STIMULATING THE USE OF MICROELECTRONICS

MANAGING ECONOMIC ISSUES

IN FIRST TIME USE OF MICROELECTRONICS

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Table of contents

Foreword

This document is intended as a guide for helping First User companies planning the development of a new product – or the improvement of an existing one – using electronic technologies. The goal of the document is showing how electronic technology can improve their overall economic results, and the kind of investments that may be necessary, using as source of information the economic data collected in the FUSE Application Experiments database. The guide is not intended to give lessons on company strategy, but only to discuss the specific topics where the use of electronic technology makes a difference, and collect the experiences of other First Users to help the reader in taking economic decisions.

The document is arranged in three parts:

- The first part shows some possibilities of product improvement offered by electronic technologies, by quoting the results reported by some First Users after they implemented their Application Experiments.
- The second part presents the different technologies with examples of their performance, always from the point of view of economic results. This section is intended as an introduction to the specific technologies documents, where the reader is referred to further details.
- The third part presents the overall scheme of tasks and costs a company should plan in order to have a product improved using electronic technologies. All the necessary steps one company must follow, from first idea to working prototypes, are explained and discussed, providing a guide or systematic allowing the reader to quickly set an action plan..

Two final remarks: first that the collection of economic data of the 400+ FUSE AEs is still in progress so the information contained in this document may be updated as the demonstrators of the database – the source of all the relevant information – are completed and improved.

Second, that the information provided in this document concerns only the first stages of the process of product improvement, i.e. from first idea to prototypes, and NOT the final stages, between prototypes testing – where FUSE help stops – and the selling of the first product. This information on the associated costs of industrialisation, production, marketing and sales will be provided by the AE follow-up activity, and may be collected in subsequent releases of this document.

Electronic technology and product improvement

The basic reason why a company decides stepping for the first time in a new technology is always economic: even the finest technology is useless if it does not provide the user company a reasonable return of the investment done.

This is attained by improving the products that the company sells so the company gets a higher market quota: whether the product provides more performance than the competitors, and customers are willing to buy them, even paying a higher price, or the products provides the same performance as the competitors at a lower price. This section shows typical examples extracted from the FUSE database.

Product positioning

One of the first basic questions to answer when improving one product is the market segment where the improved product will be positioned. One common motivation for using a new electronic technology is the possibility of offering features of a higher market segment at a cost similar to that of lower segments:

> ⓘ Case 23275: A company developed a mixed-signal ASIC for the precise control of the temperature of aquariums. In this way they could offer higher segment features, like more precision and sensitivity, a better visualisation of water temperature and even adding security functions without increasing the cost significantly.
>
> ⓘ Case 24773: A company used DSP technology to improve his position transducer performance: accuracy increased from 1.5% to 0.3%, bandwidth and temperature range were increased, and at the same time the cost was reduced in 25%.

There are cases when the company must have a hold of higher market segments in order to consolidate his position or get a better share in lower segments:

> ⓘ Case 22888: A company making electromechanical thermostats for domestic ovens developed an electronic, microcontroller-based model addressing the emerging higher segment of electronic thermostats. Although this segment is less than 10% of the wider electromechanical segment, the company gets a better visibility for competing in the much wider lower segment.

Or must be able to provide some kind of controlling unit, using electronics, that allows better penetration in the much wider segment of consumables or non-electronic parts:

> ⓘ Case 24640: A company improved his line of instruments for blood analysis using SMT technology, making a portable instrument for testing the glucose content of the blood. With this new product they expected that the profit in the sales of the necessary chemical reagents would almost double that of the sales of the instrument.

Another possibility is the coverage of several market segments with only one basic electronic module that can be used to offer different performances depending on the addressed segment:

> ⓘ Case 2179: A manufacturer of medical imaging instruments is able to equip both middle and top segment product with a single ASIC. This was possible thanks to the high flexibility of the chosen solution.
>
> ⓘ Case 23130: A manufacturer of Proportional Pressure Valves, MicroValves, Custom Made Valves and Valve Islands with several Fieldbus Interfaces (BUSLINK products), general purpose valves, cylinders and pneumatic accessory was able to implement a data communication system for all the product range wit a single ASIC.

Fulfilling market demands

Companies have made good business by foreseeing and exploiting changes in market demands, and being able to quickly deliver products fulfilling these new requirements. The opposite is also true: if these changes are not foreseen, they may have as consequence a loss to the company.

One good source of new market demands is a change in legislation. First Users have taken advantage of the possibilities of electronic technologies to launch products satisfying the new requirements:

- ⓘ Case 29418: A gun manufacturer is foreseeing the coming legislation on security features for weapons, as recognition of the shooter to block its use by unauthorised personnel or detecting if the gun is in its case to avoid accidental firing. The use of a microsystem combining a mixed-signal ASIC with a microsensor will provide this smart security features.
- ⓘ Case 2194: A company improved its noise and vibration meter using DSP technology. One of the motivations to take this step was that the new legislation on noise was making that the market for noise and vibration meters grow at a 9% annually.

Technological advances in any industrial sector open new challenges and product possibilities for the manufacturers of this sector – and for the manufacturers of the electronic instruments that may be necessary to control this finer technology.

- ⓘ Case 23091: A manufacturer of crystal oscillators developed an MCM to reduce size and cost of its oven-controlled oscillators, and at the same time to increase their reliability. The company expected a very fast growth of the sales for these devices, 20% the first year and 50% the second, as the end user of their product is the exploding mobile phone market.

Cost reduction

In cost-driven markets the main reason for stepping into new technologies is getting a lower production cost to make the product more competitive in price. The FUSE portfolio is full of examples of companies getting this goal using different technologies:

- ⓘ Case 26208: A manufacturer of electronic controls for domestic and industrial burners changed from discrete analogue components to microcontroller technology. The cost reduction achieved was 12%.
- ⓘ Case 24526: A company manufacturing odour sensors introduced FPGA technology to replace their old discrete electronics control board. The cost reduction achieved was 75%.
- ⓘ Case 24348: A manufacturer of multiplex equipment improved his subscriber lines concentrator using ASIC technology, getting a cost reduction of 12%. At the same time the new technology allowed a 60% higher MTBF and 10% reduction in power consumption.
- ⓘ Case 23591: A manufacturer of electronic injection-ignition modules for the competitive automotive market got a saving of up to 5 ECU per unit using MCM technology
- ⓘ Case 27436: A manufacturer of bar-code readers developed a microsystem to integrate the photo sensor with the AGC amplifier and the digitizer. The cost saving was 70% in front of the old product.
- ⓘ Case 27881: A manufacturer of payphones replaced 480 discrete components of their power management unit by a single ASIC. This means not only a direct saving in terms of cost of the components but also indirect, in assembly and testing costs. At the same time, the power conversion efficiency raised from 70% to 90%, decreasing the power consumption from 220mW to 180mW.

Product differentiation

The other way of getting a good position in the chosen market is by differentiating the new product from its competitors, defining distinct competitive advantages that convince the customers to buy it paying the same or even a higher price. These competitive advantages are improvements in performance, related to some specific feature like intelligence, speed, lower power consumption, portability and many others. Electronic technology allows in many cases the simultaneous improvement of several features, and quite often without significant increase or even a decrease in cost over the old product. Some examples are given below:

Intelligence

This is a very broad concept that encompasses many different abilities, and thus a bit difficult to present in a systematic way. The following examples may give an idea of some of the possibilities.

> ⓘ Case 23600: A motorised security post – used in parking places for reserving the users space or deterring vehicle theft – gained in intelligence by using a microcontroller. This way it was able to detect obstructions during operation, reducing the damage potential to the user or to vehicles.
>
> ⓘ Case 25856: A company making dough dosing machines found that the traditional mechanical control damaged the structure of the dough, leading to a bread of lower quality. By introducing microcontroller technology they were able to solve the problem, and at the same time offered to their customers a much more productive machine.
>
> ⓘ Case 1817: A company replaced the pneumatic control unit of its load manipulator – used in assembly lines to move into position heavy loads – by a microcontroller. This way they could easily implement a PID control algorithm with the required flexibility to optimise the dynamics of the system according to the needs of the operator.

Portability

Portability requires small size and low power consumption if the product has to work with batteries. Small size means also that the product is more resistant to the mechanical stress – shock, jolt – normal in this type of applications. Electronic technology makes this possible, making products more convenient and opening new possibilities of use.

> ⓘ Case 27406: A footprint analysis equipment, used for evaluating the pressures under the foot in applications like sports injury management and rehabilitation of patients had to be used with a PC. Using a microcontroller to implement the PC functions resulted in a portable and self-contained instrument that could be sold in a wider field of applications.
>
> ⓘ Case 25802: Using microsystem technology a company was able to manufacture a hand-held spectrometer for the growing market of optical spectrum analysis for the testing of optical fibre networks. Using a LIGA part with integrated self-focusing reflection grating not only provided gains in size but also in ruggedness, as it had no moving mechanical parts.

Sensitivity

Electronic sensors allow in many cases a much better sensitivity for a specific physical parameter than their mechanical counterpart, or improve the performance of the old sensor thanks to the numerical processing of the signal delivered by the classical sensor. This extra sensitivity can be used to get competitive advantages.

> ⓘ Case 1817: A manufacturer of pneumatic manipulators increased the sensitivity of his product using a load cell for detecting the attempts of the operator for moving a load, instead of the old procedure of sensing the difference in pressure in the pneumatic cylinder. This allowed the new product to be used for lifting weights heavier than 100 Kg.
>
> ⓘ Case 2194: A manufacturer of sound and vibration meters improved the analysis capability of its product replacing the previous analogue signal processing with DSP technology. The ability of processing the data at a much quicker rate gave higher resolution and accuracy, and also made possible to obtain the results in real time.

Speed

Being able to process information at higher speed means higher performance for the final user:

> ⓘ Case 2239: A manufacturer of servo systems used an FPGA for implementing a digital torque control. With this approach they attained a bandwidth of 1,7 KHz, when their nearest competitors were much below, between 400 – 800 Hz. The dynamic properties

of servo system are better, as they are determined by the bandwidth of the torque controller.

- ⓘ Case 25862: A manufacturer of video encoder – decoder systems used DSP and FPGA in order to meet the stringent speed requirements of the application. Using digital filtering techniques they could both improve the performance and reduce the cost.

Reduction in size

Some applications are improved, or even made possible if the product has the right size. Electronic, or rather micro-electronic technologies can help a lot in getting a competitive difference:

- ⓘ Case 22895: The implementation of specific functions into PCMCIA cards that can be used in conjunction with a notebook PC opens a whole range of possibilities for portable instruments. In this case, a manufacturer of ultrasonic test equipment for non-destructive testing included all the digital functions of his instrument in an ASIC, that was the key for packing all the functionality in the PCMCIA format.
- ⓘ Case 25744: A in-pipe inspection vehicle is normally used for the surveillance of gas pipelines detecting metal loss and cracks in the pipes by means of ultrasonic and magnetic sensors. This vehicle could not pass through pipes with a diameter smaller than 150 mm. This is now possible thanks to the reduction in size of the control electronics attained using MCM technology.
- ⓘ Case 529: A company was able to develop an integrated miniaturised micro filtration analysis contained microsieves with 3 different pore sizes of 2, 5 and 10 microns using a microsystem based on silicon micromachining technology.

The list of examples could continue, but this probably has been enough to wet the appetite of the readers and trigger their imagination on what electronic technologies can do for improving their specific products. So the next step could be to have a look to the different electronic technologies.

This is the goal of the next section, that lists the different electronic technologies available, their main characteristics and possibilities and a set of examples of different products that were improved using each specific technology.

The section is conceived as an introduction to the training documents that have been prepared by the FUSE team for each specific technology, where the reader will find more detailed information.

Available technologies

General characteristics of technologies from both an economic and technical point of view

The objective of this part of the document is to identify the criteria that may help European companies to assess that a given assembly technology and/or microelectronic component is relevant or not for their products according to its technical and economic capabilities.

Before selecting a specific microelectronic technology, a company needs to define its expectations and to obtain relevant information for example :

- on costs (CAD Tools, access to prototyping, access to industrialisation, price and access to the knowledge transfer, manpower needed inside and outside the company to develop the project)
- on the main technical features (potential improvements, performance, production process)

We have gathered the technologies identified in the FUSE program and their general characteristics in the following tables :

The first one concerns the *assembly technologies*.

N°	Criteria	Assembly technologies			
		PCB	SMT	ASIC	MCM
	A. From a technical point of view				
A.1	Speed	- -	-	++	+
A.2	Consumption	- -	+	++	+
A.3	Flexibility (changes of the specifications)	++	+	- -	-
A.4	Space needed	- -	-	++	+
A.5	Security against copy	- -	-	++	-
A.I	Technical constraints	A / D	A / D	A / D	A / D
A.II	Conception time	++	+	- -	-
	B. From an economic point of view				
B.1	SW & HW equipment cost	++	+	- -	-
B.2	Conception cost	++	+	- -	-
B.3	Prototyping cost (NRE)	++	+	- -	-
B.4	Industrialisation cost	++	+	++	+
B.5	Cost per unit	- -	-	++	+
B.6	Economic & technical risks	++	+	- -	-
B.I	Time to market	++	+	- -	-
B.II	Minimum production volume	100	5000	20000	10000
B.III	Added value	- -	-	++	+
B.a	Training needed	++	+	- -	-
B.b	Degree of subcontracting needed	++	+	- -	-
B.c	Degree of dependance on the supplier	++	+	- -	-

Legend	
++	very good
+	good
0	average
-	poor
- -	bad
- - -	very bad
A	analogue
D	digital

The second one concerns the *types of components*.

N°	Criteria	Types of component					
		Discrete component (PLD)	DSP	Microprocesseur	Programmable component (FPGA)	ASIC	MST
	A. From a technical point of view						
A.1	Speed	+	-	-	+	++	
A.2	Consumption	- -	-	-	-	++	++
A.3	Flexibility (changes of the specifications)	++	++	++	++	- -	- - -
A.4	Space needed	-	+	+	+	++	++
A.5	Security against copy	-	+	+	+	++	+
A.I	Technical constraints	A / D	D	D	D	A / D	A / D
A.II	Complexity (# of gates)	100 - 1000	10000 - 100000	5000 - 50000	100 - 200000	100 - 2000000	
A.III	Conception time	++	++	++	++	- -	- - -
	B. From an economic point of view						
B.1	SW & HW equipment cost	++	++	++	++	- -	-
B.2	Conception cost	++	++	++	++	- -	- - -
B.3	Prototyping cost (NRE)	++	++	++	++	- -	- - -
B.4	Industrialisation cost	++	+	+	+	- -	- -
B.5	Cost per unit	- -	+	+	+	++	++
B.6	Economic & technical risks	++	+	+	++	- -	-
B.I	Time to market	++	+	+	+	- -	-
B.II	Minimum production volume	100	1000	1000	1000	20000	10000
B.III	Added value	-	+	+	+	++	+
B.a	Training needed	+	-	-	-	- -	- -
B.b	Degree of subcontracting needed	++	++	++	++	- -	- -
B.c	Degree of dependance on the supplier	+	-	-	+	- -	- -

Printed Circuit Board (PCB)

Definition

A PCB is an interconnection of passive and active electronic components (analogic or digital) gathered on a board. The interconnections consist of metallic conductor tracks on an organic insulated bulk.

FUSE portfolio examples

- Case 25853 : A Greek company specialised in the field of industrial weighing systems has developed a new PCB to insert in one of the company's key product with 30% of market share : the D2000 batching control unit. The goal of this specific development was for the new PCB **to satisfy to the** 89/336/**EEC directive** (reduction of the EMI emissions). Given the fact that till 2002 all the weighing systems must be conform to the European directives, the competitivity of the improved product will secure the position of the company on the Greek but also on the European market.
- Case 25272 : This case concerns a British company which designs and manufactures road side signs. Thanks to the introduction of a PCB (instead of discrete electrical items) in its Illuminated Traffic Bollard, the company will include additional features (such as ice hazard warning, etc.) in its product. The improved quality of the new "smart" bollard (without any change in the standard parameters asked for this kind of equipment) will be a **significant market advance** in this industry and an important technical improvement over the competitors. This will allow the company to **conquer other home and international markets** (not only for traditional road signs but also for large car parks, timed warning signs, etc.) even if it increases the sale price of its new product.

Surface Mounted Technology (SMT)

Definition

The SMT were introduced in order to enable the assembly of components on both sides of a board. Pins of such components can be soldered on a board without crossing the board. It allows to reduce the inter-pins distance and to improve the density 5 to 20 times. This technology permits to solder directly components on both sides of a PCB.

FUSE portfolio examples

- Case 372 : It is the case of a British SME involved in the electronic design and consultancy businesses. Thanks to the FUSE program, it has developed with the help of an SMT, a new rack-based industrial computer board, the ICC board, including extensive serial communication capabilities. This new board is suitable for use in factory automation systems. In this market, the company is a small player, but with the introduction of a more modern technology, the company will **remain competitive with rivals**. That will thus lead the company to an increase of its customers base and of its sales. And, in the longer term, the SMT experience acquired via the AE will allow the company to **conquer new markets**.
- Case 26770 : It concerns an Italian company specialised in hydroelectronics. The purpose of its AE is to change an analogue PCB system with an SMT inside an electronic regulator for proportional valves (for hydraulic systems used in factory automation and machine tools). The competitive position of the company in the high-performance proportional valves is 30% market share on home market and 3% market share on international market before the AE. The company estimates that the launch of its improved product will enable both home and international market shares to be increased (respectively 40% and 15%) to the prejudice of its most immediate competitors.

> ⓘ Case 1708 : This case concerns a British company involved in the field of biomedical freezing equipment. The purpose of the AE is to improve by the introduction of an SMT the control of the freezer range. This will help the company **to maintain its leadership** on its 4 main markets towards its cheaper competitors. The new product will indeed be cheaper than the actual one because its size and **manufacturing costs will be reduced** (respective reductions of 45% an 49%) thanks to the use of an SMT.

Despite those advantages, the SMT solution is sometimes costly in terms of assembly, testing and maintenance. It depends on the requirements of the company.

> ⓘ Case 24550 : It is the case of a British company working in the data acquisition and control sector. To improve its main product, a data acquisition equipment for applications in the medical sector, the company did not choose an SMT because it offers not only a bulky and costly solution in terms of assembly, testing and repair time but also an lack of flexibility and large power requirements. The company finally opted for an FPGA.

Programmable Logic Device (PLD)

Definition

PLD is historically the generic term describing the whole class of Programmable Logic Devices. Programmable Logic Devices are standard components that can be configured by the user in order to implement a sequential or conditional logic function. Those components include one or an array of basic programmable logic cells which integrate registers and combinational functions.

The complexity of these basic cells allows to distinguish two families of generic PLD : FPGA and PLD components. This complexity can be expressed in gates-equivalent or better, in number of combinational functions that can be directly implemented in the cell. Typical gate count of the FPGA basic cells is 20 gates while it is over 200 gates for PLD components. This implies different cells architectures and induces other component characteristics such as connection network, integration density, speed and number of basic cells.

For each family, the configuration technology can be :

either ***Reversible***

- *Electrically Programmable Read Only Memory (EPROM)*
- *Electrically Erasable Programmable Read Only Memory (EEPROM / Flash EEPROM)*
- *Static Random Access Memory (SRAM)*

or ***Irreversible***

- *Fuse / Antifuse Technology*
- *Metal Mask Technology*

Inside a family of components, the configuration technology distinguishes different performances or utilisation levels.

1. PLD family

Their main characteristics are the small number of basic cells, centralised connection network, very high reaction speed and lower density integration. SPLD (Simple Programmable Logic Device) class includes one basic cell while CPLD (Complex Programmable Logic Device) class has many basic cells.

1.1 SPLD class :

PAL - *Programmable Array Logic. It is a two level logic array (sum of product) where only the product plane is programmable. The technology used is EEPROM – UV erasable technology.*

***PLA** - Programmable Logic Array. It is a two level logic array (sum of product) where the two planes are programmable.*
***GAL** - Generic Array Logic. These are two level logic components (such as PAL or PLA) with an EEPROM technology. Moreover the I/O cells structure are more complex than on the PAL / PLA ones. As for PAL / PLA, the output of the planes may be registered and/or re-entered on the input of the plane.*

1.2 CPLD class :
CPLD is a set of logic macro cells which are interconnected by a centralised array of interconnections. Each macro cells is itself a PLA or GAL like structure.

2. FPGA family : see below.

FUSE portfolio examples

- ⓘ Case 25898 : It concerns a French SME specialised in the field of transmission and switching systems for voice, data and imaging. Thanks to the change from an analogue to a digital device in its fixed terminal for radio control, the company has **decreased the size and the cost of its product**. This improvement will allow the company to **reduce the technical gap** with its main competitors, to **recover market share** and to **increase profitability** by decreasing manufacturing, installation and maintenance costs.
- ⓘ Case 2170 : It is the case of an Italian company manufacturing and distributing equipment for cardiovascular diagnostics. It has a market share of approx. 5% on the global market. The components realised during the AE are 2 PC boards included in an ultrasound Doppler system for vascular flow assessment. With the introduction of a PLD, a critical competitive edge is gained because of the combined effect of **cost reduction and performance improvement**. This will allow the company to **increase its sales** all over the world.

But the PLD is not always the appropriate solution when it comes to massive production. Let's take the following example :

- ⓘ Case 23627 : A Greek company specialised in telecommunication products, has rejected the PLD solution to speed the transfers f images via its VL-40 wireless modem. This approach would indeed have required several high capacity and high speed parts and their impact on the total cost would have been prohibitive for mass production.

Field Programmable Gate Array (FPGA)

Definition
An FPGA is a kind of Programmable Logic Device and consists of a matrix of cells, each cell containing the same basic logic components (gates, FF generally). "Field" means that the user is able to program the device himself.
Its main characteristics are the potentially high number of basic cells, use of multilevel logic implementation of combinational functions, distributed connection network, medium reaction speed and high density integration.

FUSE portfolio examples

- ⓘ Case 2173: This is the case of a German SME which produces and sells hardware and software equipment for the visualisation and diagnosis of production processes. The goal of the project is to substitute the current video control unit (based on discrete technology) of a flat panel display monitor by a digital video FPGA unit. The introduction of an FPGA in the product will make it **more flexible and reliable and**

also easier to produce. The improved product will be able to replace, during the next few years, the majority (60%) of the monitors which are still used in the industry today.

- Case 23099: This case concerns an Italian SME active in the laboratories equipment sector. This SME has decided to replace the current discrete control unit of its Scanning Probe Microscope by a single low cost electronic control unit based on an FPGA. The use of an FPGA will have several advantages for the company and its customers : the decrease of the control unit cost (from 23keuro to 10keuro) due to its size reduction, The **decrease of testing costs** due to a 60% reduction of the test time, the possibility of electronics **low cost upgrades** during the product lifetime, a **sales increase** (from 248 units in 1997 to 2378 units in 2002), the strengthening of the company's competitive position towards the American competitors on the European market.
- Case 23290: It is the case of a British company specialised in hi-fi equipment for domestic consumers. The purpose of the company's project is to **improve its noise shaper for high performance audio** thanks to the introduction of an FPGA. The improved performance and quality of the new product will permit the company to increase by approx. 30% its selling price to the dealers. Even if the price is higher, it won't be an obstacle for customers who are seeking for quality.

However, FPGA has drawbacks: its design and production costs which are quite high.

- Case 23627 : A Greek company involved in the telecommunications sector decided to abandon the FPGA solution **to improve the images transfers speed of its wireless modem**. Indeed this approach requires several high capacity and high speed parts and even then the expected throughput (in terms of time required to process an image) is not acceptable. Also, the impact on the total cost is prohibitive **for mass production** and extra costs must be added for programming the devices.
- Case 145 : This concerns a British company manufacturing motor controllers. The company gave up the FPGA approach because of the high cost of this kind of device. Furthermore, an **FPGA does not allow the integration of the analogue circuits of the system**.
- Case 24558 : A German SME designing and selling Optical Character Recognition software has considered the use of an FPGA to improve the speed of one of its OCR systems. But after some estimation, the company came to the conclusion that an FPGA was not suitable because **of the complexity of the design** and of its high cost for mass production.

Microprocessor

Definition

A microprocessor is a digital circuit able to run a program build on its instructions set. There are several kinds of architectures (CISC, RISC for example) and several kinds of microprocessors (general operations, DSP, microcontrollers,...).

FUSE portfolio examples

- Case 24578 : This case concerns a Spanish SME involved in the lifts and escalators sector. The purpose of this AE is to develop a microprocessor board that will be able to handle the communications required in a lift system through a CAN type fieldbus. With 12% market share, the company is the leader on its home market. The chief advantages of the new product will be the **improved flexibility** of the elevator systems, the simplification of the production process, the **reduction of installation time and cost**, a **better maintenance** and a **reduction of product cost**.
- Case 24714 : It concerns a British SME specialised in the industrial processing and chemical handling equipment. The electromechanical system to be improved during the AE is currently using a analogue electronics and is to become a standalone unit

controlled microprocessor board that will be able to perform automated functions (i.e. concentrate chemical dilution). This company is the leader on this market. With the AE, it will maintain and improve its leadership thanks to the extended functionality, but also ensure **lower assembly and installation costs** of its new product. The **overall cost** against the old product will be up to **50% reduced**.

- Case 24552 : It is the case of a British SME specialised in the field of patients handling systems used in hospices and hospitals. The AE consists in the improvement of the Nightingale Care system Bed via the introduction of a microprocessor (for the control of bed position, the adjustment of bed profile, the maintenance of care records requested for clinicians, etc.). The improved bed system in providing these additional user benefits and the **nursing costs saving** will generate a significant **increase in sales** in the hospice and hospital market areas. The company is also exploring licensing agreement with French and German partners which could lead to a sales increase **in the European market**.

Unfortunately, the microprocessor solution is not always cost effective. It depends on the problem to solve.

- Case 24549 : This case concerns a British company active in the high quality data acquisition and processing field for the automobile and power generation industries. The objective of its AE was to increase the functionality of the P4400 Data Acquisition System. The company has rejected the microprocessor solution because of the following economic drawbacks : the cost of the processor and the cost of associated memory and peripheral needed for the improvement were exceeding the cost of the FPGA solution.

Digital Signal Processor (DSP)

Definition

A DSP is a specific type of microprocessor optimised for adding and multiplying numbers at high speed (typically the Mac operation) and is used to manipulate signals in digital form (radar or image signals i.e.).

FUSE portfolio examples

- Case 25948 : This is the case of a German company designing measurement systems especially for the field of radiation protection. The purpose of this project is to increase the limited transmission range of an existing radio frequency transmission unit by changing the current analogue design of the unit into a digital design. The company has chosen a DSP because of its **programming flexibility**, its usability for the other projects in the future and its relatively **low cost even for a low number of units**. With this innovation, the company plans to **double its turnover within 2 years** (from 100% in ’97 to 225% in ’99).

Unfortunately, the cost of this kind of solution is increasing.

- Case 23627 : A Greek SME active in the high speed communication products has rejected the DSP solution to design a new device for wireless connections. The reasons for this is that the cost for a DSP will soon increase and the important number of chips in a DSP doesn’t fit for small areas.

Application Specific Integrated Circuit (ASIC)

Definition

The ASIC is an integrated circuit specially designed for an application. Its functionality can not be modified, oppositely to PLDs (programmable). It consists of integrating electrical components to create an electronics circuit which has been designed and optimised in all aspects of performance for a particular application. The resulting electronics design is then packaged into an IC. Components are obtained by chemical and physical operations made on a bulk (generally a silicon bulk).

FUSE portfolio examples

- ⓘ Case 25832 : Here is the case of a Swiss company specialised in the development, manufacturing and distribution of miniature fans for applications such as computer cooling or personal gas filtering systems. Its project was the replacement of the fan drive discrete components by an ASIC. Thanks to the use of an ASIC, the company has **reduced the number of components** by more than 60%, which caused **the reduction of production costs**. The ASIC also enabled the company to **offer the extra-functionality needed by the customers at a quite economical sales price**.
- ⓘ Case 23208 : It is the case of an Italian SME active in the sector of implantable cardiac pulse generator. The introduction of an ASIC in the implantable heart double chamber stimulator will **increase the reliability** of the stimulator and **reduce its production costs and sales prices**. The company will be able to compete with its American competitors. This innovation will also permit a 100% **growth in sales** during the first year, the a 25 % and 10% growth in sales respectively during the second and third year **on the national market**. A growth will also occur **on the European market**.
- ⓘ Case 2209 : This case concerns a Spanish company that designs and manufactures electronic equipment for fire and gas detection. The aim of its project was to introduce an ASIC instead of discrete components in its conventional ionisation smoke and rate of rise heat detectors. Thanks to the ASIC, the company will **reduce its total costs**. This cost reduction of respectively 13% for ionisation smoke detectors and 6% for rate of rise heat detectors, will assure a **good market positioning** and will significantly **increase the sales** of the company. Furthermore, the ASIC makes the **products more reliable** and thus **reduce the maintenance costs**. This is important for the company and it makes the product more attractive for the customers.

However, the ASIC solution does not always fit to the project.

- ⓘ Case 25895 : A Spanish company specialised in the sector of equipment for data transmission via radio has rejected the ASIC solution to replace the analogue technology of its T-MOD radio-modem by a digital technology for 2 reasons. Firstly, as the ASIC option requires a major investment in development, it's **only applicable in markets with high consumption**, which is not the case of the company's targeted market. Secondly, the ASIC technology **doesn't allow any changes** of the design's technical specifications once implemented. It's an important drawback if the company is to replicate its ASIC experience on other internal products.

Multi Chip Module (MCM)

Definition

An MCM is the assembly of several chips in one package in order to reduce the length of the connections between these different chips. This reduction increases the workspeed of a system.

FUSE portfolio examples

- ⓘ Case 2118 : The following case concerns a German SME active in the sector of gas and liquid flow control. The purpose of its project is to improve a mass flow controller. The use of an MCM is a good solution to **reduce the size and the cost of the product**. Thanks to that, the product is smaller and cheaper than the competitors' products and it can enable the company to **conquer other markets** where the size is an important criterion (i.e. the electromedicine market).

Unfortunately, the MCM solution only becomes cost effective for a minimal quantity of 20.000 units.

ⓘ Case 25111 : An Italian SME specialised in the electro-optical sensors and systems for process control automation has abandoned the MCM solution for the design of a new electronic board for optical distance sensors because this technology only becomes **cost effective for a minimum production of 20.000 units** (in its case).

Micro System Technology (MST)

Definition

A micro system can be considered as any device made of a number of micro-engineered components. It can be for example MEMS (Micro Electro Mechanical System). MST combines at least 2 of the 3 following functions : sensor, actuator and signal processing.

FUSE portfolio examples

ⓘ Case 26793 : This case concerns a British SME that designs and sells diagnostic and prosthetic medical systems. The project is the improvement of a device, currently based on a microcontroller, that is able to determine the rate of airflow from patients' lungs. The use of an MST will **reduce the size and the production costs** of the device. The device will be easier to use and so, will be more attractive for the customers (i.e. the clinics). The consequence will be the increase of units sold both on the European and world markets (22000 extra units sold during the second year), which will **enforce the competitive position** of the company.

How to get there

This section presents the overall scheme of tasks and costs a company should plan in order to have a product improved using electronic technologies. All the necessary steps one company must follow, from first idea to working prototypes, are explained and discussed, providing a guide or systematic allowing the reader to quickly set an action plan

The barriers

The FUSE program was set up with the aim of helping companies to overcome the barriers that prevented them from using new electronic technologies. This section summarises the barriers perceived by the First Users and the steps they took to overcome them.

<u>Knowledge barrier</u>

This knowledge, or ‘technological’ barrier is by far the most frequently perceived by the companies. Here are some of the First Users’ reports of the difficulties they felt for using electronic technologies due to this lack of knowledge :

- ...the company does not know the possibilities of the technology...
- ...the company does not have the competence or confidence to design using the new technology...
- ...fear of choosing the wrong methodology, technology or supplier because of our inexperience...
- ...lack of information: case studies were unavailable to the company management...
- ...don’t know how to make cost comparisons for the various options...
- ...no feasibility study had ever been undertaken by the company....

<u>Risk barrier</u>

This barrier is a consequence of the previous one. Sometimes referred as ‘lack of confidence’ or ‘psychological’ barrier by the First Users, it basically reflects the fear of failure due to this lack of knowledge. Failing would mean not only the direct loss of the time and resources spent in the project, but also the risk of endangering the company’s reputation if a defective product is put on the market. Here are some comments of First Users:

- ...the technical risk is that we would choose and attempt to adopt a new technology without adequate training and support. This could result in the launch of a badly engineered product or service or worse still in no product...
- ...the commercial risk is primarily the damage that could be done to the reputation of the business, as a direct consequence of the technical risks...

<u>Resources barrier</u>

Next barrier hindering the companies to start the improvement of their products with electronic technology, even when the knowledge barrier is broken, is the lack of resources. The main problem, specially for SMEs, is that the technical staff is very busy with the everyday tasks – a totally logical fact, as the daily income of the company depends very heavily on the work of this skilled and scarce personnel. The result is that the urgent issues don’t leave much time for the long-term projects. This problem has also been reported as one of the sources of delays in the Application Experiments.

The second problem is the lack of the specific design and development tools required by some electronic technologies, like FPGAs or ASIC. First Users find very difficult to justify the acquisition of these tools, that may be very expensive and represent a heavy burden in the financial accounting of the company, without being sure of the future use they will give to these tools once the Application Experiment is completed. These are some comments of the companies:

- ...we were also concerned about the impact of the diversion of extremely scarce management and engineering resources during the early stages of growth of the business. The concern has proved to be valid...
- ...another important commercial risk for an SME is that personnel undergoing a training still have to paid, but are temporarily unable to contribute to the income of the enterprise...
- ...another barrier was about the new approach to the use of FPGA devices necessary for prototyping and its software design tools...
- ...lack of knowledge regarding the design methodologies, cost of components and development tools, and above all the belief that a small company would not have the annual sales sufficient to justify the use of such new technology...
- ...there was the added fear of an excessive investment regarding development tools and the learning of new technologies...

The first step: breaking the barriers

The combination of TTN plus subcontractor is broadly reported by the First Users as the solution to overcome these barriers. These are the reports of companies concerning the breaking of the knowledge barrier, and its closely related risk barrier:

ⓘ Case 2212: A British manufacturer of cooker hoods, who improved his product using microcontrollers reports: The technical risks were overcome by establishing a close working partnership with our subcontractor. FUSE provided the ability to apply an appropriate new technology in a virtually risk free manner, with highly skilled support, both from the TTN and potential suppliers of components and services. The skilled support and training overcame the technical risks, the message being do not try it on your own without some advice and support..

ⓘ Case 22824: An Italian manufacturer of gas sensors improved his product using Microsystem technology. The company reports many intake meetings held at the TTN's facilities

- to support the company with initial feasibility considerations, especially concerning various possibilities about the electronics for the control unit for the signals coming from sensors (microprocessor and ASIC based solutions were evaluated)
- to carry out an effective and well balanced workplan
- to reduce risks at minimum

ⓘ Case 503: A German company manufacturing pig feeders improved its product using SMT and fieldbus technology. They report that the process of overcoming the barriers in adopting the new technology started with the initial contact with the TTN. During this process the company was provided with training by the TTN on the following topics:

- The available technologies and their merits
- The economic and business implication of adopting the new technology
- Technology and subcontractor selection process
- The First User conducted, with the support of the TTN, a detailed feasibility study into the improvement of their feeding valve and also other products in the future. This study has resulted in the selecting SMT as the base for their new valve electronic and covered the technical and economic aspects of adopting the technology.
- The initial training and the feasibility study have allowed the First User to address and overcome the knowledge barriers.

This independent, unbiased advice of the FUSE TTNs is still available. Any company who thinks that it's product can be improved using electronic technology but feels not confident on its knowledge to do the right decision, can ask to the TTN of its choice to provide information and training to select the most suitable technology and subcontractor and defining the workplan to follow.

The resources barrier was also overcome using a suitable subcontractor. The company could perform the project allocating only a limited amount of staff resources and did not need to invest in development tools:

ⓘ Case 197: A British company manufacturing run-time recorders improved its product using ASIC technology. ... It also made the ultimate decision to subcontract the detail design work to the ASIC vendor affordable. We had initially intended to tackle the work ourselves but it became apparent that to do an effective job would require too much training, to acquire skills that would not be used on a daily basis. We therefore only undertook familiarisation training and gained experience by participating as an observer.

ⓘ Case 23275: An Italian company manufacturing aquariums that improved its product using ASIC technology ...to overcome technical barriers we used the expertise of the subcontractor and of the foundry technicians, who have always proven to be professional and open to our questions.

ⓘ Case 1005: A Swedish company manufacturing fax printers improved its product with ASIC technology We learned...how effective it is to use subcontractors in all phases of the project. The right subcontractor, help you out even during stages where it not were planned.

ⓘ Case 22964: An Italian company manufacturing gasoline pump controllers improved its product using FPGA technology: ...subcontractor (and TTN) supported our activity in three different phases of the project:

- In the first phase the TTN followed the proposal documents preparation; it allowed Company to have all essential information regarding the issues to control the technology selection phase.
- In the second phase our technicians received technical training which provided them the capacity to describe the block functionality using VHDL language. Moreover, the subcontractor helped Company to solve the problems related both the system and the development tools.
- Finally the TTN had taken care all the managerial aspect of the contract.

ⓘ Case 2209: A Spanish company manufacturing smoke sensors improved its product using ASIC technology:

- ...the ASIC solution to product improvement became a feasible alternative when the TTN introduced project FUSE to the company. TTN supplied us with all technical and economical details of the project.
- .. first subcontractor trained a member of our technical staff in the field of microelectronics ... During this period the company got started designing ASICs with software design tools available in the subcontractor laboratories. This knowledge transfer will establish the basis to launch future projects...

The next steps: the development plan

Developing and selling a product requires that the company invest in the following areas:

1. Market research: to assess the potential size of the market and the price the customers are willing to pay for the product.
2. **Specification, design and prototype manufacture**: The areas covered by the help of FUSE, and explained in detail in the next sections.
3. Industrialisation and tooling: To make the prototype ready for volume manufacturing sometimes requires modifications. Also, the production line, machinery, tools and assembly facilities must be set up before starting volume fabrication.
4. Manufacture: The actual making of the products requires materials, labour and utilities consumed.
5. Marketing: publicity and advertising among potential customers.
6. Distribution: transportation to customers and dealers
7. Product support: after sales maintenance and servicing

This document deals with the second area, where the use of electronic technology has a clear influence, and where the experience of FUSE AEs is collected in the Demonstrators database. It is foreseen that as the data of AE follow-up are collected, the experiences on the influence of technology on the following tasks can also be extracted. and appended to this document.

The organisation of a development project

The first step before starting the development project is of course the project set-up. The general process of innovation, independently of the technology, is the following :

1. Imagine a new product or new functionality
2. Describe the new product and / or the new functionality as an 'ideal' specification
3. Study the technical and economical feasibility with existing technologies or with new technology to get a realistic technical specification
4. Contact potential subcontractors
5. Refine or rewrite the technical specification according to the chosen technology and the subcontractor's advice
6. Set up the work plan in terms of phases, resources, delays and deliverables

Once the company has imagined a new product or new functionality that takes advantage of the possibilities of electronic technologies, they need to select a subcontractor and define a workplan. This is what First Users get as a result of the removal of the knowledge barrier, so the advice on how to proceed to take this step is the same as before: get in touch with a TTN, which, from an independent, unbiased position, will show the possibilities of the technology, recommend the technology that is more suitable for the application, both from the technical and from the economic point of view, and provide a list of possible subcontractors.

The company contribution at this stage is the description of the desired new product in terms of functionality / use, price, size. The intake meetings should include technical, commercial and quality people. If possible a "friendly" customer could be associated in order to validate the new idea. After this discussion with the TTN, the 'wish list' of the company should be much more precisely focused, taking into account the possibilities of the technology. When the technology is selected, the company can choose a subcontractor that has the required ability to complement the company's staff.

The following step, once the subcontractor has been selected, is the definition of the workplan. Here the TTN can provide the First User with the experience reported in the Demonstrator documents of the 400+ Application Experiments funded by FUSE, selecting the ones that are more closely similar – by company size, by type of application or by technology to use – to the project that the new company wants to start. Some examples are given below. (See also cases 2212, 22824 or 503 in previous pages).

ⓘ Case 23133: Can be a very costly mistake if the wrong choice of microprocessor/controller is used, also making the initial process of developing an updated product can also be difficult. With the help of the TTN it was possible to overcome these barriers because of the TTN's knowledge in micro technology.

ⓘ Case 27535: The help of the TTN was necessary and particularly significant during the first phase of training and of the outlining of the project by means of the VHDL language. Indeed, the FPGA was designed from the beginning with a forefront and timesaving method that in plus is a good way which will make it possible and easy, in case, to change it into ASIC. It is therefore necessary to resort to the co-operation of the TTN, which is highly specialised as concerns all the problems of microelectronic projects as well as in project developed in the form of job training; this guarantee us of a complete and correct know-how.

ⓘ Case 23275: With the help of the TTN we made an evaluation in order to decide which technology had to be used to implement the project in order to improve the actual version, realised with discrete components assembled on a PCB. …After comparing the possible technologies of microprocessor, ASIC and microsystem we selected the ASIC technology as the most suitable.

The phases of the development project

With the help of the TTN and subcontractor the company should plan the project in order to get a contractual document, where job partition and responsibility are explicit. (See also training document on Subcontracting). The workplan must:

- create a work breakdown structure
- describe the tasks (task specification)
- define the output and interrelationship of each task (Gantt chart)
- evaluate task duration
- allocate resources and estimate cost
- assign responsibilities

The workplan of a project for the development of an electronic component or subsystem can be divided in the basic phases of Specification, Design, Building of prototypes and Test and validation. The typical flow of activities and the tasks to be performed at each phase are described below.

<u>Specification</u>

With the help of the TTN and subcontractor the company should refine or rewrite the initial technical specification in order to get a contractual document and a more precise quotation. If the technology is not mature, the process of defining the specifications is normally a work intensive part of the overall development: design and specification are linked and an iteration process of specification – design – refining of the specification may be possible. If the technology is mature enough, the specifications phase could be included by the subcontractor as part of their "commercial" work to get the order from the company. But even in this case it is advisable to include a specification phase into the contract in order to be sure of the mutual agreement, as the biggest source of failure or delay come from a badly prepared specification.

This is probably the most important phase for the success of the project, and where the company must be deeply involved. During this phase the initial ‘wish list’ of the company is trimmed and precisely defined in terms of electronic functionality so the performance of the different elements of the electronic subsystem is stated without ambiguity.

Critical decisions are made at this stage, like the partition of the functionality between hardware and software and among different hardware elements (off-the-shelf or customised components), with a clear incidence in the final cost of the product. Normally this is the phase with the highest rate of knowledge transfer to the company, specially to companies normally not involved with electronics, as the possibilities, limitations and cost of each possible electronic implementation is clearly seen, and decisions have to be made based on this new knowledge.

It is not too strange that the First User discovers in this phase more possibilities than he/she expected at the beginning: this is the moment for investigating them all, before starting the next phase. First Users who discover new possibilities at a later stage, and want to implement new features when the design phase has started get in the best case a delay in the launching of the product to the market, and in the worst an increase of costs, as the implementation of the new function may mean discarding some design work already done.

<u>Design</u>

This is the phase where the specification is converted in detailed electronic schematics that will allow the manufacturing of the working prototypes, and constitutes the core of the development project in terms of time and resources. This phase is effectively accelerated with the use of computer-aided design/engineering tools (CAD/CAE), like simulation software packages (allowing the designer to ‘see’ in the computer screen the electric behaviour of the circuit) or emulators (hardware equipment, connected to a computer, that physically generates electric signals and reacts to electric stimuli in a similar way as the final prototype – normally at a lower speed).

Designs of low to medium complexity can be described by the designer directly as an schematic, which is drawn in the computer screen (with the help of one part of the CAE suite called schematic capture) and fed as input to the simulator. But the higher complexity allowed by some specific technologies, like FPGA or ASIC makes more efficient the use of the so-called 'Hardware Description Languages' (HDL). With this approach, the designer describes the circuits with a structured text, that is processed first by the simulator, and when the designer is happy with the results, the textual description is automatically converted into a schematic with the help of a new (and normally quite expensive) tool: the synthesiser.

This approach is not only more efficient: it has the added advantage of allowing the design to migrate easily and at reduced costs from one technology to another, i.e. from FPGA to ASIC. This allows the company testing the market with a reduced number of FPGAS, and investing in ASIC development when the market demands higher production, or convert its old design from an older, discontinued ASIC technology to the most recent one.

The use of simulators and synthesisers requires the availability of 'models' of the basic building blocks of the circuit to be implemented. This collection of models is what is called the 'library', and in the case of FPGA or ASIC technology the library is specific for each tool vendor, each tool version and also for each FPGA / ASIC manufacturer and each possible technology of fabrication of the final devices. Getting in time the right library for the specific combination of CAE tool / CAE version / devices manufacturer / device version is important for avoiding uncontrolled delays.

The output of all these tools is the design of the circuit at the electrical level. But the final implementation of the prototypes requires a still more detailed description, at the physical – or geometrical – level. This is performed with the next suite of tools, that convert the electric description in a detailed plan of the interconnection of the different circuit elements – discrete electronic components in a Printed Circuit Board (PCB) or the different basic cells of an FPGA or an ASIC on the surface of the silicon chip. The reader is referred to the specific training material on FPGA / ASIC for more details about the use of these tools.

Just designing the prototypes is not enough: an integral part of the overall design is the design of the testing procedures that are necessary to certify that the prototypes – or the circuits in production – are working properly. This design part cannot be neglected, as it may take a substantial amount of time and resources when designing very complex systems.

The project manager decides how much of the design phase will be done with the company's resources and how much should be subcontracted The main responsibility of the design manager is to monitor closely the progress of the design in order to identify as soon as possible the troubles that may endanger the project and taking the suitable corrective measures.

<u>Building of prototypes</u>
The simulations provide the almost complete confidence that the design has fulfilled the requirements of the specifications. But the real proof comes when prototypes are built. This phase can be quite quick and cheap, in the case of technologies like microcontrollers or FPGAs, but much more expensive in technologies like MCM, ASIC or Microsystems, that require very complex machinery to implement the prototypes. For these technologies, this step is performed by the devices manufacturers at their fabrication plants, without intervention of the company or design subcontractor.

<u>Test and validation</u>
Finally, the prototypes are tested to check that they comply with the specification in different working conditions, and fulfil the pertinent regulation (EMC etc.).

<u>Knowledge transfer</u>
The knowledge transfer is not normally included as one of the standard parts of a development project, but is important to take it into account in a high tech project. The company should carefully plan this issue and address the following items :

- Objective
- Modality
- Content
- Articulation with the other phases of the project

The general objective of a knowledge transfer is always to reduce the cost of future projects. So it is important to set up goals that fit perfectly the company profile in order not to over spend money. For example, a company which wants to design only one ASIC will not need to transfer the complete design skill including the use of advance CAD tools, as such an investment would need around 40 designs per year to be profitable. This is also the case of complex technologies like MST or MCM, where the interest of mastering the technology is not at all evident if the company is sure to never have the equipment.

The knowledge transfer should always concern more than one person in the company. If only one person gets the training and then decides to leave the company, the investment will be lost.

There are three basic kinds or modalities of training, which are not exclusive (and more effective when they are combined)

1- Training: Most common. In this case content and duration are to be evaluated by a professional training organisation in order to validate the objective. Be careful with training provided by service vendors.

2- Technical assistance or mixed team (subcontractor and FU). Very effective way if this is really negotiated with the subcontractor. Usually the job of a subcontractor is to do the work and not to show how to do it , so the company should not expect getting knowledge transfer without providing to the subcontractor a clear incentive. The transfer could occur during the job, when some company’s staff work together wit the subcontractor engineers, but most often during specific technical meetings. It is good to prepare these meeting with a short training by lecturer.

3- Hiring external skill. A very good way of knowledge transfer is to hire skilled people. It is important to insure that the newcomer will transfer his knowledge to the company’s project team.

The costs

Costs are reported by many First Users as another barrier to overcome. And one important component of this barrier is the lack of knowledge on the factors that may affect this cost. This knowledge is of course necessary to do a sound financial planning.

First Users are interested not only in knowing the average cost of a typical project but also on the **differences** their specific project may have with respect to this average cost. And very specially in the kind of unforeseen events that may **deviate** the final cost of the project with respect to the planned amount.

The FUSE project, with its more than 400 Application Experiments, is providing a wealth of information on these issues. The goal of this section is giving to the interested companies a summary of the data available at this moment in the Portfolio of Demonstrators that may be used by the companies as a guide for making an estimation of the possible costs of their development project. So it is important to clarify the sources of the economic data presented in this document and the extent of the information available at the moment.

The first restriction to the information contained in this section is that **it deals only with the cost incurred in the phases between and including Specification and Prototypes validation**, as explained in the previous section. It is one objective of FUSE to collect and compile information coming from the companies (that want to co-operate after FUSE help finishes) providing extra information on the additional costs they need to face after prototypes are completed and until the first units of product are sold (qualification, industrialisation, marketing, etc). The first significant input of information on this subject is expected by the end of March, so we expect **including post-prototypes costs in the third issue** of this document, due at the month of June.

The next restriction comes from the type and structure of the data contained at the moment in the FUSE portfolio. For the sake of simplicity and manageability, FUSE has classified the multiple ways of using electronics applying innovative ideas to industrial products, in **six categories**: PCB/SMT, Microcontroller/DSP, FPGA, ASIC, MCM and MST. The order in which these technologies appear in the list is important, as carries the implicit assumption that the higher one technology appears in the list, the more complex is it to handle. This higher complexity also carries an implicit suggestion of higher cost.

When one tries to apply this simple model to the economic data available and calculates the average cost of the projects of the different technologies, the result is as shown in the following table (source: total cost stipulated in the contract as appear in Finances view of Lotus Portfolio).

Technology	Average cost (KEUR)
PCB	60.31
SMT	45.98
Microcontroller	51.63
DSP	75.07
FPGA	55.83
ASIC	115.36
MCM	91.84
MST	126.61

Table no. 1: Average cost of the projects of each technology

These data are quite useful in the sense that they make evident a new parameter: **Complexity**. For example, a ‘dummier’ technology (according to this simplistic model) like PCB happens to be on the average more expensive to implement than FPGA. Influence of complexity is shown more dramatically in the next histograms grouping the costs of all the AEs of one specific technology

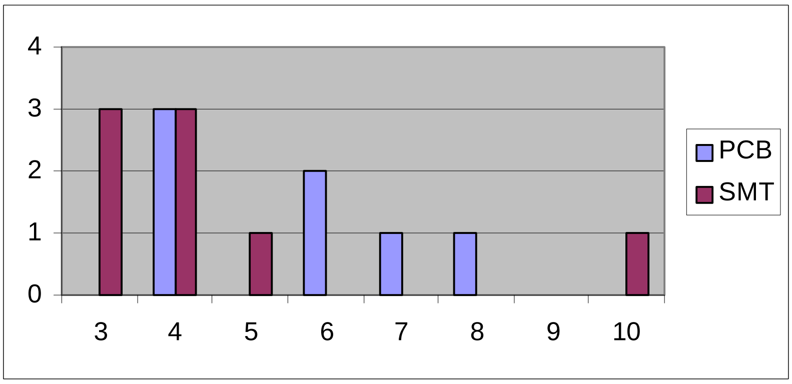

Chart no. 1: Number of PCB/SMT projects by cost (horizontal axis = x10KEUR)

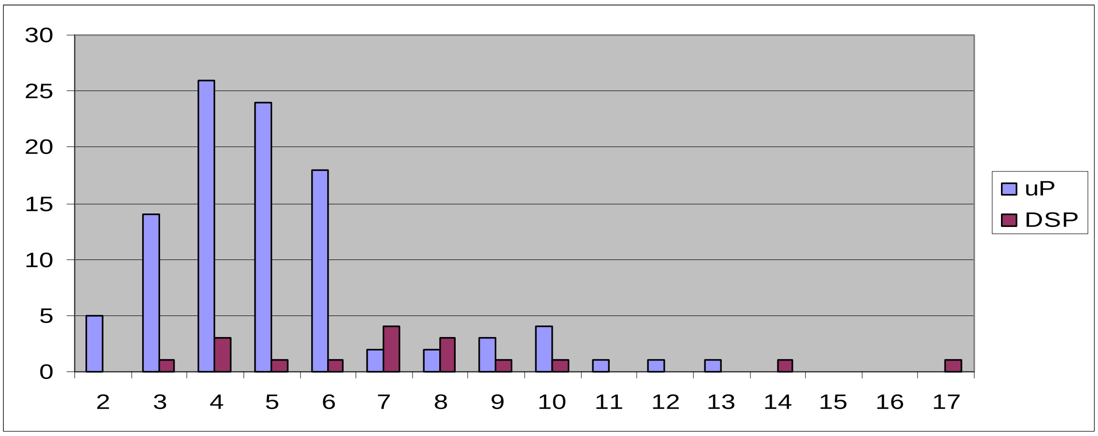

Chart no. 2: Number of Microcontroller/DSP projects by cost (horizontal axis = x10KEUR)

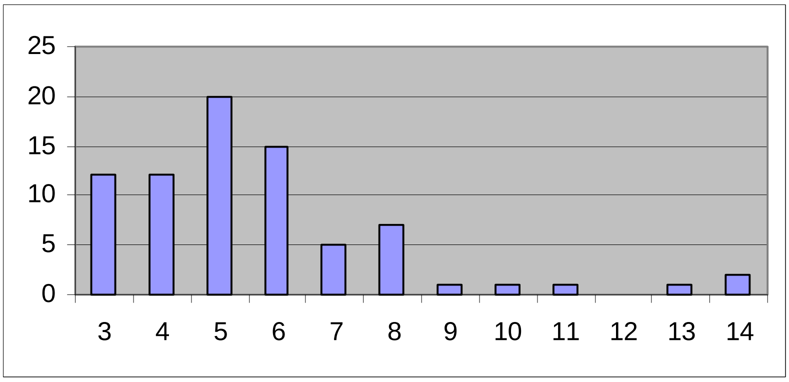

Chart no. 3: Number of FPGA projects by cost (horizontal axis = x10KEUR)

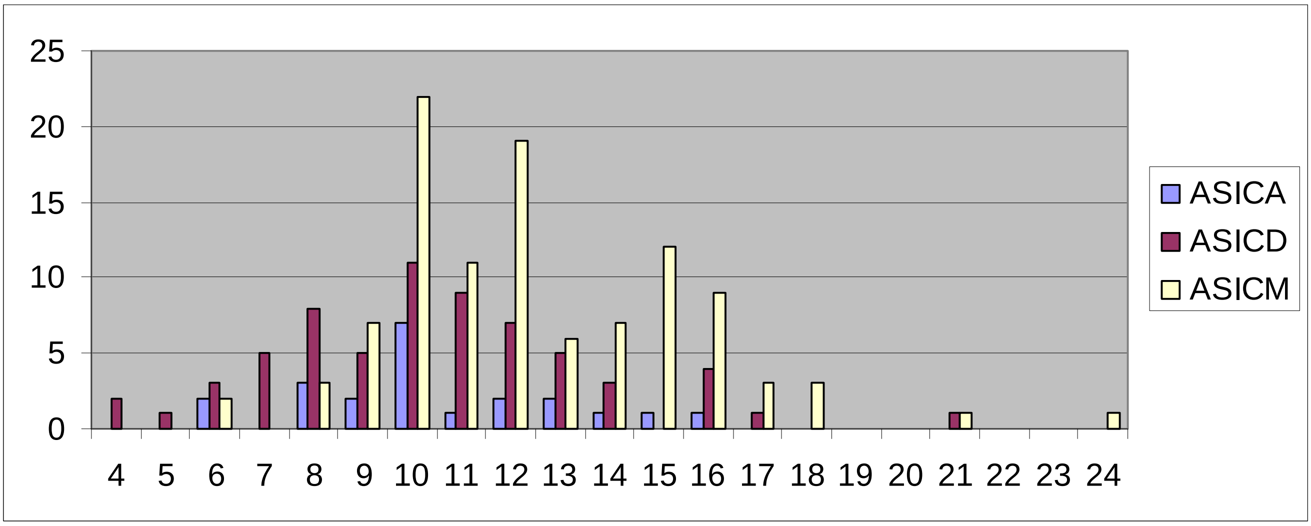

Chart no. 4: Number of ASIC projects by cost (horizontal axis = x10KEUR)

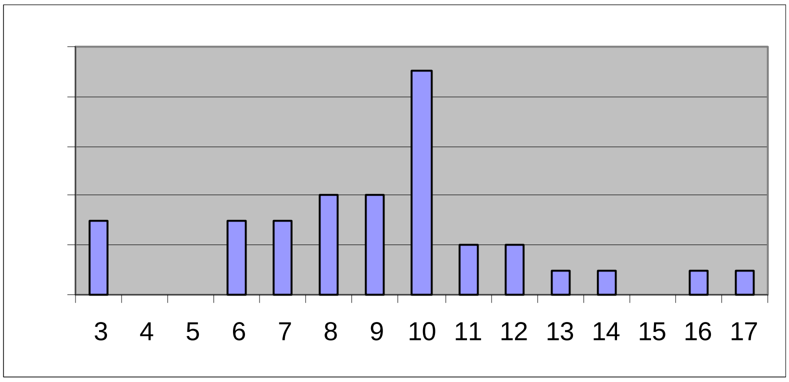

Chart no. 5: Number of MCM projects by cost (horizontal axis = x10KEUR)

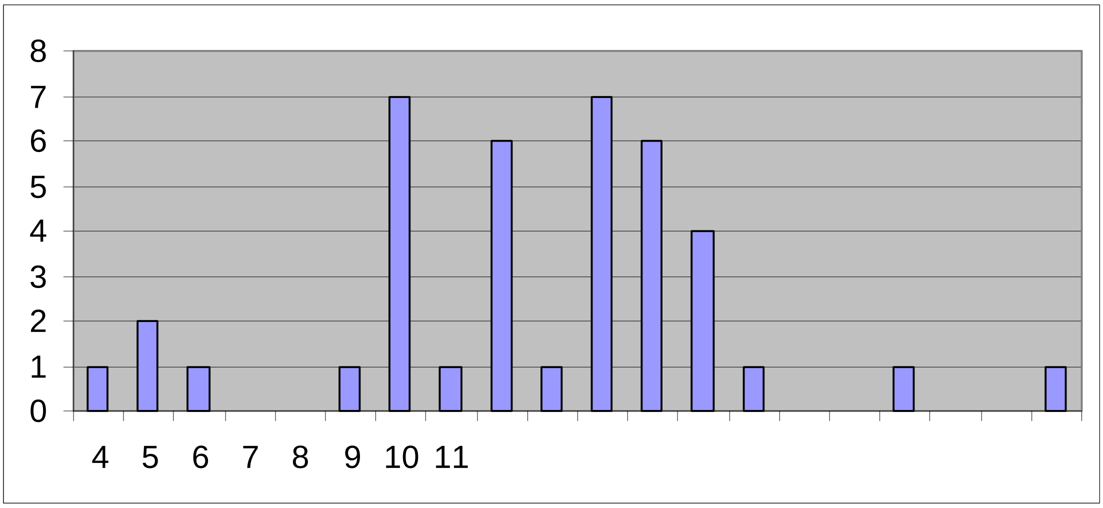

Chart no. 6: Number of MST projects by cost (horizontal axis = x10KEUR)

The explanation of the reasons behind this ample variety of cost figures would of course require a much more detailed, case by case study that goes beyond the scope of this introductory text, and may be found in the specific training material of each technology. The costs by task of some selected typical projects of each technology are summarised in the following tables as reference.

Technology	Duration (months)	Effort (p·days)	Overall prototype development costs (KEUR)	Case study
uP/DSP	12	239	58	2174
	8	320	80	2194
	8	163	41	23600
FPGA	9	180	82	25788
	7	143	41	22964
ASIC	18	423	150	22949
	21	245	110	23208
MCM	12	150	104	418
MST	15	200	132	22824

Table no. 2: Duration, effort and cost of selected projects

Technology	Management		Training		Specs & Design		Fabrication		Evaluation		Case study
	Com.	Sub.	Com.	Sub.	Com.	Sub.	Com.	Sub.	Com.	Sub.	
uP/DSP	24	1	59	3.4	102	6.8			54	1.8	2174
	48		30	6.5	177	13.1			65		2194
	15		10	1.5	113	12.2			25	3.8	23600
FPGA	15		45	6.2	90	5.7			30	1.3	25788
	10		25	6	50				40	2.4	22964
ASIC	66		110	10	88	15	5	19	154	2	22949
	60	1.7	25	2.6	110	22.7	5	11	45	3.5	23208
MCM	35	8	25	8	80	34			10	10	418
MST	50		30	5	100	24		40	20	13.5	22824

Table no. 3: Effort and cost per task of selected projects (Com: company effort person·days, Sub: subcontractor cost KEUR)