FUSE DEMONSTRATOR DOCUMENT

Application Experiment number 29736

A Drug Screening Instrument

Microcontroller Technology Automates Visual Inspection System

Cozart Bioscience Limited

TTN: (UGCS) Ltd.

Sept. 1999
AE Abstract

Cozart Bioscience Limited was founded in 1993, and is a small company of 14 people specialising in the design, development, manufacture and sales of immunoassay strips for drugs testing. The company’s products are used in the medical and drugs testing market sectors. Company sales in 1997 were approximately 600 KECU. The company’s industrial sector is defined as chemical products (Prodcom Code 2466). Prior to this application experiment, the company had no experience of microelectronics technology.

The existing products are entirely chemical, and require that drug level results be interpreted visually using trained operators. This interpretation is subjective, and as the process is non-linear the process is inadequate for use in widespread drugs testing programmes.

The objective of this application experiment was to develop a device (the Cozart RapiScan) similar to current breath alcohol instruments, but using saliva as the sample for the detection of drugs saliva samples processed by the company’s current immunoassay test strips. The improved product is a hand-held instrument complete with integral reader and microcontroller. The functions performed by the improved product include:

♦ Displaying the results of the sample evaluation on a LCD display.
♦ Result storage and facilities for transferring this information to a PC.
♦ LED display status to indicate the progress of the test.
♦ Extraction of test sample bar code information and the storage of this data with the test results.

The improved product is a unique product for the drug testing market, providing Cozart with a patented, market leading technological solution to the problem of low cost, widespread drug testing. The improved product enables the company to meet the increasing demand for easy to use, on-site drug screening equipment in such application as prisons, drug addiction centres, clinics and emergency centres, the armed services, pre-employment and employment screening, and roadside drug testing.

The costs of the prototype product development were 46 kEUR, and the application experiment (to the prototype stage) was completed in 8 months.

The increased product sales delivered by the introduction of microcontroller device technology will increase Cozart Bioscience’s sales revenues significantly, and produces a payback period of 11.2 months for the prototype development costs. The return on investment for the prototype development costs over the 10 year product life is estimated to be 1,200%.
Keywords and Signature

Keywords:
Illegal Drugs
Drug Testing
Drug Misuse
Visual Inspection
Drugs Testing
Microcontroller

Signature:

2 0151 555 0204 2 2466 1 24 UK

1. Company Name and Address
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2. Company Size
Cozart Bioscience Ltd employs 14 people and achieved an annual sales revenue of over 600
KECU in 1997. The majority of employees are of a biochemical/laboratory based background
(9 people), finance (1 person), sales (1 person), administration (2 people) and a recently
appointed design engineer.
3. Company Business Description

Cozart Bioscience is a small, privately owned company founded in September 1993. It specialises in the design, development, manufacture, and marketing of immuno-diagnostic kits. These are used in the field of drug abuse testing, and for medical applications such as cancer testing. Immuno-diagnostics involves the use of antibodies to detect very small quantities in biological fluids and other matrices.

The company’s industrial sector is defined as “Other Chemical Products” - PRODCOM Code 2466.

4. Company markets and competitive position at the start of the AE

Cozart Bioscience supplies immuno-diagnostic kits for the detection of specific antibodies. The company sells its products in the UK and exports them through international distributors. The industrial sector within which Cozart operates is defined as ‘Other Chemical Products’, with the corresponding PRODCOM code 2466.

The company’s market includes the medical testing market, and drugs of abuse testing market. The market for immuno-diagnostics kits is an emerging market, replacing the traditional use of laboratory-based analysis and reporting services.

The market for drug of abuse (for example, cannabinoids) is a rapidly developing and growing market as a result of the recognition of the damaging effects of such drugs in many areas of normal daily activity.

The market for single or multiple on-site drug testing devices is large. Recent surveys have estimated the market size for such products to be between $12 to $20 million in the USA alone. The value of laboratory-based drug testing services is estimated to be 10 times this amount at present.

The US market for drug testing has grown to this size since many companies operate mandatory testing in the form of pre-employment and employment testing. The European markets have been slower to develop, and only within the last couple of years has the impact of larger drug screening programs in the military, prison services and for employment screening resulted in a growing demand for these products. The market size for drug testing products for the combined European Community is now estimated to be equal to that of the US, and is growing rapidly as awareness through education and the media increases.

The market for drug of abuse detection products is split between public and private sectors:

- Public sector markets encompass police forces, the prison service, Customs & Excise, Military services and Government Departments such as the Department of Environment Transport and the Regions in the UK (focused on road traffic accidents and drug driving). Schools and colleges also have an interest in testing for drugs in an on-site drug testing system.

- Private sector encompasses; employers with safety sensitive equipment such as airlines, railways, shippers, and heavy plant. There is also the area of general industry where employment-screening programmes are being introduced.

The main alternatives to monitoring the use of drug of abuse include:
• Laboratory based test methods where a sample is collected and sent through to a laboratory for analysis. This process, although giving accurate results, is costly and does not provide immediate results.

• On-site tests available for the detection of drugs in urine. These tests are geared for measuring the much higher levels of drug and metabolites observed in urine, and are often inconvenient to use, especially in environments such as road side driver testing.

• Devices for the measurement of drugs in sweat. These devices have been adopted from their designed use of testing for surfaces (bench, case etc.), and the detection of drugs in sweat can be complicated by the collection of a sample from a skin surface which, amongst other problems, is exposed to contamination from other sources.

Whilst there is currently nothing to directly compete with the Cozart saliva based drug testing system, there are several on-site tests available for the detection of drugs in urine samples. Theses however, are inconvenient to apply in many situations requiring the taking of an urine sample. Cozart’s system operates using saliva samples therefore offers user convenience, as well as providing several advantages in terms of technical performance over competing technologies. These advantages can be applied to capitalise on the following emergent market opportunities: There are no competitors currently using saliva based samples for drug of abuse analysis.

The purpose of this project was to create an easy to use, semi-automated, portable drug screening device which would find application in several areas, two of which are detailed below:-

• Increased recognition of the need for roadside testing to identify drivers under the influence of drugs. For example, the UK is currently piloting a trial programme with a view to introducing legislation in this area. Currently, it is estimated that over 10% of accidents in the UK may be due to drug misuse. The 43 police regional forces in England and Wales are projected to require 4,500 roadside drug testing systems units to complement the existing number of breath alcohol instruments held by the police.

• Random drug testing of employees will continue to expand as the safety implications for people in charge of heavy machinery, process equipment or in other responsible positions is recognised. The use of an on-site device will significantly reduce costs and improve convenience for this type of testing over samples being sent to external laboratories.

The combination of an easy to obtain sample, coupled with an easy to use on-site device will revolutionise the way in which drug screening is approached in both of these market areas.

A total European market demand of 24,000 drug testing systems per annum is projected for 2001 and beyond. The market size in the USA is of the same order. The estimated market share attained by the existing cellulose strip product is <5% in the UK and <1% in the USA.

The price of the company’s immuno-diagnostic kits depends upon the number of drugs to be tested on each strip. A typical price for a kit involving one cartridge with a 5 drug test capability is approximately 15 Euro.

The main obstacle to developing this market was the development of electronic equipment to provide unbiased analysis and report results. This application experiment has succeeded in addressing this requirement, and will lead to a rapid increase in both sales and market share over the next 5 years.

Sales of Cozart’s diagnostic products over the past three years are indicated in Table 1:
Table 1: Sales Revenue of Diagnostic Products

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<td>100</td>
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<td>(kEURO)</td>
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</table>

5. Product to be Improved

The existing product consists of a multi-zone cellulose strip, with each zone being chemically designed to react to a certain drug found in the sample to be tested. The level of drug in the human body is derived from the colour changes to the strip. The current product is entirely chemical in its composition and does not incorporate any microelectronics.

The nitro-cellulose membrane strip used in the current product contains drug-protein derivatives, which are bio-chemically bound in specific zones (test line). Antibodies to the drug conjugated with colloidal gold are placed on an adjoining pad downstream of the drug-protein zones. When a sample is added to the strip, via an absorbent pad, it mixes with the antibody-gold conjugates and they ‘travel’ together across the nitro-cellulose membrane and pass over the drug-protein zones.

The antibody-gold conjugate will either chemically bind to the drugs present in the test specimen or to the drug-protein conjugate strips on the nitro-cellulose membrane. Therefore, the amount of antibody-gold conjugate, which binds to the test line, is inversely proportional to the amount of drug present in the test specimen. The level of antibody-gold conjugate is detected by a colour change at the drug protein zone. This result is then read by eye to give a qualitative (positive/negative) result.

To provide a quality control ‘reference’ line, a second line further downstream of the test line is provided to capture additional antibody-gold conjugate and demonstrates that the test has run correctly.

Illustrations of the test results obtained are shown in Figures 1 and 3. As Figure 1(a), (b) and (c) illustrate the determination of drug levels from the information on the immunoassay strips is difficult to derive accurately. In practice these images are coloured against a white background. These results were derived using controlled amounts of a cannabinoids (i.e. as present after cannabis use) spiked into drug free saliva. Figure 1 indicates that with increasing amounts of added drug we get increased inhibition of development of the test line compared to the control line. With 25ng/mL the line is absent; with 6 ng/mL the line is reduced from that found with 0 ng/mL but it is becoming more difficult to differentiate these two samples visually.
Figure 1: Cannabinoids in Saliva
On-site test response as measured electronically, via prototype instruments, for a range of cannabinoid concentrations in saliva. The “response” is a measurement of the intensity of the test line relative to the control line. Note the improved sensitivity in the critical area zero and 6 ng/mL when compared to visual interpretation.

Figure 2 shows responses generated from trial assessments conducted using a CCD camera instrument with these same samples. This response graph clearly shows a much-improved ability to differentiate sample concentrations between 6 ng/mL and a negative specimen, compared to the subjective human visual inspection.

The ability to detect reliably and accurately the levels of several drugs is achieved using a multi-drug membrane immunoassay strip.

Figure 3 shows the image generated from such a membrane strip for a negative test result for four different drugs. To date, eight separate drugs have been identified as being of interest and diagnostic chemistries have been developed to detect each of these.
Figure 3: Image of Test Strip showing a Saliva Sample Negative for four Drugs

Reasons to innovate: The major barrier to the wide spread adoption of these immunoassay strip detection systems is the subjectivity of the measurement level, which renders it unsuitable for the targeted market sectors. The application of a PC based visual inspection system demonstrated the technical mechanisms to remove this barrier. However, the use of commercially available CCD camera systems and PC based processing was clearly too expensive and unwieldy for practical drugs testing in environments such as roadside testing.

Therefore, the application experiment’s objective was to detect the presence of shaded lines on the immunoassay strips and to convert these indications into a quantified measurement of drug concentration in the saliva sample. The equipment that was developed during this application experiment now provides a relatively low cost electronic measurement solution, using the existing multi drug membrane immunoassay strip.

The immunassay strips are illustrated in Figure 4.

Figure 4: Photographs of the Existing Test Kits
6. Description of the Product Improvements

The improved product (know as ‘RapiScan’ ) uses the same immuno-chemistry system as the existing products but is incorporated into a system, which includes a means of reading, calculating and storing results electronically.

The improved product is illustrated in Figure 5.

![Figure 5: Photograph of the Improved Product](image)

The improved product’s functional block diagram is illustrated in Figure 6.

![Figure 6: Simplified Block Diagram](image)
The improved product uses a CMOS imaging array, directly interfaced to a microprocessor to capture, process and interpret the shade variations on the immunoassay test strips to produce a small, hand-held, instrument for displaying the results of multiple drugs testing.

The micro-controller device:

1. Interfaces to the CMOS imaging array, producing the clock and interface signals to extract the image information, integrate the results of each of the drug test bands in two dimensions to eliminate the effects of line edge variations caused by variations in the chemical reactions at each drug band.

2. Detects the presence of a test sample in the instrument, and determines the appropriate test time.

3. Performs the calculation of the level of each particular drug in the specimen being tested. This automation greatly improves the overall accuracy and reliability of the drug testing system as a whole by minimising the involvement of the operator and using sophisticated image analysis routines to internally quantify the drug concentrations.

4. Provides automated results storage. The results are stored to on-board non-volatile memory for future recall if necessary.

5. Provides visual feedback to the operator by means of a small graphical display showing detailed test analysis results.

6. Provides visual feedback using a series of LEDs to indicate the progress of the test and whether the results are above predetermined limit thresholds. If all drug tests proved negative then a green light flashes otherwise a red light flashes.

7. Provides facilities for the results of the sample test and unprocessed images of the test cartridges stored in the instrument to be uploaded to a central computer at a convenient time.

8. Extraction of the test sample serial number, and storage of this information with the test data results.

The process for obtaining a test result starts with the taking of a saliva sample from an individual by means of a saliva swab. This swab is then placed in a sealed test tube with a measured volume of buffer solution, and agitated so that the saliva and buffer solutions are mixed together.

From the resulting mixture, ten drops are transferred to the test cartridge using a disposable pipettor. As this is done, the fluid begins to flow across the nitro cellulose, the cartridge is inserted into the RapiScan cartridge entry port and a countdown timer commences. For each of the drugs being tested for by each individual cartridge, a test band is provided. At the farthest end of the cartridge, where the chromatographic flow take the most time to reach, a reference band is provided. After a predefined time, the chemical reaction has stabilised and the different bands can be interpreted by the electronic measurement systems of the RapiScan instrument. The samples are illuminated at various selected wavelengths to maximise the responsiveness of the measurement process.

Subsequent micro-controller processing of the information obtained determines the level of intoxication for each drug. Each test cartridge will have a unique test number which is stored along with the test results ensuring traceability of tests and linkage to the individual providing the test sample.
To guard against the ingress of dust and condensing humidity within the instrument during operation, a special ‘system test cartridge’ is provided with each instrument. This can be analysed in a special mode to confirm that the system is operating correctly in the field. The equipment then compares the image of the system test cartridge taken during manufacture with the one obtained in the field, and if a significant difference is detected, a system test fail indication is provided. This self calibrating and test facility means that the customer can then return the RapiScan to Cozart for inspection and repair if the transient environment cannot account for the test failure.

The functional parameters of the improved product includes:

- **Number of Drugs Tested**: Up to 5 drugs per strip
- **Test Time Requirements**: 6 minutes per test
- **Test Result Indication**: LCD screen provides ‘graded’ results

The new product represents enhanced system functionality, and a far more appealing proposal to potential customers. In relation to the cost of test cartridges, the purchase cost of RapiScan instruments is of minor concern to most customers yet it is an incentive for them to continue purchasing drug test kits from Cozart in the future.

### 7. Choice and rationale for the selected technologies and methodologies

The selection of sensor and processing technologies are defined in this section. Both of these technology choices are influenced by the need for of a low cost and compact design solution.

Several sensor system options presented themselves:

- Two dimensional CCD array
- One dimensional CCD array
- Two dimensional CMOS array

The second option was rejected because it did not represent significant cost savings relative to the other options and would have severely restricted the accuracy and functionality of the system. For instance, Cozart Bioscience were keen to prevent their competitors in future from selling test cartridges to run with the Cozart RapiScan instruments. One way of achieving this is to visually analyse the test cartridge for evidence of a Cozart copyright legend which would be illegal for a competitor to replicate. The accuracy would have been adversely affected with a one-dimensional sensor because the chromatographic flow within the test cartridges can be very unevenly distributed across its width. In order to obtain the best results, it was necessary to image the entire surface area of the nitro-cellulose test strip where the chromatography was taking place. The first option was rejected after some work had been done in developing prototypes. The main reason for this was that the cost of the CCD sensors, even in volume was quite substantial. It was also necessary to generate several different voltages to control the CCD and interfacing to it would have required numerous timing and digitisation circuits. Finally, once a two dimensional CMOS imaging device had been identified and evaluated, it was found that this option provided better flexibility, enhanced video resolution, simplified interfacing and reduced system size and costs. It was also advantageous that the supplier of the CMOS sensor could also provide high quality plastic (and therefore low weight and low cost) lenses to accompany the sensor.
The two dimensional sensor also provides benefits in:

- Reducing the problems associated with test cartridge strip misalignment.
- The storage of images for test confirmation.
- Tolerating blemishes on the surfaces of the test strips

The processing requirements for this application were based on proprietary image processing algorithms tailored for the task in hand. Typically, algorithms were explored by analysing typical images in a high level language on a PC before being optimised and hand coded in assembly language for the target system.

The processing device technology choice is influenced by the need for a low cost and compact design solution. This requirement immediately means that the use of discrete device solutions are too unwieldy for this portable product application.

Potential implementation technologies included micro-controller and microprocessor devices, DSP devices, and hardware implementations in FPGAs or ASIC device solutions. The FPGA device solution was rejected because this implementation would result in a highly committed design, and the potential for display customisation, serial data format customisation and drug combination selections by the company’s customers required a more flexible design approach. Rapid customisation of FPGA implementations were not considered as achievable as devices using software amendments only, and operations such as display generation are best achieved using programmable device technologies. ASIC device solutions were rejected for the same technical reasons, and because of the much higher Non Recurring Expenses (NREs) associated with adopting this technology. Cozart also consider that their microelectronics experience would not allow the development of this technology at low risk.

The selection of a suitable device technology from micro-controller, microprocessor or DSP devices was influenced by the speed of processing required, the number of peripheral ports required in a small volume and external memory capabilities. In this application the processing of the drug result information is not real time limited, and is limited by the development rate of the chemical reaction on the slide. Therefore the use of high speed DSP devices dedicated to real time algorithm processing was not required. Speed also meant that microprocessor devices were not essential. The use of 8 bit micro-controllers was obviously not possible due to the need to address large blocks of external memory. A low cost Hitachi H8/3002 16/32-bit micro-controller without on-board program memory was eventually selected because of the comprehensive I/O facilities offered by these devices, and the ability of the devices to address large amounts of external memory via paging facilities integrated into the devices. Additional features of this device which were well suited to the application were:

- The availability of an extremely low power software standby mode (5uA).
- In-built Direct Memory Access controller (DMA) for rapid video acquisition & processing.
- Internal A-D converters for battery voltage/temperature monitoring.

A large 16Mbit FLASH memory device was selected for use as both program memory and results memory.

To facilitate the software development process the subcontractor developed a dedicated circuit board to interface the parallel output port of the PC directly to the circuit board under development. The use of simple, custom written software utilities then allowed the developed
software to be downloaded into the microcontroller memory for testing. This mechanism allowed for rapid first-time and subsequent program iterations to be performed. The application of this custom facility meant that the RapiScan software could be compiled, downloaded and executed in real time almost as rapidly as would be the case for high level software development within a PC/Windows environment.

The software development process consisted of two stages. First the image processing algorithms and related data manipulation procedures were written in C on a PC based compiler. These algorithms were fully simulated using representative data to ensure that the algorithms functioned correctly.

The second phase of the software development process was the coding of these routines in the microcontroller’s assembly language. Assembly language programming was used for speed, and because of the sub-contractors familiarity with this language.

The software testing process used use both high-level routine simulation prior to being embedded in the micro-controller, and the use of in-system testing. Self-diagnostic test software was included to facilitate production testing along with the ‘SYSTEM TEST’ utility provided as an option on one of the RapiScan menus for confirming correct operation in the field.

The development process is summarised in the following diagram.

![Diagram of the development process]

**Figure 7. Simplified Overview of the Development Process**

The hardware implementation used surface mounted devices almost exclusively to reduce the space taken by the components. Bare board testing of the PCB prior to attachment of semiconductors is to be used in production. The modular design of the PCB is such that the functional sections have been separated and can be tested individually prior to final assembly.
This allows the independent testing of the video circuits, the micro-controller and memory sections, the individually adjustable LED drive circuits, and the power regulation and control sections.

8. Expertise & experience in electronics of the company & staff allocated to the project

Cozart Bioscience develops, manufactures and sells a wide range of immuno-diagnostic kits for drug abuse and cancer testing. The expertise of the company lay in biochemistry and did not involve electronics.

Cozart Bioscience Ltd did not have any electronics design engineers within their staff when the experiment began. The company’s Managing Director (MD) had previously been head of a biochemistry research and development department of a separate company. This experience had provided a fairly wide industrial experience, and although the MD had no previous electronic technical managerial experience this background provided the basis for the MD to undertake the Technical Management role for the company.

The company had originally identified a post graduate bio-physicist researcher to be recruited to undertake the electronic engineering tasks during the application experiment. Unfortunately, this researcher took a position with another company, and the company undertook to recruit a specialist engineer with electronics knowledge to support the application experiment. This individual was a graduate engineer, with approximately 10 years experience.

9. Workplan and rationale.

The workplan adopted for the application experiment consisted of 6 main phases as follows:

**Technical Management:**

The technical supervision and guidance of the application experiment towards a successful completion. This task involved resource, risk, and time and subcontract management tasks. Task allocation: Cozart 100%

**Engineer Training:**

Training support in electronic design management’ including the provision of advice on subcontract management aspects, time planning, and risk avoidance in electronic systems design.

Training in the selected micro-controller device, including training on the internal hardware structure of the selected device, development tool use and an introduction to programming in ‘C’ for this device. (Cozart 50%; training subcontractor 50%)

**Specification Phase:**

Comprehensive technical and functional specifications were developed for the Rapiscan product. The documents specified in detail the operational aspects of the equipment, as well as performance characteristics. Task allocation: Cozart 60%; Design subcontractor 40%.
Hardware Design:
The initial systems design, and the selection of major components including the microcontroller device, illumination sources, and CCD array device and lens systems, was carried out jointly by Cozart and the design subcontractor.

This exercise was followed by the development of microcontroller interfaces to the CCD array device, including the development of synchronisation and analogue video digitisation circuits.

The final step in this phase was the development of a final schematic for the hardware, including the design of the microcontroller, memory and peripheral circuits for battery recharging, battery monitoring and RS232 communications. The layout of the circuit board was also completed at this stage. The overall task allocation on the hardware design phase was Cozart 45% ; design subcontractor 55%.

Software Design:
Following the completion of the software specification, the high level design of the embedded software system, definition of program subroutine requirements, and the definition of all operator control and display sequences was implemented.

This was followed by the development of the core processing functions for the improved system, including the code development for image acquisition, image analysis and the graphical display and formatting of the result data.

The development of auxiliary processor functions such as battery recharging control and serial communication and printout facilities were then completed.

Finally, software was developed to enable the improved system to communicate with a PC, a feature which was required for both development testing and functional operation. Task allocation : Cozart 40%; design subcontractor 60%

Development Testing / Field Trials and Evaluation:
The initial evaluation of the circuit board was carried out using standard test equipment and ‘trial’ software modules. The main task was to ensure that the operational code was ‘interfacing’ correctly to peripheral devices (CCD array device, memory etc.)

Final systems evaluation was carried out using trial slides to ensure operational accuracy and functional compliance. Task allocation : Cozart 65%; design subcontractor 35%.
Table 2 shows the planned and actual ‘person days’ expended on the project, together with the subcontractor costs incurred:

<table>
<thead>
<tr>
<th>Work-Package</th>
<th>Company Resources Person days (Planned)</th>
<th>Company Resources Person days (Actual)</th>
<th>Sub-contractor Costs (kEUR)</th>
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<tr>
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<td>18.9</td>
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Table 2: Planned and Actual Costs for the Application Experiment

It can be seen from the above comparison that there were only minor variations between the planned and actual person days expended.

The following project plan shows the comparison between the scheduled sequence of tasks and the actual sequence followed.
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<th>TASK</th>
<th>DESCRIPTION</th>
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Planned Actual
Knowledge of the development and application of microcontroller technology was transferred into Cozart by the following process:

- By working with the TTN at the feasibility stage when different forms of microelectronics technology were explored
- By receiving formal training in the capabilities and design approaches required for microcontroller technology.
- Working with the design subcontractor at the specification stage. Being able to discuss ideas and debate the relative strengths and weaknesses of each approach allowed Cozart to appreciate the decision process involved.
- The ability to work with the subcontractor and to have ‘on-site’ support allowed Cozart to move rapidly up the learning curve. Relatively simple problems that would have been difficult to resolve either over the phone or via email were resolved quickly by having that personal contact.
- Learning how to use the development system enabled Cozart to really appreciate the intricacies of microcontroller code development.
- From a programme management point of view, the regular monitoring meeting with the TTN gave Cozart the opportunity to review progress. The facility to be able to discuss potential ways in which problems could have been handled differently, and to discuss how future issues may be resolved, was extremely useful.

10. Subcontractor information.

The major factors concerning the selection of an appropriate subcontractor for the application experiment included:

- Experience of previous instrument product design, including a holistic design experience to including packaging and design for manufacture issues.
- Experience of the development of image detection and processing systems.
- Experience in battery powered instrumentation based on microcontroller device technology.

The selected subcontractor met all of these criteria, and had a track record in design of portable, battery powered electronic systems and several years experience in designing systems containing imaging sensors and optical components.

The selected subcontractor was identified as the result of their previous association with the company’s Managing Director’s in a previous employment position. The subcontractor relationship was co-operative throughout the application experiment.

The contract was negotiated as a fixed cost contract with milestone payments to agreed deliverables. Because the subcontractor had undertaken similar projects in the past, they foresaw very few technical risks in this instance. The issue of intellectual property was dealt with by assigning all of the intellectual property developed during the project by the subcontractor to the First User by means of a deed of assignment. A patent application was drafted and is being actively pursued.
11. Barriers Perceived at the start of the Application Experiment

The barriers perceived by Cozart at the start of the experiment included the following:

- A total lack of knowledge in microelectronics technologies, and the capabilities and costs of adoption for these technologies. This was a fundamental barrier to the adoption and support of microelectronic technology faced by the company. The risk of facing unknown obstacles after committing to a product development with no experience on how to extricate the company from these difficulties was a real concern. Some of the company’s fears regarding the use of microelectronics were justified because some hitherto unexpected issues were revealed as the project progressed.

- A lack of knowledge in the area of electronic product management. Without understanding the precise nature of the technical developments, Cozart were unable to accurately quantify the risks and financial penalties associated with delayed deliverables. This represented a commercial risk for a small company, and presented concerns about the risks of investing in a new technology area for the company. This was compounded by the very low levels of starting knowledge in the company.

- No knowledge of how to specify functional requirements to a subcontractor. This represented a risk in receiving a product with incomplete or incorrect functionality, and subsequent costs in correcting such errors. This unpredictability in the design process was perceived as difficult to manage.

- The risk involved in related tasks was also a major consideration. For example, the company was concerned that the mechanical design of the instrument housing would cause additional problems. This was relevant as the company considered mechanical design firms to be concerned with either styling issues or functionality, but only rarely combine both satisfactorily. The risks were also amplified by the company’s opinion that it was common for these mechanical design subcontractor companies to provide time and cost estimates for the work which they cannot adhere to, and for them to stray from the initial specification somewhat.

- The complete absence of electronic manufacturing know-how provided a further barrier, in that the company did not have the knowledge to take a prototype through to full scale production. The company was aware from its own chemical product developments that problems in scaling up for volume production could cause problems, and result in unnecessary costs if not managed appropriately. The risks in this process included:
  - Scheduling purchases from electronic suppliers that had never been attempted before.
  - No understanding of how to control quality of an electronic product
  - No understanding of how to implement testing of these products.

12. Steps taken to overcome barriers and arrive at an improved product.

The company addressed some of these concerns during the preparation of the application experiment proposal. This brief activity provided the company with an ability to derive confidence in the design approach, design subcontractor and TTN support mechanisms. This provided the company with the confidence that it could overcome the remaining barriers by applying the knowledge and skill development activities that had been proposed.

The knowledge barriers were overcome by initial training by the design subcontractor in the area of product specification, and in developing an understanding of specific technical management aspects particular to electronic design. For example, regular communication between the First User and subcontractor were important in order to gauge the issues that were important in bringing a new microelectronics based product to the market. For instance, Cozart were unaccustomed to waiting up to
three months for goods to be shipped from their suppliers. This issue was discussed in sufficient time for component orders to be placed. This co-operative subcontractor relationship allowed the company’s Managing Director to develop knowledge, and to be provided with guidance from the TTN or subcontractor as issues arose.

The comfort gained from the selection of a subcontractor with a proven track record of developing products with similar technical specifications combined with the TTN’s support when required, meant that the company was able to fully discuss the concerns regarding technical and non-technical barriers which needed to be overcome. This process perceptibly diminished the risks involved. The process of developing the original FUSE proposal provided the opportunity for the costs, time scales and risks of the development approach to be quantified.

The process of identifying a subcontractor that had been through a similar design process several times before and had been involved in the mechanical design tasks reduced the fear of meeting problems in areas not related to the microcontroller prototype development.

This process also finalised the outline requirements for the product development. This brief outline document development led to the development of a fixed price subcontract with the subcontractor based on a reasonably detailed outline requirement. This submission study and subcontractor discussion removed to a large extent the risks inherent in an ill considered brief to the subcontractor, and provided time-scales that seemed reasonable to both parties. This developed company confidence in the development plan.

The recruitment of a specialist engineer with electronics experience was not originally considered as part of the prototype development phase. However, the industrialisation process and the need to provide technical support and well argued information to potential high volume customers (police forces etc.) on such issues as reliability, repeatability or accuracy of the instrument, indicated that such recruitment should be considered. This step into a new technology would not have been undertaken had not all of the previous prototype barriers have been removed, and the risks in this development removed. The recruitment of an engineer, during the industrialisation phase, provided the in-house knowledge to overcome this barrier.

13. Knowledge and experience acquired.

At the outset of the application experiment Cozart had identified several knowledge development targets, including the ability to:

1. Critically evaluate technology options and select the most appropriate for a particular application.
2. Write a detailed technical specification for a microelectronics-based system.
3. Implement software using a top-down approach in both high level languages and assembler.
4. Be sufficiently familiar with embedded system tools to debug code on target systems.
5. Understand the interfacing requirements for an imaging array linked to a micro-controller.
6. Co-ordinate the activities of subcontractors, and manage projects within time and cost targets.
7. Utilise modern pc-based pcb design tools for developing new boards.
8. Fully document the hardware and software phases of future product development cycles.
9. Identify appropriate opportunities for developing other microelectronics-based products.

These capabilities have been delivered through the application experiment. Although the company recruited an engineer, and thereby developed detailed technical know how, it was apparent that the
company’s Managing Director had developed the capability to produce a product design specification, coordinate subcontractor tasks, and identify future replication potential independently (items 2, 6 and 9). It is therefore, unlikely that Cozart will need to avail themselves of external microelectronics design subcontractors in future.

In assessing the level of knowledge and experience acquired, Cozart consider that this actually exceeded the company’s expectations. The fact that the application experiment progressed smoothly with few problems has given the company a high degree of confidence in microelectronics technology.

14. Lessons learned

Cozart have identified an unexpected level of benefits from its adoption of microelectronics, including the capability for the company to diversify and enhance its product range, the perceived additional value of semi-automated drug screening systems to its customers, and economic benefits derived from these. These benefits include the substantial increase in potential sales revenues for several existing products and the clear market lead generated by this innovation.

Based on its experiences during the application experiment Cozart offer the following advice to prospective first users of microcontroller technology:

- A full discussion of the various project phases should be conducted in conjunction with the subcontractor prior to commencing the project so as to identify and assess the potential risks in the prototype development. This discussion should discuss and plan the contingencies to be adopted should any unforeseen developmental difficulties.

- It is probably inevitable that the system specifications will be refined as the project progresses. The company’s experiences indicate that the contingency planning, together with a straightforward and non-bureaucratic approach to the project adopted by those involved in the development, prevented any significant delay.

- The development of a ‘partnership’ style of relationship with the subcontractor is recommended. Had this not been the case then it would have been necessary to ascertain estimates for the maximum development cost in the most pessimistic scenario and use this as a guideline when considering minor refinements to the specification.

- Care is necessary when communicating relevant information from the non-electronic (in this case the immuno-chemical research team) to the electronic designers of the subcontractors and vice versa. In most cases this information flowed satisfactorily, but seemingly minor changes in one area can have major consequences in the other without the parties being aware of it. One example in Cozart’s application experiment was when the chemistry of the visible marker was altered in such a way that necessitated a new illumination wavelength. The sub-contractor who was unaware of the impact of the chemistry change then ordered production quantities of LEDs emitting light of an unsuitable wavelength. This could have been avoided by better communications based on fewer assumptions.

- Multidisciplinary projects are difficult to manage especially when the various disciplines are brought together for the first time. A seesaw effect can be observed in which one discipline tries to compensate for weaknesses in the other. For example, the RapiScan software had to be far more tolerant of optical misalignments and resistant to incoming stray light because of production tolerances in the casing mouldings. This means that the importance of multi-disciplinary team working and effective communications between experts in different fields is essential.

- The subcontractor relationship should be developed so that a valuable alliance can be forged. This not only offers the subcontractor the potential for undertaking additional when new requirements arise in
the future, but also the loyalty, co-operation and mutual understanding thereby established will ensure that the project will be able to progress more efficiently.

- It is important to consider other services and experiences that the subcontractors have besides their core electronic design skills. In this particular application experiment, the generation of a mechanical housing specification and the selection of a subcontractor to design an enclosure for the RapiScan instrument was assisted by the subcontractor. The company therefore learned what to avoid when subcontracting mechanical design, and gained valuable experience in the management of this associated task.

15. Resulting product, its industrialisation and internal replication.

This application experiment has satisfied all of its initial goals. It has been particularly successful in that it has been completed on budget and within forecast time-scales. There are several possible improvements that can be implemented in the future, such as improving the band intensities and accelerating the chromatographic development time, but the system as a whole now is functioning satisfactorily. The proposed enhancements are not essential to its basic functioning.

A pre-launch seminar was held with potential customers and distributors of the RapiScan in attendance early in 1999. The reaction of the participants was extremely favourable. Several international police forces are eager to commence drug driver screening trials. There is every chance that the system will be widely adopted in such an environment in the coming years. Time is needed for customers to become familiar with the system and gain confidence in the rapid drug screening system, which is the first of its kind world-wide.

A number of instruments and test kits have already been supplied to end customers. The remaining stages of industrialisation required are:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Scheduled for</th>
<th>Cost /kEUR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of initial customer comments and the inclusion of modifications as a result of the feedback gained from these sources.</td>
<td>Months 1-4</td>
<td>7.0</td>
</tr>
<tr>
<td>Compliance testing for EMC and other EC Directives, and minor design amendments possibly required thereafter.</td>
<td>Months 4-5</td>
<td>4.0</td>
</tr>
<tr>
<td>Automation improvements for the production test equipment to improve the product’s reliability and quality whilst achieving further cost minimisation.</td>
<td>Months 2-5</td>
<td>6.5</td>
</tr>
<tr>
<td>Selection and negotiations of production subcontracts for volume manufacture.</td>
<td>Months 1-6</td>
<td>2.5</td>
</tr>
</tbody>
</table>

The total costs of this industrialisation process are estimated at 20 KECU. Further development will be undertaken thereafter to reduce the volume production manufacturing costs of the instruments, particularly regarding the replacement of the externally sourced display module. These savings will be implemented once full production is underway.

The internal replication potential lies in the development of tests for new drugs. The RapiScan product will be modified to accommodate them. The company is also planning to apply the results of this project to other areas of immuno-diagnostics. Several potential on site testing areas can be developed based on
the use of the acquired technology, including detection of therapeutic drugs, tumour markers, or markers for infectious diseases.

**16. Economic impact and improvement in competitive position**

The markets targeted to achieve the projected sales figures are:

- Police Forces
- Prisons
- Clinics and Surgeries.

Initial sales will be targeted at drug clinics and doctors surgeries in the first year of launch. Sales to the UK prison service will be achieved starting in 2000 after trial evaluations are completed.

The major improvement in the company’s sales revenue arises from the fact that sales of drugs testing cartridges for use in the equipment will grow directly in line with the sales growth for the RapiScan product. The improvement in competitive position of the company as a result of the RapiScan product introduction illustrated in Figure 6.

![Figure 6: Sales Increase Projections for Existing and Improved Technology](image)

The figures in Figure 6 demonstrate a sales growth of 29% in the first year of sales (end 1999), and subsequent substantial sales revenue growths thereafter.

A patent application is underway which, one year after filing, has met no objections. The application is now being extended by means of the Patent Co-operation Treaty for near world-wide coverage. Should the application be successful, then the sales projections illustrated here may be somewhat pessimistic. This will mean that the product has at least a 10 year product life.

The additional sales (compared to the existing product) are projected to produce a payback period of 11.2 months. This calculation is based on the prototype development costs supported under FUSE funding of 46 kEUR.

The new Rapiscan product is expected to have a product life of 10 years. Recognising the projected increasing rate of sales growth in following years, Cozart projects a return on investment over this 10 year product life of approximately 1200%.
It is estimated that the market share for Rapiscan will increase over the next 5 years to 20% in the UK and 15% in the USA. As other regions around the world take up the concept of random drug testing, Cozart will also start to develop market segments in these areas. Cozart have already developed a network of distributors in selected countries, and this presence is set to increase in the next few years. Up to date information on the sales territories can be found on Cozart’s web site identified in section 1.

These economic benefits ignore the impact of the positive company image of Cozart generated by the RapiScan drug screening system which will further boost the sale of Cozart’s existing products.

17. Best Practice and Target Audience.

The application experiment was conducted to schedule and within budget, and offers best practice guidance in the areas of subcontractor relationships, development programme planning, technology selection and development methodologies applied. The lessons learned by the company will also be of value to other potential first users of microcontroller technology.

The audience have been selected because of the synergy with Cozart’s industrial sector and include the Managing Directors and Technical Directors of small companies in the following market sectors.

- The chemical and pharmaceutical industry, especially those sectors operating on advanced chemical detection methods for diseases such as prostrate cancer etc.
- Laboratory based chemical analysis activities that could consider conducting on site analysis.
- Environmental monitoring agencies requiring on site verification technologies.

The target industrial sectors include companies in the following industrial sectors:

- Chemical Product Manufacture: Prodcem Code: 24
- Food and Beverages: Prodcem Code: 15
- Medical Instrumentation: Prodcem Codes: 3310, 3320
- Optical Instruments and Photographic Equipment: Prodcem Codes: 3340