilities with FE sites, and as the FE have much more importance in terms of costs the definitions have to be in line with them. This study is described in section 9.1.

Utilities and maintenance material costs are normalised with equivalent volume of investment, because these material consumptions are scaled with the number and type of equipment as is investment consumption, while MIP and OMIP are scaled with equivalent volume of direct and auxiliary material.

The Material Efficiency is measured in cost (in Euro) per piece, and is computed according to the following expression:

$$\text{MAT Efficiency [EUR/eq. kpcs.]} = \sum\nolimits_{\text{all categories}} \left(\frac{\text{MAT Cost aoR [Mio EUR]}}{\text{Equiv VOL [eq. kpcs]}} \right) * 1000\,000$$

The memory components are not considered in the material costs for modules, nor are the chips in the material cost for components, since they are produced in-house.

7.2.3 *Personnel*

In the personnel category another efficiency parameter is used apart from cost per piece. This happens because the personnel cost indicator depends on the location of the site in terms of wages and salaries, which is suitable for making the decision to build a site in a certain place or not, but not for measuring the pure efficiency of employees. For this measurement the indicator used is the hours needed for producing each product. Here, the annual working hours also have an effect, which has to be considered. This is defined by how much volume the site can reach with the working hours that they complete. Thus the net productive working hours per year are a target too.

The personnel category is divided into Operator and Maintenance. In calculating efficiency the equivalent volume used is Equivalent Volume for Operators. The expression for personnel efficiency is the following:

$$\boxed{\text{PER Efficiency [hr/eq. pcs.]} = \Sigma_{\text{all categories}} \left(\frac{\text{Effective working Hours per period [hr]}}{\text{Equiv VOL [eq. kpcs]}} \right)}$$

The Effective Working Hours per Period reflect the total hours dedicated to production of all the headcount in production, and are computed according to the following expression:

$$\boxed{\text{Eff. Work. Hrs per per. [hr]} = \frac{(\text{n.HC} * \text{NPH [hr]})}{52} * \text{n.weeks}}$$

The Net Productive Hours (NPH) consider the shift model, which is different from site to site, and how many shift hours an employee works per year, after deducting paid and unpaid breaks. After that the non-productive hours have to be deducted, which include Fab closing days (because of holidays and other reasons), employee holidays, vacation, absenteeism (due to illness) and diverse leave (due to maternity, compassionate[8] and matrimonial leave). Overtime and Training hours are also considered.

The NPH that each site can achieve must be distinguished between the sites, which greatly depend on the laws of the country where the site is situated, and the personnel efficiency of the site. In conclusion, NPH and Personnel efficiency are two different indicators measuring different things, the second one being independent from local characteristics.

7.2.4 Overhead

This category includes all costs that are not directly allocated to production. Therefore, the capital overhead costs (e.g. laboratories and computers for administration), the material overhead costs (e.g. office supplies) and the personnel overhead costs (e.g. wages and salaries for site management employees) are distributed to the products and considered as value added to these products. The overhead efficiency is computed according to the following expression:

$$\text{OH Efficiency [EUR/eq. kpcs.]} = \frac{\Sigma\text{all categories }(\text{OH Cost aoR [Mio EUR]})}{\text{Equiv VOL Total Cost [eq. kpcs]}} * 100000$$

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[8] Compassionate leave means the leave that is granted in the event of the death of an employee's immediate family member.

7.3 General Concept of the Reference Fab Model

The model uses a reference fabrication site, which is a virtual site, as its starting-point. It is assumed that the cost targets calculated for the Reference Fab are caused by a best case situation, because the Reference Fab is operating under the optimum manufacturing conditions. For the cost calculation, based on production know-how, the Reference site has input from the improvement roadmaps[9], external benchmarks[10] and market studies / prices[11]. After the Reference Fab cost targets are defined, they must be transformed according to the reality of the existing sites. This transition takes into account: the different volumes produced at each site, the production mix, the factor costs (especially labour costs) and other add-ons[12] (for example specific equipment). With this information, cost targets for each site are calculated. The actual costs and performance indicators are compared against the calculated targets. This comparison is the driver for continuous improvement. The performance of each site is also compared with the other sites in order to benchmark internally, to set best practices and to create the opportunity for the sites to learn how to improve from each other. This loop is shown in Exhibit 13:

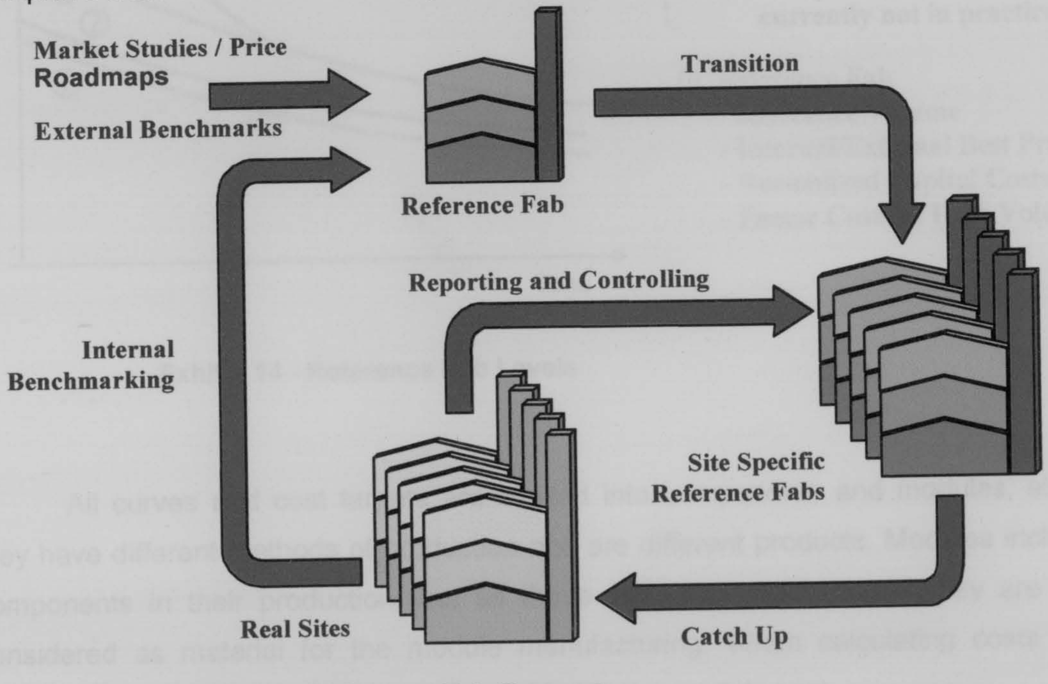

Exhibit 13 - Reference Fab Concept

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[9] The improvement roadmaps give the targets for equipment throughput capacities, yields and purchasing prices. They are based on technology development and experience.

[10] Some external benchmarks have been obtained and some factor costs were derived from them.

[11] The most important input from the market prices is the effect of Moore's law, which has to be followed by the manufacturing costs at least.

[12] Henceforth called "adders"

This model creates curves for cost in a timeframe. The curves are shown in Exhibit 14. Curve “1” is the Reference Fab efficiency target. Curve “3” reflects the efficiency target for the sites, and curve “4” shows the planned efficiencies for the next five years. The “FC” curve shows the costs forecast by the sites, which are not calculated by the Reference Fab but by the sites. It is used in the Reference Fab environment only for the purpose of comparison. In the beginning a curve “2” was used, which reflected curve “1” with the sites’ factor costs, but as it did not bring much value added to curves “1” and “3” it has been skipped.

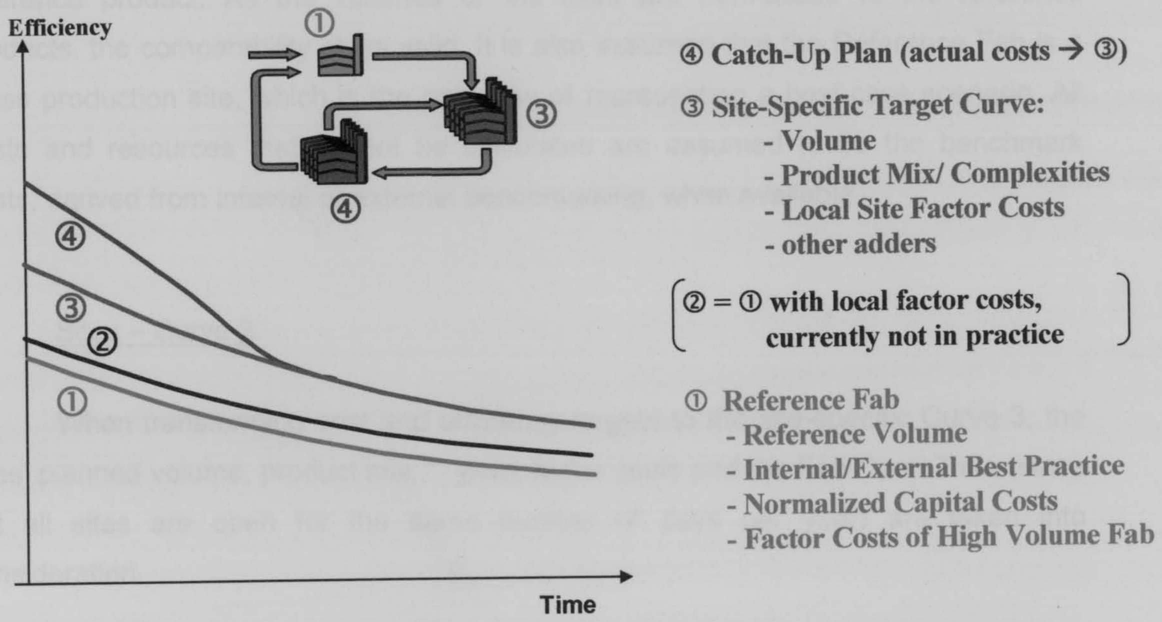

Exhibit 14 - Reference Fab Levels

All curves and cost targets are divided into components and modules, since they have different methods of production and are different products. Modules include components in their production, but as these are produced in-house they are not considered as material for the module manufacturing. When calculating costs per product the costs of the components are added to the module cost.

7.4 The characterisation of the Reference Fab Model

7.4.1 General

Reference Fab – Curve 1

The Reference Fab curve (curve 1) produces a reference volume of the reference product for components and modules. For simplification it is assumed that the Reference Fab product mix is reduced to only one component and one module, the reference product. As the volumes of the sites are normalised to the reference products, the comparability stays valid. It is also assumed that the Reference Fab is a mass production site, which is the only way of representing a best-case scenario. All costs and resources that cannot be calculated are assumed to be the benchmark costs, derived from internal or external benchmarking, when available.

Sites – Curve 3

When transforming cost and efficiency targets to the site-specific Curve 3, the sites' planned volume, product mix,[13] yield, factor costs and the Fab Open Time (since not all sites are open for the same number of days per year) are taken into consideration.

7.4.2 Capital

Reference Fab – Curve 1

For the Production Equipment, reference models and their planned capacities are used. Not all sites reach these capacities even with the reference equipment models, and others are using old models.

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[13] The product mix is used in another model in order to calculate the Equivalent Volumes. In the Reference Fab only the Equivalent Volumes are considered in order to simplify the calculation without losing accuracy (see chapter 6).

For curve 1 it is assumed that it is possible to have a non-integer number of machines. This means that a loss of efficiency does not occur due to the problem of having to have more capacity than needed. It uses a list of the main equipment needed for production. Apart from this equipment, a top-down percentage of this equipment is used as 'fixed equipment' (equipment number not scaled with volume) for production.

The equipment prices are given by the purchasing department, which reflects their price targets according to the numbers of equipment to be purchased and their power of negotiation. The prices used were the ones for which the equipment was acquired, but during the update they were changed to the planned prices. This was done in order to simplify and not to influence the targets with the different prices achieved by the central purchasing department.

The exchange rates used are the ones planned for the next business year.

As far as the components are concerned, the most relevant area is the test one. The Burn-In and Test equipment is the most expensive, and it is where capacity is more complicated to calculate because it depends on the type of tests done, on the type of product, its package, generation and organisation. Another influence factor is the DUT's, which means Devices Under Test, which gives the number of devices that are tested simultaneously. When the number of DUT's is higher the test equipment becomes more efficient. For these reasons a roadmap for capacity is established in order to improve equipment efficiency. For the assembly area a factor of efficiency improvement is used, which is planned top-down. For the module production a roadmap for assembly and test is calculated, because it is not yet a mature process and therefore there are many opportunities for improvement.

The Building and Facilities Investment had already been calculated, having an external benchmark as the basis.

Sites – Curve 3

The Equipment is calculated taking the planned volume as the basis, but since it is not possible to have a non-integer number of machines, economies of scale have to be taken into account. Last year, other equipment that was not listed in the main equipment was also calculated and negotiated. The same values were used since no major changes were to be made.

In the component production some adders had to be used.

Except for BI equipment, the differences in equipment types in the sites do not have a significant influence. Two of the four sites use BI equipment from a different vendor, which has less capacity and therefore is less efficient. The difference between them results in about 42% less capacity.

One of the sites is producing with much smaller lot sizes because they do engineering activities to support a Frontend site.[14] Due to this fact an adder was calculated for the assembly and for the test area.

In the module production, a factor called SMT Factor was used, which reflects the difference in speed of the different sites' lines.

The Building and Facilities Investment used was the site specific one, because no investments in this category are planned for the next year and no improvements can be made in this category. All the expansion in volume can be done with the existing buildings. New ones are planned for the following years, which are not reflected in the Reference Fab yet since they are not expansions but new modules in existing sites or even new sites in different locations. The Investment needed in B&F can be a reason for building a site in a certain place or not.

7.4.3 Material

<u>Reference Fab – Curve 1</u>

For relevant material in consumption and cost, such as with lead frames and Burn-In Boards (BIB), the purchasing team sets roadmaps for its cost per piece. For the other materials in production, the values used for curve 1 are derived from the cost per piece resulting from the internal benchmark. Since almost all materials are purchased centrally by the headquarters in order to obtain better prices, and as the consumption should be almost the same by all sites, the benchmark is valid as a target setting. On top of the benchmarking an average top-down improvement percentage is assumed, since the prices should decrease every year.

The utilities and maintenance material cost per piece cannot be targeted with benchmarking because the factor costs are relevant. One part is dependent on volume and the other is not. This leads to considering fixed and variable percentages. These percentages were agreed on by the sites and are based on experience. For curve 1 the internally benchmarked costs are used and scaled with the Reference Fab volume.

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[14] This topic was object of a deeper study, which will be reported later on.

Sites – Curve 3

For the Material in Production (MIP) in both curve 3 and curve 1, the same method and costs per piece were used since the purchase price roadmaps and the benchmarks are valid for all sites. For the Other Material in Production (OMIP), which should include only fixed material costs, the target setting had to be changed at the request of the sites, because one site also reported variable costs. This led to more discussion because the allocation between MIP and OMIP is not standardised in the sites.[15] In the end, before a common agreement was achieved on the allocation, the target was set having the sites' specific costs per piece from last year with a top-down percentage improvement as the basis.

For utilities and maintenance material costs per piece the same method as for curve 1 was used, but having the sites' specific fixed and variable costs from last year scaled with their specific planned volume as the basis.

For one of the materials, the Burn-In Boards, an adder was calculated to reflect the different cost per piece that each site could achieve. The differences were high, the main reason being very high prices for BIB's for one new product, and their lower efficiency because they lasted less time than the old ones. The BIB's were discussed and the result was to set a price roadmap in order to reduce costs with the objective of increasing BIB efficiency for the new product. After this decision, the BIB adder was skipped for the following year. In the next planning period the effectiveness of this price reduction and efficiency increase should be evaluated, in order to re-evaluate the need for this adder.

7.4.4 Personnel

Reference Fab – Curve 1

Personnel target costing uses the factor costs (salaries) and net productive hours of an external benchmark done in 2000. This benchmark was used because it reflects less cost and more NPH than Infineon sites. The personnel efficiency, measured in hrs/kpcs, used the internal benchmark with a percentage improvement on top. The personnel efficiency and headcount target considered a fixed headcount, which reflects the part that is not scaled by volume, such as shift leaders and supervisors. This fixed HC was also subject to internal benchmarking.

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[15] This topic lead to some changes and problems reported in another chapter (see section 9.1).

Sites – Curve 3

Site-specific factor costs are used in addition to their NPH for the calculation of curve 3. The fixed headcount was assumed to be the same as last year, with the agreement of the sites. The sites also used the internal benchmark for efficiency as a target. Although it is a valid benchmark some adders have to be considered. One of them is the economy of scale factor since a “minimum headcount” is needed to ensure some activities, because even with little volume they have to be operating. With the volumes produced in the sites this “minimum headcount” is not felt at the operator level, but it is felt in the smaller sites in the maintenance personnel. The other adder concerns the two sites that have different BI equipment as was mentioned above. Apart from being less efficient, this equipment needs more time from the operator for the set-up. This adder was included this year, while doing a revision of personnel complexities in one of the sites.

After the targets were set, the site mentioned earlier on as doing engineering activities had a plan which showed much less efficiency than the target. Because of their special activities of engineering and Frontend support, they could not achieve the target, which was unreal for this site. Because of this, special adders had to be used, such as dedicated engineering personnel, maintenance personnel doing additional set-ups due to the high number of new products being developed, adders due the smaller lot sizes, and more “minimum headcount” and therefore lower economies of scale due to a new line of production for a new product. Another target was set and inefficiency was identified. After some discussion the target was agreed on.

The personnel targets are sensitive because the headcount targets derive from them. Modelling the number of people needed for each function or department is very difficult and open to question, since each department has its singularities and exceptions that can be used as an excuse to question a headcount model. Therefore it always results in a negotiation.

7.4.5 Overhead

Reference Fab – Curve 1

The Overhead Capital and Material efficiency are calculated using the Capital Investment and Material Cost of the Porto site, since Porto is a stand-alone site, where facilities are not shared with other business units. For the Overhead Personnel category, the benchmark Overhead headcount was used. Since the overhead efficiency is not proportional to volume, to use the benchmark is a valid assumption.

Sites – Curve 3

In curve 3 the site-specific costs and Capital Investment from last year are used for next year as no major changes occur. For Overhead Personnel the same headcount is also used, because overhead functions are not dependent on volume.

7.5 The Reference Fab Tool

The Reference Fab tool is based on a Microsoft Excel file. Some disadvantages exist regarding its lack of stability. A great amount of data is needed, all the calculations of efficiencies and cost per pieces for the four BE sites are done, which results in a big file. The instability of the software leads to many problems in dealing with it. On the other hand it is a very flexible software application, changes can be easily made, interfaces to other tools can be made with less effort and software knowledge is not as demanding as for other software programs. It has to be said that almost all planning, target setting and reporting tools in Infineon are based on Excel. Therefore, the software was not changed.

The model used inside the tool is very effective, because it uses an input sheet, some calculation sheets, especially for the internal benchmarks, a central sheet for the curves calculation and output sheets with graphs. The linking of the data between the sheets and between the tool and other tools is done via "lookup keys" in order to ensure data integrity. The "lookup keys" are also needed because the calculations in the Reference Fab are done site by site. In the main sheet, the number of the site is chosen, and the "keys" ensure that the right data for the right site are obtained. The tool under improvement only had data that was two years old because the Reference Fab was not used last year, due to a lack of resources. Almost no links between the files and input sheets were available, nor were the formulas. The values had been “copy-pasted”, which made working with them more difficult. The documentation available was three years old and therefore not up-to-date. However, it was helpful for the general understanding of the model.

Some modifications were done to this data organisation. First an external file was created in order to build the interface between the Reference Fab and the other tools. This interface is needed because the data, especially the volumes, are updated quite frequently, and they come from different files with different formats. In this way, the Reference Fab tool is not affected. After all updates are done, the interface can be linked to the reference Fab, which leads to the updating of all values and calculations.

The input sheet in the Reference Fab tool was divided in three. One for the drivers that influence the efficiencies and can be the object of top-down changes for scenario calculations, another for the secondary data, and a third one for the top-down planning data. All benchmark and important cost values and parameters must be changed in the first input sheet in order not to loose the linking with the main calculation sheet. This input sheet is divided into Components and Modules; in each cost category and then in the type of influence in the calculation. This type of influence can be curve 1 or curve 3. The objective of this organisation is to ease the top-down planning for curve 3.

The calculation sheets were simplified and only the core calculations for the target setting were used in order not to overload excessively the file.

Another new sheet was created in order to have a view of the transition from curve 1 to curve 3 in each cost category. This was done category-by-category, driver-by-driver, with the result that each site can see the effect of each driver quantified by its efficiency. For example, the sites that have an adder for personnel efficiency for a special reason can see how much cost weight it has on their cost per piece. They can quantify how much the gain would be if they could improve this area. This overview is a very important step, especially for the understanding of the targets and for their acceptance.

7.6 Results of the Reference Fab Target Setting

In addition to reviewing and updating the Reference Fab model, our objective was to use it in setting targets. This objective was accomplished as the cost targets were set, and also they were agreed on and understood by the sites. The bottom-up planning by the sites shows that the targets are reasonable as they are achievable or almost achievable, at least by the mass-production sites. The minor gap between the planned and targeted efficiencies is a challenge to improve.

Capital efficiency is a target that should be (or almost) achieved by all sites, because it is only derived from the number of equipment and volume. The equipment is very much standardised and its capacity very well developed. Research is done in order to increase equipment output. As the capacities used are planned, or given by the suppliers, it can happen that the mass production sites can exceed these capacities. The plan for the mass production sites differs from the target by a maximum of 20%, which is explained by a 75% increase in volume. The ramp-up of the equipment is not considered in the model, which gives origin to this difference. The economies of scale are a very important factor for the smaller sites. The mass production sites are very near the EOS factor of 1 but the smaller sites are up to 24% above the mass production sites. The economies of scale are mostly reflected in the Pre-Assembly, where the equipment has a high throughput because it operates on the wafer scale. The capital efficiency of module production in the smaller sites is much higher than the mass production ones because their lines are very small. The two lower module volume sites produce 9% and 40% less than the one producing more. These values are in equivalent capital because the complexity is essential for the efficiency.

The material efficiency, which is calculated as the material cost needed per piece, should be achieved by the sites because the usage per unit should be almost the same and almost all the prices are negotiated centrally, what means the same prices for all the sites. The target is calculated using an internal benchmark of material cost per piece and price targets for some of the more relevant materials. The sites use the same price targets for the most relevant materials and for the others they use their plan. As the sites are increasing volume, the cost per piece should decrease, which is the effect of the volume, and they plan improvement projects in order to decrease consumption that they consider to be high.

This is valid for almost all materials except for one, for which the price is very high and the consumption for new products is very high as well. The core-buyer target was re-defined, but it is still the object of study because the results are not yet satisfactory. If the price and consumption does not decrease, this new product does not make sense, because the total cost is very high. This is the situation for components.

For modules, the material cost per piece should be achieved by the sites. This does not mean that there is no room for improvement, because the material cost is around 70% of the total cost for modules. Any improvement in price or consumption is very relevant. There should be more opportunities in the reduction of prices, because of the increased volume and the resulting power of negotiation.

Personnel efficiency is calculated based on an internal benchmark of the hours needed per equivalent piece produced. For components one major change has occurred since last year, which is the planned achievement of the target of one of the mass production sites. The mass production sites plan to achieve their targets and the smaller sites almost achieve them. For the Dresden site the calculation had to be revised because of their engineering activities that overload the direct personnel. These adjustments were made with the use of adders in headcount, which should be avoided. But as the model does not include the additional efforts of these engineering tasks this temporary solution was implemented. A proposal for a realistic and wider solution to this problem is made in chapter 10. The impact on the efficiency of these engineering tasks seems to result in 50% worse efficiency. For modules, the personnel efficiency is not so good for almost all of the sites. One of the mass production sites plans to achieve or even exceed the target, but the other one does not. The explanation for not achieving the target is that it still needs much visual inspection, because of customer samples and new products. However, it is lower than last year, which is indicative of good progress.

The economies of scale have a great impact in personnel, especially in the area of maintenance personnel. This can be seen in Exhibit 15:

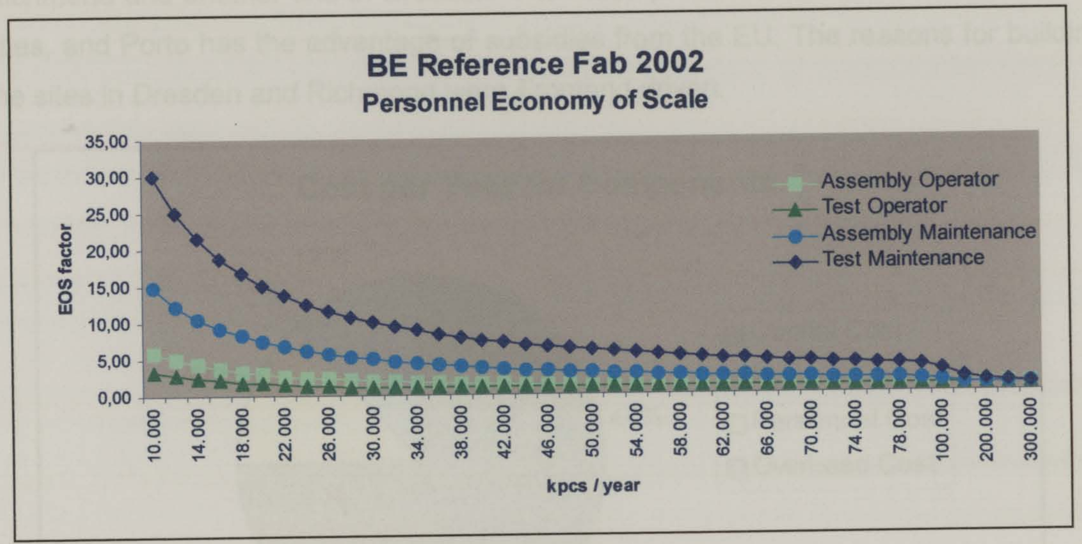

Exhibit 15 - Direct Personnel Economies of Scale

The overhead efficiency target was calculated under the following assumptions: as the structural changes will only be shown in a volume increase, the overhead capital cost, the overhead material cost and the overhead headcount should not be increased. Therefore, the values from the site reports for the past year were used. What the site plans show is that the mass production sites can achieve these targets, which does not happen with the smaller sites. The reason for this result is that the mass production sites will achieve a very large increase in volume.

8 Cost Structure at Infineon Backend Sites

The Backend sites are comprised of two mass production sites; one in Porto and the other one in Malacca, and two sites to support two Frontend sites, one in Richmond and another one in Dresden. The mass production sites are low factor cost sites, and Porto has the advantage of subsidies from the EU. The reasons for building the sites in Dresden and Richmond were Frontend driven.

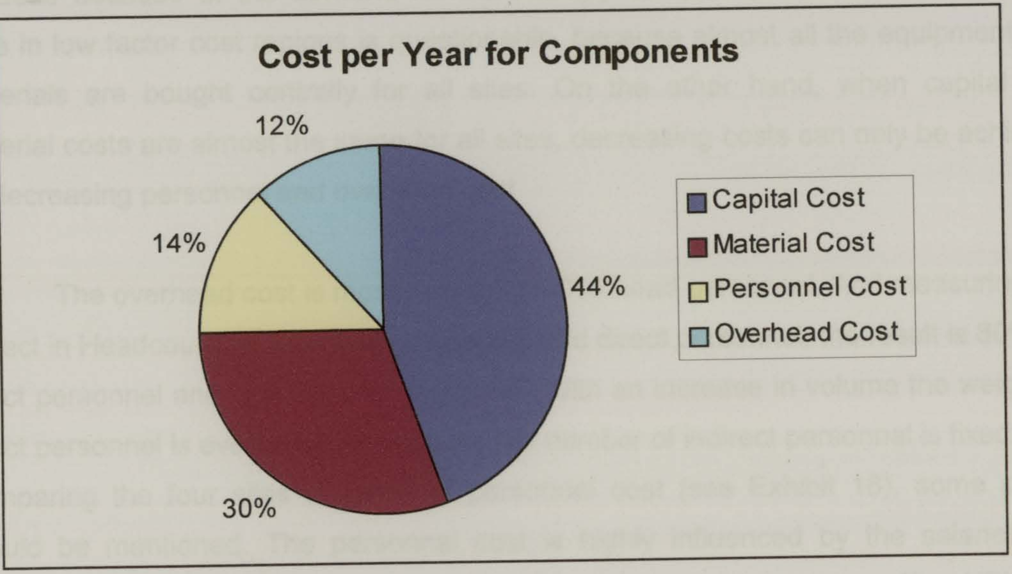

Exhibit 16 - Cost Structure for Components

Analysing the total cost per year for components in Exhibit 16, it can be seen that the capital cost in components is very high, especially the test capital cost, which is around 80% of the capital cost.

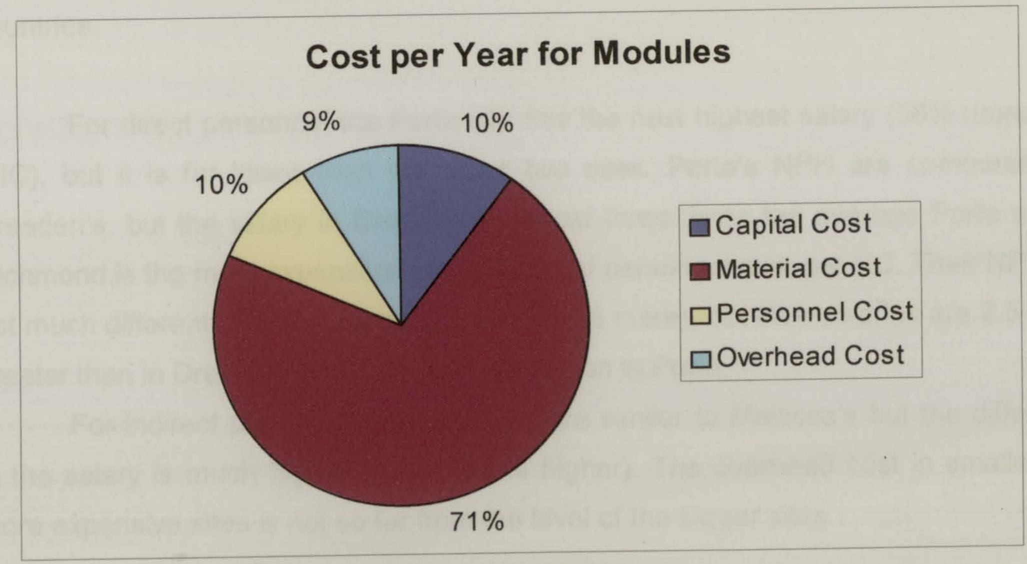

Exhibit 17 - Cost Structure for Modules

For modules the picture is not the same. In Exhibit 17, it can be seen that the material cost represents 70% of the total cost, and capital only represents 10%, the same for personnel and overhead costs. Modules have a more flexible cost structure than components, because of the lower capital cost.

Capital and Material costs have more importance than Personnel and Overhead for both components and modules. In addition, the weight of material cost tends to increase because of the demand for increasingly complex products. Thus, locating sites in low factor cost regions is questionable, because almost all the equipment and materials are bought centrally for all sites. On the other hand, when capital and material costs are almost the same for all sites, decreasing costs can only be achieved by decreasing personnel and overhead cost.

The overhead cost is mostly driven by Overhead personnel. And measuring the impact in Headcount for Overhead personnel and direct personnel, the result is 80% for direct personnel and only 20% for overhead. With an increase in volume the weight of direct personnel is even greater, because the number of indirect personnel is fixed.
Comparing the four sites in terms of personnel cost (see Exhibit 18), some points should be mentioned. The personnel cost is highly influenced by the salaries per headcount and the net productive hours achieved by each employee. The NPH are also highly influenced by the local labour laws. The values for IFIC (Malacca) are set at 100%, because it should be the site having the minimum personnel costs with its lowest salary per HC and the highest NPH per year. The reason for this is that the hours an employee is permitted to work in Malacca is higher than in the other countries.

For direct personnel the Porto site has the next highest salary (58% more than IFIC), but it is far lower than the other two sites. Porto's NPH are comparable to Dresden's, but the salary in Dresden is almost three times the average Porto salary. Richmond is the most expensive site in terms of personnel cost per HC. Their NPH are not much different from the European sites (14% more), but their salaries are 2.5 times greater than in Dresden, and 7 times greater than in Porto.

For indirect personnel, Porto's NPH are similar to Malacca's but the difference in the salary is much higher (about 105% higher). The overhead cost in smaller and more expensive sites is not so far from the level of the bigger sites.

In conclusion, when building a new site, choosing the region where to build it is very important when taking personnel costs into account, and the most important factor cost is for direct personnel because it signifies about 80% of the total headcount.

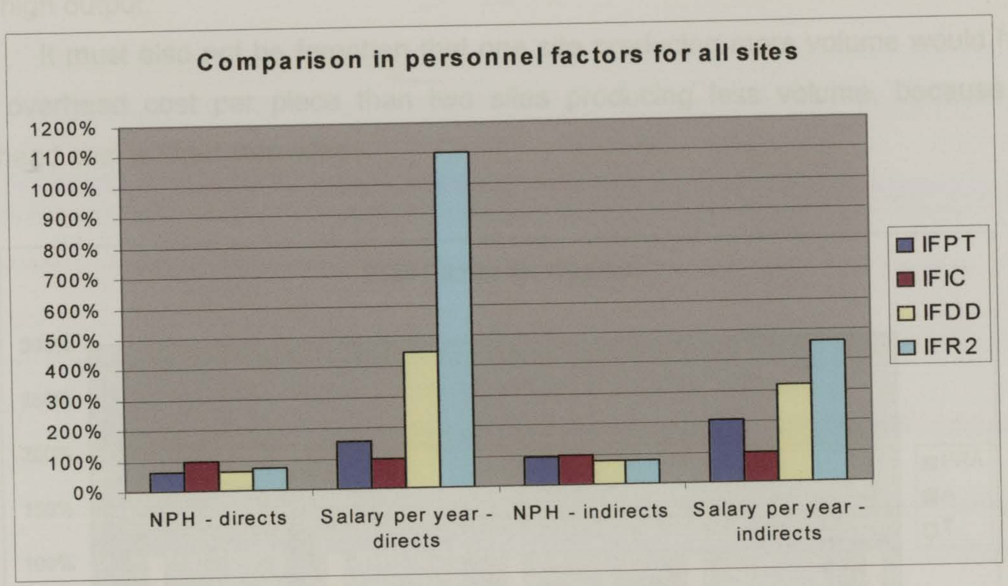

Exhibit 18 - Comparison Between BE Sites for Personnel Factors

Comparing Porto to Malacca, personnel efficiency is similar. Thinking about the reasons for building factories in Porto or Malacca, the first impression is that Malacca can achieve lower Building & Facilities cost and personnel costs, but Porto is in Europe, near the European FE site in Dresden, and had subsidies to build the fab there. The future should see the concentration of more sites in Asia, because almost all the suppliers for material and equipment are situated there, the factor costs are lower and the work laws are not so rigid as in Europe and America. But the strategic reason is the proximity to the local markets and to Infineon's Frontend fabrication sites.

To have one mass production site in Asia and another in a relatively cheap European country appears to be a good strategy of "dividing the eggs into several baskets". But the reasons for locating the sites in Dresden and Richmond, apart from the fact of being near the Frontends, are more questionable. If the intention is to have engineering support and be near the FEs, then this is explainable. But perhaps engineering support can be achieved in "cheaper countries", too. Or all engineering and support could be concentrated in Dresden, which has the cheaper personnel cost of these two sites. The two smaller sites cannot achieve the same economies of scale as the bigger sites. Since the bigger sites achieve a factor of almost 1, the smaller sites have different factors, which can be seen in Exhibit 19, as well as the economies of scale factor that a site producing Dresden's and Richmond's volume would achieve. It can be concluded that combining these two sites into one would be an advantage in terms of capital investment, especially in the PRA area, where the equipment has a very high output.

It must also not be forgotten that one site producing more volume would have less overhead cost per piece than two sites producing less volume, because the overhead cost is fixed step-wise.

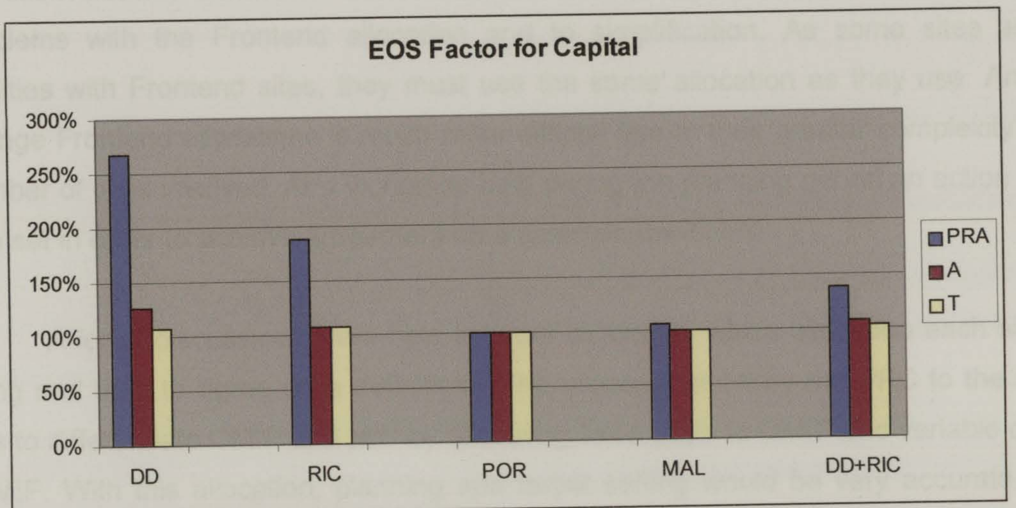

Exhibit 19 - Comparison in Economies of Scale for Capital Investment

9 Special topics

9.1 Allocation of Material Costs

Some problems arose during the update and review of the Reference Fab. One was the allocation of the material costs. The major difference was identified in the allocation to Material in Production (MIP) and Other Material in Production (OMIP). A definition existed, which was not followed by the sites due to lack of awareness, to problems with the Frontend allocation and to simplification. As some sites share facilities with Frontend sites, they must use the same allocation as they use. And to change Frontend allocations is much more difficult due to their greater complexity and number of sites involved. At a workshop held during the planning period an action item was set in order to achieve agreement on a common definition.

A lot of discussions were held in order to identify which allocation each site is using and then to agree on a definition. The proposal given by the PPC to the sites was to differentiate OMIP and MIP by allocating fixed costs to OMIP and variable costs to MIP. With this allocation, planning and target setting would be very accurate. For MIP an internal benchmark would be done and the costs scaled with volume; for OMIP the total costs would be considered fixed from year to year. This proposal was generally not accepted as the sites would prefer the distinction between material incorporated into the product (in MIP) and material not incorporated (in OMIP). The result is that OMIP has fixed and variable material costs with this definition. Because of the impossibility for the sites to make major changes in the allocation, this definition was set. In order to plan and target costs it was assumed that 20% of the material in OMIP is fixed cost and 80% is variable.

For those material costs that some sites could not allocate to the categories according to the definition (because of the Frontend allocation, or because the SAP is already configured to allocate material costs in this way and the changes to be done were not simple) the sites were asked to report these differences to the definition in order to know what can and cannot be compared when evaluating costs between the sites.

Regarding this issue, I was aware that the SAP systems and therefore the method of allocation is an issue to be studied because a project is being undertaken to have a standard system. This is being done in Infineon, at least for BE and FE, and therefore until it is ready and all sites are using the same definition, the only way of knowing the difference is to investigate amid all the sites in order to reach an agreement on one allocation and to report the differences to the definition.

Regarding material costs, something has to be added. A project named "MACORE" is defining and implementing a model, a tool and some procedures in order to benchmark consumption between the sites. The objective is to identify opportunities for improvement in material consumption. As this is a big project involving all sites it should be used not only for material consumption but also for material costs. As the prices are more or less standardized the effort in extending it to costs would not be very difficult or demanding. On the basis of this information, more accurate cost target setting could be achieved in the Reference Fab because the Reference Fab benchmarks the total costs on a yearly basis, and the aim of "MACORE" is to benchmark material consumption on a monthly basis.

Apart from that, "MACORE" benchmarks materials at a deeper level for the most important materials used in the component and module production, which could add value to the Reference Fab. An approach to this idea was tried during the internship, but the output of the "MACORE" tool is still very unstable because inconsistencies between its data and the reported data still occur. It needs further improvement in order to make its output trustworthy.

This is a very important project, with an aggressive target of cost reduction, and improvements have been made as the project goes on.

9.2 Overhead Costs Allocation

Another topic under discussion was the allocation of overhead costs to components, modules, assembly and test. Again, because of the Frontend allocation and of different methods of allocation, sites show differences in this allocation. This allocation is especially important on the component-module level, as it leads to different costs per piece. Although it is a very relevant topic and influences all reporting systems at Infineon Memory Products, it is an issue that has to be treated on a wider level. This is a complex issue and there are costs caused by making any change, thus the value added by every change must be questioned.

9.3 Transition C1 - C3

Due to the importance of the C3 curve, an overview of the transition from curve 1 to curve 3 was created in the Reference Fab tool. The objective is to show the impact of the site-specific adders on the efficiency and on the cost per piece for each site, and to justify why the targets are higher or lower for one or the other site. The objective is to make clear what each adder means in terms of cost per piece. The most important result is that of tracking opportunities for improvement.

An example is given below in Table 1 (for Capital Efficiency in Assembly for Components):

	IFPT	IFIC	IFDD	IFR2
BEC CA CAP EQIP C EQIP CA C1	100%	100%	100%	100%
BEC CA CAP EQIP Real Volume/EOS	6%	6%	31%	31%
BEC CA CAP EQIP Adders in Equipment	0%	0%	0%	0%
BEC CA CAP EQIP Fab Open Adder	1%	2%	0%	0%
BEC CA CAP EQIP YLD	0%	0%	0%	0%
BEC CA CAP EQIP Other Equip	4%	14%	51%	77%
BEC CA CAP EQIP small lot size adder	0%	0%	9%	0%
BEC CA CAP EQIP C EQIP CA C3	111%	122%	191%	208%

Table 2 – Example for C1-C3 Transition

Starting with curve 1 at 100%, the first transition for capital efficiency is the difference in volume and therefore in economies of scale. It can be seen that smaller sites (IFDD and IFR2) suffer a greater effect from economies of scale. The adders in equipment are not relevant for Assembly. The Yield (YLD) gives no transition because in Assembly the Yield is almost 100% for all sites. The 'Other Equipment' adder indicates the additional equipment that is site-specific. The small lot size adder was agreed on with Dresden (IFDD) in order to reflect the fact that they have smaller lot sizes.

These transitions explain some differences between site costs in a few figures, and also show the influence of cost drivers in their efficiencies. These transitions were done for all sites and all efficiency types. The result of this can be a better understanding of the targets imposed for each site, why each site has a more or less aggressive target, and what each adder means for the target setting. It should also be the cause for the discussion; are these adders reasonable and do the assumptions of the Reference Fab Model reflect the reality?

10 Dresden's Corridor of Additional Efforts

10.1 Definition of the Problem

Dresden has a BE site that, apart from producing, supports two Frontend sites, one producing 200mm wafers and another producing 300mm wafers. The Backend site does engineering projects, especially developing new products and other "special" activities that occur due to the fact of having the Frontends nearby. The sum of these activities is called the Corridor of Additional Efforts (CAE), which was changed from Engineering Corridor because it included more than the engineering projects. This change in denomination was made during the identification of the additional work that the Dresden Backend site has to perform, because engineering projects are only a part of their efforts and other activities were identified.

These activities are very difficult to plan and to control. Until now the volume produced in Dresden is considered to be "normal" volume without the effect of additional efforts. In addition, the volume produced under the denomination of engineering activities is not considered, but the resources are. The result is that the KPI's show much less efficiency than the models because these efforts are not modelled. This lack of visibility has many results:

- Lack of control of inefficiencies.
- Non-comparability to production sites, which reduces the meaning of benchmarking.
- Difficulty to plan centrally and to evaluate the site's plans
- Avoidance of doing engineering activities in other sites so as not to spoil their KPI's too.
- Difficulty of tracking what engineering projects are being performed and of allocating the efforts to the project owners.

In order to report these additional efforts, what is done now is a percentage deduction of the engineering corridor costs from the total costs. This percentage is a rough estimation of the additional efforts having as basis production time. The disadvantage is that this method only explains the costs *a posteriori*. This means that the planning and visibility of costs and efficiencies is not achieved. Implementing the Activity Based Cost Model (ABC-Model) is planned, but due to lack of resources it has not been put into practice yet. A description of the engineering activities was to be done in Dresden, because of the need for implementing an attribute in the software systems in order to identify the volume produced under several projects, but the identification of the projects had not yet been achieved.

Although it is an artificial way of deducting the engineering costs from the total costs of production, this is only done in the monthly reporting and controlling. It is not included in the cost target setting and consequently in the Reference Fab.

This year, as a response to management demand, some effects of these activities done in Dresden were included in the form of adders in the Reference Fab. This was a temporary way of explaining some efforts. First, it was only made in the personnel efficiency category, because the gap between plan and target in Headcount was very high (about 40% more planned by the site than targeted by the headquarters) as it can be seen in Exhibit 20. Moreover, it only explained the efforts; it does not constitute a plan or a target for these efforts, because the information and a model or way to do it is missing. And finally, no visibility is created, and the addition of adders that cannot be calculated by the PPC central department is to be avoided in the Reference Fab, because of their lack of controllability.

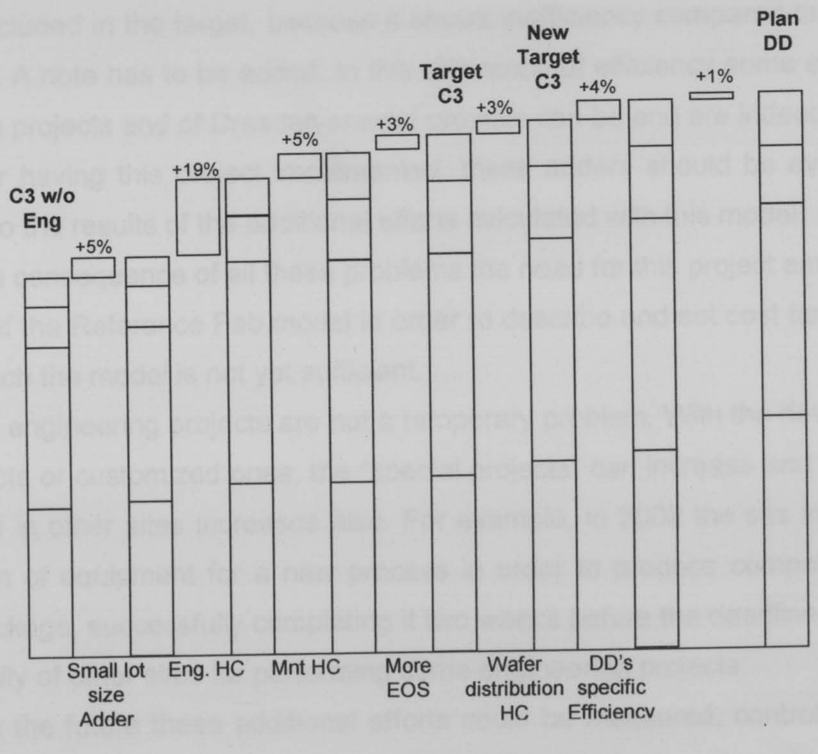

Exhibit 20 - Direct Headcount Bridging Due to Additional Efforts

This bridging is the result of the adders proposed by Dresden in order to explain their plan values. The small lot size adder was introduced in the form of a percentage on top of the personnel efficiency, which should reflect the small lot sizes that the personnel have to deal with. It is estimated by experience and not calculated. In this proposal the additional efforts due to smaller lot sizes should be calculated project by project.

The engineering and maintenance headcount are the number of people that support the engineering activities. This maintenance headcount is responsible for doing the set-up of machines when changing tools.

3% more headcount was also added because of economies of scale, since Dresden site has a separate production line for a new product. The economies of scale are the result of the minimum headcount needed, which is constant when producing greater or less volume. The production line for this new product is separate from the other one, but similar. The fact of being separate may be a problem of area and layout, and therefore it should not be included in the targets.

The wafer distribution headcount is necessary due to this special task of Dresden. This is one of the projects that this proposal covers.

Dresden's specific efficiency is the efficiency that the site uses for the headcount calculation, which increases the headcount by 4%. Of course this should never be included in the target, because it shows inefficiency compared to the internal benchmark. A note has to be added: in this difference of efficiency some effects of the engineering projects and of Dresden special projects can be and are indeed included.

After having this project implemented, these adders should be evaluated and compared to the results of the additional efforts calculated with this model.

As a consequence of all these problems the need for this project emerged as an extension of the Reference Fab model in order to describe and set cost targets for one site, for which the model is not yet sufficient.

The engineering projects are not a temporary problem. With the development of new products or customized ones, the "special projects" can increase and the need for doing them in other sites increases also. For example, in 2002 the site in Porto did a qualification of equipment for a new process in order to produce components with a smaller package, successfully completing it two weeks before the deadline. This shows the capability of other sites for performing some engineering projects.

If in the future these additional efforts could be measured, controlled, planned and the object of target setting, they could be performed in other sites with lower factor costs since the needed know-how is already available.

10.2 Proposal for a Solution

10.2.1 General Concept & Objectives

In order to solve this problem, some objectives must be taken into account, namely the following ones:

- To create visibility in costs and resource usage for tasks that are not covered by today's models.
- To make cost controlling of these activities possible.
- To make planning and target setting possible.
- To achieve the necessary conditions in order to unite mass production and engineering in one site without spoiling the planning ability.

The scope of the project is the Corridor of Additional Efforts, which has to be described in detail. The additional efforts are, in general, all activities which are not "normal production". This corridor includes the Engineering corridor, which comprises the engineering projects (such as development and qualification of products), the production of customer samples, and it also includes the work effort of other activities, such as wafer distribution, which is the distribution of wafers to other sites after coming from FE. All these activities are part of the mission of the Dresden site and one of the reasons for its existence.

The projects have to be characterised therefore, which will be done in section 10.3.

As mentioned earlier, in chapter 6, different products are normalised to an equivalent Volume with the help of complexity factors that represent the cost difference among them in Capital, Material and Personnel.

The difference between "normal production" and these projects are mostly differences in the process flow. This diversity can also be calculated with the help of complexities. Take a customer sample for example; what is the difference for the same product in producing it as customer sample or as production to be sold? The answer is that most customer samples use different packing and undergo additional tests as required by the customer. These are then the additional activities that have to be included in the complexity of a customer sample. After the complexities are calculated it is easy to include them in the normal reporting, only the equivalent volume needs to be calculated and no major changes have to be made to the normal reporting process.

The issue is how to calculate those complexities. As the engineering projects differentiate from the normal production flow (called Process of Record (POR)) in the level of process steps, the projects have to be characterised first in terms of these process steps. The differences have to be calculated for drivers. Drivers are key measures that influence the calculation of cost. For example, for capital cost in test the drivers are the lot size and the test time performed.

The difference for the drivers' influence in each process step has to be accounted for. This can be done by calculating weights for each driver for each process step. As the complexities are aggregated to Assembly and Test in the normal reporting system, this must be done with all the complexities generated for all projects. By using the weights of each process step for each area, the aggregation is basically done. In the end, complexities, which reflect the additional efforts for each project, are calculated for each area and each cost category.

The process is illustrated in Exhibit 21:

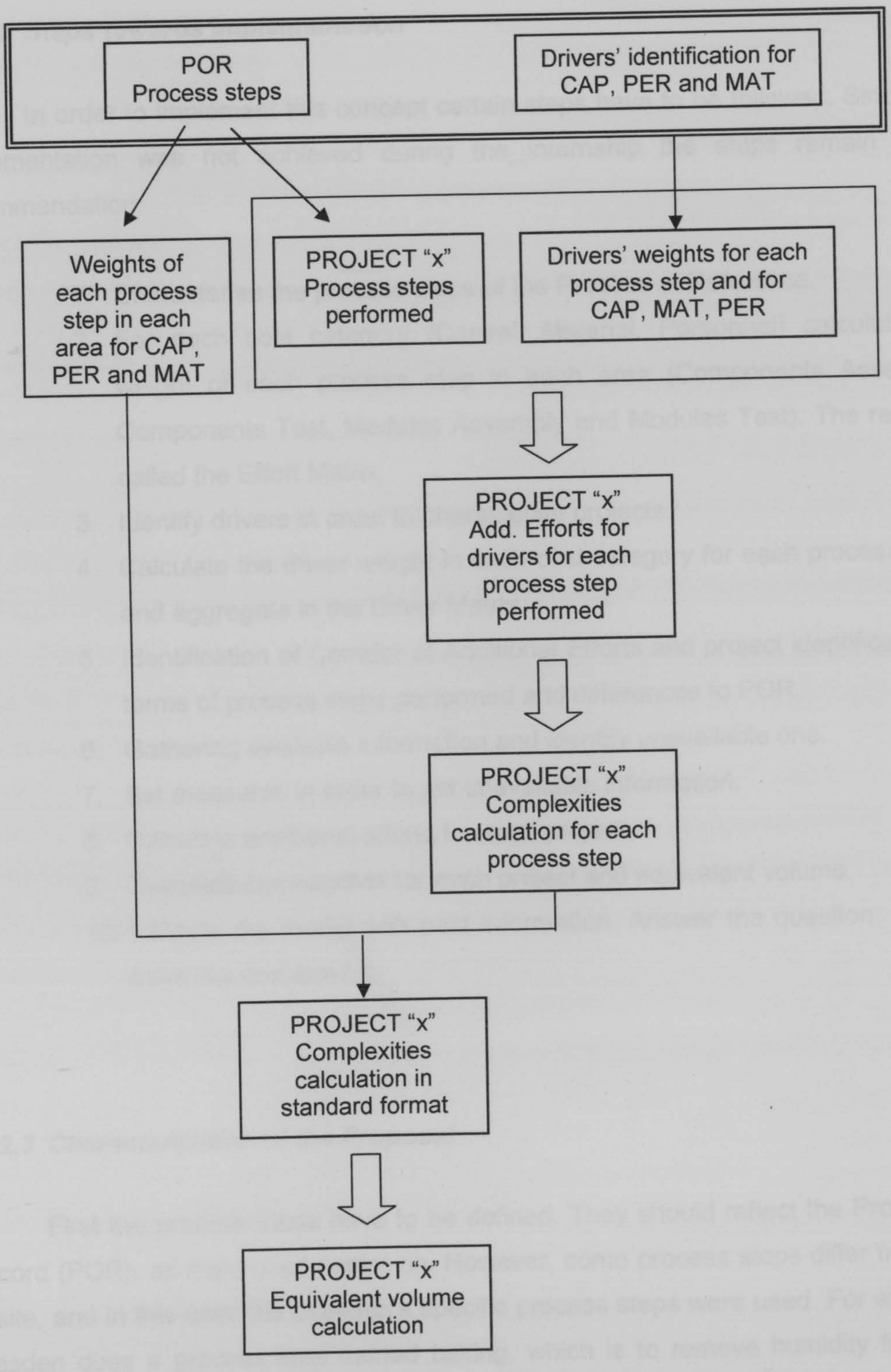

Exhibit 21 - Proposal for CAE Solution

10.2.2 Steps towards Implementation

In order to implement this concept certain steps have to be followed. Since the implementation was not achieved during the internship the steps remain as a recommendation.

1. Characterise the process steps of the Process of Reference.
2. For each cost category (Capital, Material, Personnel) calculate the weight of each process step in each area (Components Assembly, Components Test, Modules Assembly and Modules Test). The result is called the Effort Matrix.
3. Identify drivers in order to characterise projects.
4. Calculate the driver weight in each cost category for each process step, and aggregate in the Driver Matrix.
5. Identification of Corridor of Additional Efforts and project identification in terms of process steps performed and differences to POR.
6. Gathering available information and identify unavailable one.
7. Set measures in order to get unavailable information.
8. Calculate additional efforts for each project.
9. Calculate complexities for each project and equivalent volume.
10. Validate the model with past information. Answer the question: does it solve the problem?

10.2.3 Characterisation of the Proposal

First the process steps have to be defined. They should reflect the Process of Record (POR), as mentioned earlier on. However, some process steps differ from site to site, and in this case the Dresden's specific process steps were used. For example, Dresden does a process step named baking, which is to remove humidity from the components that enter the production in the middle of the process. The other sites do not do this because the components they receive are packed differently and do not need the baking process, but this can change in the future. Other process steps are specific to some products, such as the heat-spreader attachment for some modules, but these differences should be covered by the complexities calculated in the existing models that cover the differences between products, for which the “Toolbox” is used.

Next the Effort matrix, which includes the weights of each process step for each category, has to be calculated.

For Capital, the weights of each process step are derived from the price of the equipment needed divided by its capacity. The prices are given by the Core-Buyers and the capacities by the Capacity's Model, which calculates the planned capacities of all equipment for the cluster. Each site can achieve this capacity or even exceed it, but as a planned capacity it is the reference.

For Material, the cost per piece of the main materials consumed in each process step was used. The values used were those of the Malacca site since they are free of any engineering projects.

For Personnel, two drivers have to be considered: one is the Men-Machine-Ratio for process steps which are highly dependant on machines; the other one is the time needed per device for highly manual process steps, such as visual inspection. With these two indicators the Headcount needed for each process step for a certain reference volume can be calculated, and the weights can be derived from it. These values, especially the time needed per device are almost invariably estimated by those responsible for each process area. For the components, the Men-Machine-Ratio and times per device used are the ones from Dresden, but the ones for modules are from the site in Porto. The module line in Dresden is very small and some functions are aggregated to the components line. The module headcount model used is very explicit, which also helped to better understand the drivers and impact of visual inspections in the module production.

The resulting effort matrixes for components and modules are presented n Table 3 and 4, respectively:

Components		CAP	PER	MAT
Assembly	Laminating	1%	2%	2%
	Grinding	8%	4%	1%
	Peeling	1%	2%	0,3%
	Mounting	2%	2%	1%
	Dicing	11%	6%	0,3%
	VI	0%	0,4%	0%
	Die Bonding	20%	11%	71%
	Wire Bonding	12%	34%	7%
	Molding	19%	15%	15%
	Post Mould Cure	5%	10%	0%
	Dedam Dejunk	4%	5%	0%
	Plating	5%	5%	3%
	Trim & Form	11%	5%	0%
	TOTAL Assy	100%	100%	100%
Test	BI Load	2%	4%	0%
	BI Oven	20%	30%	78%
	BI Unload	2%	4%	0%
	U4 Test	37%	21%	0%
	U2 Test	36%	21%	0%
	Baking	0,04%		0%
	MSP	3%	20%	22%
	TOTAL Test	100%	100%	100%

Table 3 - Effort Matrixes for Components

Modules		CAP	PER	MAT
Assembly	Solderpaste Printing	13%	9%	95%
	Pick & Place	77%	13%	5%
	Solder Reflow	9%	9%	0%
	VI pre-singulation	0%	21%	0%
	Singulation + labelling	1%	30%	1%
	Visual Inspection	0%	12%	0%
	Rework	0%	7%	0,2%
	TOTAL Assy	100%	100%	100%
Test	P5 Test	100%	21%	0%
	Application Test	0%	17%	0%
	Visual Inspection/ QA Check	0%	59%	0%
	Packing	0%	4%	100%
	TOTAL Test	100%	100%	100%

Table 4 - Effort Matrixes for Modules

The 0% values in grey indicate that there are no resources of the cost category used or that the resource usage is not relevant. For example, the process steps that are visual inspections use no capital investment and almost no material; the only resource needed is personnel.

For identification of the drivers some characteristics need to be established, namely:

- They should reflect the impact of the additional efforts in each cost category.
- If an indicator is a driver for a process step, but does not change for engineering activities, it should not be considered.
- They should be measurable.
- The impact of the driver should be on the efficiency level.

The identified drivers were:

- Lot size: when the lot size decreases, which happens in engineering activities, the equipment and personnel efficiency value increases, what means less efficiency. This is not a consequence of inefficiency but of impositions from the project. This is the most important driver, as almost all activities use smaller lot sizes than mass production.
- Additional Machine Time: this can be divided into fixed and variable. When the machine time increases, due to more test time performed for example, the Capital and Personnel efficiency value increases because they are operating at the same volume for more time than supposed. The machine time can also vary because of the lot size effect, but this should not be taken into account because this is the variable time that decreases due to the decrease in lot size. This does not change the efficiency.
- Additional Material Consumption: some projects can give origin to greater consumption per piece, which is the case of some customer samples. This driver is one of the easiest to identify and calculate.

The material consumption driver only has impact in the Material Efficiency. In contrast, both the lot size and the additional machine time have impact on the Capital and Personnel efficiencies. This impact has to be evaluated.

The machine time has to be separated into set-up times, machine fixed time and machine variable time. The lot size has impact in the set-up times and machine fixed times, because the relevant impact is on the efficiency level. When the lot size decreases, the fixed times do not change, and the result is that the efficiency is worse. The additional machine time can be an additional machine fixed or variable time. The distinction between machine fixed and variable time must be made step by step and project by project, because almost all process steps have step-wise functions of machine time. For example, if 200 devices can be tested at the same time in a tester, when varying the lot size between 0 and 200 devices the time should be considered fixed, but in intervals of 200 the time is variable.

This is true in terms of capital efficiency and personnel, too. When varying the lot size only the fixed times matter in terms of efficiency.

For example, the Die-Bonding process needs a set-up time of 90 sec/lot, a fixed time in exchanging each wafer of 1200 sec/lot and a variable time for bonding of 8680 sec/lot. The fixed time is step-wise; it is fixed in steps of the size of each wafer. This would give a result of 1% of the time as set-up time, 12% fixed time and 87% variable time. So, when decreasing the lot size, the impact should be on 13% of the time of this process step. This must be done in all process steps.

10.3 Characterisation of the CAE

Some characteristics which had to be identified for each project were the following ones:

- The project name.
- The project owner, who is the person responsible for the project.
- The project description in order not to confuse it with similar projects.
- How the volume is planned, because, for example, engineering projects are planned separately and in a shorter time frame than "normal" volume planning.
- How the volume is reported in order to identify if it is reported in the normal reporting process, which is the "Spline Tool".
- The process flow that the products undergo.
- The additional efforts in each cost category: capital, material and personnel.

This characterisation is very difficult to achieve, because the projects change considerably, the people responsible for them are not worried about costs and efficiencies, and almost no information is available.

Another problem is that the software in the line only identifies whether a lot has productive volume or engineering volume, but the type of engineering project that these volumes involve cannot be identified. In order to solve this problem the addition of an attribute in order to identify the project is planned. Also, for this identification and the definition of the attribute, the characterisation of the projects done during this internship is needed. A similar characterisation was initiated some months ago in Dresden, but it was not completed and it is not valid anymore.

Two types of projects were identified, namely:

1. Projects that use the Process of Record process steps with variations in lot size, equipment times or material consumption for the production.
2. Projects that are characterised by the rent of the capacity and personnel of a part of the production line, but the volume produced can not be identified and the resource usage is the responsibility of other departments apart from the BE.

One note has to be added: some engineering activities are also done in other sites, as for example the cluster evaluation. These activities are considered normal in all sites and should not be considered in the Corridor of Additional Efforts.

Other projects such as tester correlation for new products, are also done in other sites. But here some differences have to be identified between mass production sites and Dresden. In Dresden the lot sizes are smaller; these projects occur more often because new products are handled with more regularity than in other sites and support has to be given to the FE.

10.3.1 Variations in the Process of Record

The projects that use variations in the Process of Record include

- projects that are characterized as having more tests, such as the PPT and the DCTC Measurement;
- customer samples;
- product qualifications or support to new products developed in the Frontend;
- specific projects because Dresden Backend site is near a Frontend site, like wafer distribution to other sites, technology development, delivery of components to other sites and wafer inking.

These projects are explained in detail in the Appendix.

10.3.2 Renting of Equipment or Building and Facilities

Most of these projects rent a part of the production line for a certain objective. But, in almost all cases the project owners rent a certain capacity of the line, rent the personnel that is working in the line, brings their own materials and their own lots of products. The problem is that the backend is not responsible for the volume produced, and the information on this volume is not kept. The result is that an equivalent volume cannot be calculated, because the volume is not available.

One solution could be to consider that, for the time rented, the site would produce at full capacity, which would make the volume of the reference product available. This assumption has a mistake, which is that the reference product is not produced by the sites anymore; more complex products are now produced. The result would be the advantage of having the line rented instead of producing more complex products.

Another solution is to think about what would happen if the capacity was not rented. The site would produce more volume of the products that are now needed in the market, which would be the cost of lost volume. In order to calculate this, the site would offer two kinds of capacity, a real one and the other as if engineering did not exist. Then, the volume-planning department in Munich would give a hypothetical volume to this loss, and then two scenarios could easily be calculated, one with engineering and the other without.

This last solution would be the most accurate one, but also the one that would take more effort and would complicate the planning method even more. If the assumption of the reference product were not significantly incorrect, then the people involved in the process would prefer it.

The rent of a special process step or a part of the production line can occur more often in the future. Once the problem of how to treat it is solved in this model, it will be easy to adapt to these new projects.

The characterization of these projects is done in the Appendix.

10.4 Examples

After the characterisation of the projects was concluded, some of them were singled out in order to exemplify the process of calculation of the complexities and the equivalent volume. The complexities influence on the KPI's was calculated, too. One of the examples, OP Qualification, is shown below, and the others are shown in the Appendix.

OP Qualification

Almost no information was available for this project. Some assumptions were made in order to make its calculation possible. From the information gathered it is known that the lot size average is 1000 pieces for components and 100 for modules. This is smaller by up to 12 times in components and up to 32 times in modules, than the Process of Record. Only the smaller lot size causes additional efforts, especially in Test Capital and Personnel. Calculating the additional complexities for each process step and taking into account the weights of each process step in the total complexity, the result is:

	CAPITAL	PERSONNEL	MATERIAL
Components Assembly	1.86	2.10	1
Components Test	3.87	4.60	1
Modules Assembly	1.02	1.74	1
Modules Test	2.03	6.02	1

Table 5 – Result of Additional Efforts in a Qualification (only Lot Size)

The Reference Product would have these complexities if being qualified, taking only the lot size into account. The major impact can be seen in test, where for components they are up to 4.6 greater and for modules up to 6.02 greater in personnel. The impact in personnel is greater than in capital, because the process steps with more impact, such as Burn-In in components and Application Test in modules, have a greater weight in Personnel than in Capital. In Material cost no additional complexity exists because the lot size has no impact on material consumption.

But when doing a qualification other additional expenditures apart from the lot size have to be considered. One obvious one is the additional tests that the components have to undergo. Considering one P1 test before Burn-In, which is equivalent to a PPT Measurement, the Components Test complexities would be even higher. The result would be 4.76 (instead of 3.87) for Capital and 5.11 (instead of 4.60) for Personnel.

This example is very elucidative in order to see the impact of engineering projects and the reason why these engineering projects should be identified, quantified and even targeted.

10.5 Conclusions & Recommendations

There was little time available to develop this project, the Dresden's Corridor of Additional Efforts, because it was held in the last part of the internship and being in Munich made the task more difficult. Therefore, only one week was spent in Dresden, where these projects are being developed. As the conclusion of this very ambitious project would not be completed, the focus was set on the characterisation of the projects, even though not quantitatively. The reason was that this characterisation is very important for the beginning and implementation of a project of this kind, and it was already tried in Dresden without success. This characterisation would also facilitate a change in the data warehouse, which would implement an attribute to the volume produced in order to identify which project each lot belongs to. Because of this, all effort was placed on the characterisation of the projects.

The number of engineering projects that are performed almost simultaneously is very large as is shown in the previous chapters, although the impact of each one that was calculated is around 1%. It can be seen that in the characterisation of projects it is necessary to have the time that the equipment is doing engineering tasks. The percentage of the total time spent in engineering projects in recent months is given in Table 6 for Components Test, Modules Assembly and Modules Test.

	03/02	04/02	05/02	06/02	07/02	08/02
Components Test	45%	39%	26%	26%	21%	21%
Modules Assembly	37%	37%	35%	35%	35%	35%
Modules Test	15%	15%	15%	15%	15%	15%

Table 6 – Engineering Time per Month

What is measured nowadays reflects only pure engineering projects, the ones from which the production is not saleable. If all additional efforts were measured, the result would be even higher, which shows the importance of this project.

In order to follow this project until the implementation, its real importance first has to be recognized. If the people that should cooperate do not see its importance and the need to make engineering activities visible, then it becomes very difficult.

Until now the thinking about engineering activities has been different at various levels of the organisation. The management is aware that a site is very expensive, that the reason may be the engineering activities, but they need a way of measuring the sites' efficiency. Because of high expenses, reducing cost is a pressure on a site, and as precaution almost all engineering activities are left to be done in Dresden in order not to spoil the efficiencies of the mass production sites.

Additionally, people who are working at the site and are more in touch with production see the Backend as an engineering site, or even a laboratory. They do not understand why there is pressure on costs if their task is not to produce at low costs. Seen from both sides, the conclusion is that more and more pressure will be put on the site by cost reductions in the future, because even engineering can be done to lower costs. Improvement opportunities have to be found in order to maintain and even improve competitiveness. In a fast-moving industry like semiconductors, cost reduction is not only necessary in mass production but also in research and development because of its very high weight. Thus there is a need for a change in the thinking of those who still see the Dresden site as a "lab", where costs do not matter.

With the implementation of this project and understanding which projects are of the most importance in terms of cost and looking for improvement opportunities, people can begin to understand and to accept that the costs in a site like Dresden matter and can be improved.

Another problem that was identified was the need for having other ways of measuring performance, and of catching the project owners' attention to this measurement. Reporting is made on efficiency and cost per piece with the help of the KPI's. This is very suitable at a management level, but not very appropriate at the project owner level. With the projects characterised and the additional efforts calculated, the efficiency for each project could be calculated in detail and discussed with the project owners. The trends in resource usage could also be targeted, which made the whole picture clearer to the people who can change something in practice.

11 Final Conclusion

Since the Reference Fab is a dynamic model which reflects conditions that vary over time it has to be updated to ensure a continuous improvement process on a regular basis, and not only during the planning period. This update and continuous improvement has to be done together with the site managers for production planning and cost analysis in order to reflect the reality as much as possible, and to ensure that the results of the model are accepted. My experience of dealing with this model is that it is known as a "black box from which some targets are extracted - those which are not understood by the sites' users". This idea of the model had to be consequently de-mystified, which was more or less achieved this year. Some sites were required to work with the model and they concluded that it can be understood and that their previous idea was wrong.

Because the results of the Reference Fab are cost targets that have to be achieved by the sites, they have to understand them clearly. In order to achieve this not only were the model and tool updated, but also their documentation. The documentation provides the most important inputs and assumptions made, all the top-down figures used and explanations of how the model and tool work. This documentation should also be the basis for the next users of the Reference Fab.

This model and tool were very old and the lack of actual documentation made updating them much more of an effort. However, if constantly maintained it is a very useful model for target setting and planning. It is also a valuable tool for identifying opportunities for improvement.

Having deficient modelling for the smaller Backend site that is doing engineering activities, the Reference Fab should include the results of the project about the Corridor of Additional Efforts.

The Dresden site should complete this project because of their proximity with the information source, i.e. the production lines. Afterwards, the reporting and the controlling system and the Reference Model should be adapted to this situation.

This topic of the engineering effort is very important and one which has seen previous attempts to deal with it but, because of its complexity and lack of resources and information, it has been neglected. Nevertheless, it should be given high priority. In future, the new products will come faster and perhaps there will be a need to develop them in other sites too, which is already being felt today.

In this internship the projects were characterised and a way of treating these costs was given. The way ahead is to use this proposal, to create the possibility of gathering the information needed and validate the model. The result will have the most important advantages for both the Dresden Backend and the Controlling department in Munich.

After the model is implemented some questions can then be asked: is it necessary to have a Backend in such an expensive country in order to do engineering if other sites can do it also? Or, can this site in Germany achieve competitive costs for engineering projects?

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Appendix

A. Project Description from Dresden's Corridor of Additional Efforts

A.1. Variations in the Process of Record

- PPT Measurement

  This project is done in order to do product monitoring, especially for new products. It consists of one test before the Burn-In, called P1 test. As the time for this test is similar to one of the standard tests, the calculation for it could be done. First, the only process step performed is test. Since the test times and lot sizes are known, the additional complexity in personnel and test can be calculated.

- DCTC Measurement

  This measurement also consists of additional tests done to the products, but two kinds of projects must be considered here. One is the DCTC Measurement done because of FE's demand, where the objective is to compare products coming from different FE's. The other one has the aim of qualification of a new product. The problem in characterising this project is that the test times for the DCTC Measurement are not available because they are not registered.

- Tester Correlation

  Tester correlations have to be done in two cases; when testing a new test program (software) or a new tester (hardware). When other sites receive new testers they must also carry out this project. The difference is that, Dresden's BE must do it many more times because its demand is much higher and it therefore has much more influence in the production line. Because of cases like this these projects should also be identified in other sites, and a comparison between the sites in terms of additional effort should be done. For this project, the only information available is when the testers were performing tester correlation, but what kind of tests were performed and how many tests were done during this time is still not available.

- Customer Samples

  There are two kinds of customer samples, the ones that are done with qualified components and the ones that are done with unqualified components. The products for customer samples undergo all the process steps, only having additional effort in application test on demand from the client, or from engineering personnel when done with unqualified products, and from packing material per piece. It is packing material per piece because the packing material is the same, but, for example, in a box for 100 modules only 3 or 5 samples can be packed. Consequently the cost per piece increases. The demands in application test are highly dependent on the product type and on the customer. Customer samples also undergo another application test in an oven in order to be tested in hot and cold environments.

- Frontend Learning

  In the scope of this project products that need monitoring as a Frontend support are qualified. Here some sub-projects have to be itemised: whether it is a saleable product or not, and whether they derive from 200mm or 300mm wafers. The distinction regarding the wafer size has to be made because two different FE sites are responsible for the project, and because the content of the projects is therefore different. The distinction between saleable and non-saleable products is made because the method of planning and reporting is very different.

- OP Product Qualification

  The OP (Operations) department is responsible for the qualification of new products. The products undergo all the process steps but can require additional work due to test times, smaller lot sizes and engineering support. At the end of the production process the products are not saleable, at best they can be used for customer samples.

- Delivery of components to other sites

At the Dresden site not all the components assembled are tested. Some are only assembled and then tested in other sites. In this case the components have to be packed after assembly. As the pack operation is covered in the test area this effort is not considered because it is considered to be Volume Assembly. So, the calculation to be made is to add the complexity of the Mark, Scan & Pack process step to this volume, since the packing can be assumed to be the same.

- Technology Development

This project aims at the development of new Frontend technologies that need support from the Backend. The products undergo the normal process flow and have to perform additional tests.

- Wafer distribution

Because the Dresden BE is supporting two FEs, it has additional tasks that other sites do not have. One of them is wafer distribution to other sites. The wafers can be packed for distribution without doing any process steps in the BE or after they are laminated and ground. At present they are not diced before going to other sites because a package for diced wafers is still under study.
For this project the packing expenditures are added to the material consumption, because the wafer packing is not a process of the Process of Record.

- Wafer inking

As some sub-contractors cannot read the wafer map from Infineon, the chips in the wafers have to be marked with ink so that it can be seen which chips are good and which are damaged in the wafer. Under this project, the wafers are cleaned, marked with ink and then packed to be shipped to the subcontractors.

In the calculation of the efforts for this project, capital and material efforts have to be added to the POR. The wafer inking needs a machine to do the marking on the wafer, and the materials used are ink cartridges.

A.2. Renting of Equipment or Building and Facilities

- Technology Development

  Under this project, new technologies in the Backend are developed and qualified, and there is a separate department responsible for it. The time needed and, therefore, the capacity in the line is rented to this department and all costs are allocated to them.

- Prototyping

  The production of prototypes is done in the Assembly of modules. It is under the responsibility of the same department as Technology Development and a fixed maximal capacity of the module line is rented on demand, which is 15%.

- OP Utilisation of Application Testers

  This application test rented by OP is not the normal application test, but uses some ovens where application tests with warm and cold cycles are done. An application test is done on the memory modules connected to motherboards. This can be done at ambient temperature, which is the normal application test, or in ovens with cycles of warm and cold tests, which are named Application Testers.

- IAT Rent of Pre-Assembly

  The object for rent in this case is the Pre-assembly, but the conditions are the same as for the other projects of this category. Therefore, the equipment is rented, the volume produced is not under the responsibility of the Backend, and the BE personnel is used for this rent.

- IAT Rent of part of the Cleanroom

  This project is a little different from the others. Here the equipment is not rented but a part of the cleanroom, which is free. In this case the additional effort that is not used by production volume is the use of Utilities, the support given to this part of the cleanroom, such as air conditioning, cleaning, etc. Another cost has to be identified, which is the cost of opportunity, because this area is being rented and not used for production. An extension of the line could be done and more volume produced, instead of always having the area free for the IAT department.

  The solution mentioned above for this kind of project, which is to calculate the volume that could be produced instead of the rent, is not so easy in this case. As there is no equipment belonging to the BE not only would the volume have to be considered, but also additional equipment, additional personnel and additional material.

  A way of solving the problem is to deduct the Building & Facilities Investment and all costs that this rent creates in order to obtain all costs as if this area was not there.

- Reliability Methodology

  In this project the object for rent is a laboratory in Dresden for the Qualification and Monitoring of new products. Until now the rent has not been considered because the work done by the lab for the BE would be equal to the work done by the BE for the lab. But now doubt arises whether this assumption is still valid. Apart from this, the BE will also rent the time of another laboratory situated in Regensburg.

B. Project Examples for Dresden's Corridor of Additional Efforts

B.1. PPT Measurement

The products in this project undergo another test where the aim is to do product monitoring before the Burn-In. As the test time is the same as in a normal U2 Test the additional effort is to undergo one more test with a minor lot size. As the factor between the normal lot size and the lot size used in this project is 2.8, the factor would be the same for set-up time and equipment fixed time.

The final result is an additional complexity in capital of 45% and in personnel of 26%. Calculating the additional equivalent volume for the month of July, it gives 0.4% more Equivalent Volume Test Capital and 0.3% more Equivalent Volume Test Personnel. This would also be the decrease in the value of test efficiency, since Efficiency is inversely proportional to Volume.

B.2. Wafer Inking

As explained before, wafer inking is done in order to substitute the wafer map for Subcontractors. The wafers do the normal process steps of Laminating, Grinding and Peeling, and are then inked. If counting only the three normal processes the complexity for these chips would be 10% of Assembly Capital, 8% of Assembly Personnel and 3% of Assembly Material, because they do not do all the Assembly process steps.

Adding the process step of inking results in 12% of Assembly Capital and Personnel, and 6% of Assembly Material. This is calculated for a normal lot size of 25 wafers.

B.3. Chip Delivery to Other Sites

For the reference product the additional effort for chip delivery to other sites is 3% in capital, 20% in personnel and 22% in material. The values represent the weight of the Mark, Scan & Pack process step in the test area. The result in Equivalent volume would give 0.2 % more in Equiv. Volume Investment, 1.9% more in Equiv. Volume Personnel and 2.2% more in Equiv. Volume Material for the month of July 2002.

C. Glossary

Chip	Popular term describing a small piece of silicon that contains a complete discrete component or an integrated circuit. [9]
Component generation	The generation reflects the component capacity in Mbit.
Component organisation	Memory chips can be manufactured in several organizations. A chip with a memory capacity of 256 Mbit may be organized in the following ways: 64Mx4, 32Mx8 or 16Mx16. The first figure (i.e. 16M) refers to the depth of the memory chip. This means, for each bit of width, there are 16 Mbit of storage. The second number (x8, x16 and so on) refers to the width of the memory. The width of the data bus indicates how much information can be transferred in each clock cycle. The depth multiplied by the width of the memory chip gives us the storage capacity (in Mbit) of the memory chip. [12]
Component package	The sealed, protective container that houses an electronic component or die. External terminals provide electrical access to the components inside. Packages provide for power and signal distribution, power dissipation, and protection of the circuits. [9]
DRAM	Dynamic Random Access Memories are the most common RAM's. It is called "dynamic" because it can only hold data for a short period of time and must be refreshed periodically. [12]
Heatspreader	As memory components get faster, chips become denser and more circuits get squeezed onto smaller boards. Dissipation of excess heat becomes more of an issue. For several years now processors have incorporated fans. Newer memory module designs use heat sinks or heat spreaders to maintain safe operating temperatures. [12]
Integrated Circuit	A microcircuit consisting of interconnected elements inseparably associated and formed in situ on or within a single substrate to perform an electronic circuit function. A semiconductor or semiconductors die contains multiple elements (which may be located on the die or on a hybrid substrate) which act together to form the completed device circuit. [15]
Lead frame	The metal part of a solid-state device package, which makes the electrical connection between the die and other parts of the system of which the IC is a component. Large-scale integrated

	circuits are welded onto lead frames in such a way that leads are available to facilitate making connections to and from the various solid-state devices to the packages. [15] A stamped or etched metal frame, usually connected to the bonding pads of a die by wire bonding that provides external electrical connections for a packaged electrical device. [9]
Microchip	The semiconductor industry differentiates between three types of chip, Infineon manufactures each of them: microprocessors, logic chips and memory chips. Microprocessors and logic chips are analogous to tiny computers that receive the information they require from the memory chips. Microchips are manufactured from materials such as silicon or gallium arsenide, the so-called semiconductor crystals, which will only conduct electricity under certain circumstances. Above all, manufacturing chips requires silicon that has been purified to an extremely high degree in clean-room factories and has been grown into single crystals. Wafer-thin slices cut from these single crystals serve as blanks for chip production. The finished chip contains electronic circuitry that can process and store signals and has a wide field of applications. [1]
PCB Stencils	A stencil is a metal frame with customised holes that match the PCB's schematic drawing.
Printed Circuit Board (PCB)	The Printed Circuit Board or PCB is the basis of the module. It consists of several layers (usually 4 or 6 layers) and contains all the circuits, contacts and pins necessary for running a module. All components needed on the module are mounted on the printed circuit board. The PCB is usually the most expensive component of a memory module after the memory chips.[12]
Shrink	The reduction of die size through conversion to a process within the same basic process family, but with smaller feature sizes. [15]
SMT	Surface-Mount Technology. The mounting of components on the surface of a printed circuit board, as contrasted with through-hole mounting where component leads extend through the board. [9]
Solder	A low melting point alloy used in numerous joining applications in microelectronics. The most common solders are lead-tin alloys. Typical solder contains 60% tin and 40% lead - increasing the

	proportion of lead results in a softer solder with a lower melting point, while decreasing the proportion of lead results in a harder solder with a higher melting point. [13]
Solderability	The ability of a conductor to be wetted by hot solder and to form a strong low-resistance bond with the solder. [9]
Wafer	The thin (a few hundred microns) slice sawn from a cylindrical semiconductor crystal which serves as the substrate for the fabrication of multiple individual integrated circuits or chips. [14]
Yield	The ratio of usable components at the end of a manufacturing process to the number of components initially submitted for processing. Can be applied to any input-output stage in processing. Usually measured in percentage (%) i.e. 1000 units in, 900 units out, yield = 90%. [15]

D. Abbreviations

BA	Business Administration
BE	Backend
BIB	Burn-In Board
BOM	Bill of Materials
DDR	Double Data Rate
DRAM	Dynamic Random Access Memory
FE	Frontend
HC	Headcount
IC	Integrated Circuit
MB	Mega Byte
Mbit	Mega Bit
MHz	Megahertz
MP	Memory Products
MSP	Mark, Scan & Pack
NPH	Net Productive Hours
PCB	Printed Circuit Board
PPC	Production Planning and Controlling
RAM	Random Access Memory
REFFAB	Reference Fab Model
SDR	Single Data Rate