AE Abstract

Company Name, Business and Culture

Tramex Ltd is located at Shankhill Business Centre, Shankhill, Co. Dublin, Ireland. employing seven people, three with electronics experience, and design and manufacture a range of instruments for measurement/detection of moisture in wood, fibre glass, concrete, plaster, roofing and other building materials. The company utilises sub contractors for most of it's electronic sub assembly/mechanical detail fabrication and deploys it's staff on design/development, coordination of manufacture, final assembly/test, marketing, and overall management.

Objectives and Rationale for the AE

The objective of the AE was to improve the company's competitive position by designing a hand held, battery powered, wood moisture meter/recorder embodying a microcontroller system, a non-volatile memory and a dot matrix liquid crystal display (LCD). The new instrument, which is operated via a 3 x 4 keypad, digitally processes the inputs from an analogue capacitive moisture transducer, digital temperature sensor and stored materials library to provide corrected moisture values which are displayed on an LCD and can be recorded in non-volatile memory. Stored readings and their identification/date/time stamps can be viewed on the LCD or downloaded via an RS232 link to a PC.

Existing Product, its Technology, Functions and Application Areas

Existing wood moisture instruments, manufactured by the company, use two co-planar electrodes (mounted on the base of the instrument) which are lightly pressed onto the wood/material sample. An oscillator creates an alternating electric field between the electrodes causing an AC current flow through the wood sample. This current is amplified, rectified and presented as a wood moisture percentage reading on a moving coil meter. Simple analogue electronics are employed in all current instrument designs, i.e., operational amplifiers, transistors, CMOS logic parts, etc.

The New Adopted Technology and Product Improvement (Functions and application)

Current wood moisture meters are calibrated for a wood specific gravity of 0.5 at 20º C. Readings can only be recorded by writing into a logbook. Moisture percentage is dependent on the specific gravity of the wood species and its temperature (there are several hundred wood species with a wide range of specific gravities). Thus it necessary to provide printed charts listing specific gravity/temperature corrections.

The new product removes the need to refer to printed tables/charts to manually correct readings for temperature and material specific gravity, and write the results into a logbook. The ability to download stored readings to a PC permits more detailed analysis and presentation of moisture data than previously possible.

Cost and Duration of AE, including Start and End Dates

The budget was 50 KECU and the actual duration 14 months (originally planned for 10 months). The AE started 7 April 1997 and ended 9 June 1998.

Benefits of AE including Econmical Benefits and Increment in Capability. ROI and Payback Period.

The advanced features and operational benefits of the new product combined with the flexibility provided by the new technology to address new applications by firmware and PC software alterations, will enable Tramex to establish a lead position for this class of instruments and thus increase the company's market share.

In addition to the 50 KECU FUSE funding, Tramex are investing a further 68 KECU to cover the industrialisation costs of the injection moulded instrument case, PC software and Intellectual Property Rights or IPR. Tramex are generating a patent to protect our IPR.The payback period for the net 118 KECU investment is estimated to be 2.2 years. It is estimated that the new product will contribute an ROI (Return Of Investment) of 250% over a period of 5 years. There will also be an ROI from a number of future planned projects which have been enabled by the new technology.

Lessons Learned (Best Practice)

A major lesson learned was the need to take expert advice and the importance of a feasibility study to break down the barriers to give confidence to Tramex that introducing a new technology was possible. The above highlighted how to choose and source microcontroller information, technical support (largely via the Internet). During the development the value of extensive testing the firmware with hardware ("what if" scenarios) was found to be very important. The preparation of a detailed project plan allowed Tramex to estimate more accurately the project timescale and hence development costs. It also allowed project progress to be monitored accurately. The unique and time consuming experience of finding a manufacturers design error in a real time clock IC highlighted that even small companies should not be frightened of questioning data sheets and the operation of ICs of major manufactures. Big companies can be in error.

Wood Moisture Meter/Recorder

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1. Company Name and Address

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2. Company Size

Tramex Ltd. is a small independent company employing seven people, three with analogue electronics experience. The company has appreciable experience in managing development projects from concept to final finished marketable product, it has limited experience in the design of analogue circuits, simple CMOS discrete logic circuits and PCBs. Tramex also has some experience of the benefits of using simple analogue simulation. It has obtained the CE mark for most of its product range, has an appreciation of the influence of the EMC Directive on circuit and overall instrument design.

The staff allocated to the AE project were :-

Mr Alan Rynhart	Project Manager
Mr Jim McIlroy	Analogue circuit/PCB designer
Mr John Ashworth	Analogue electronics engineer

3. Company business description

Tramex design and manufacture a range of instruments for measurement/detection of moisture in wood, glass fibre, concrete, plaster, roofing and other materials.

The primary activities carried out directly by company staff include :- design/development, coordination of manufacture, final assembly/test, marketing, and overall management.

The design includes the development of the discrete electronics and the layout of the PC Boards for the analogue meters. The company also designs the cases or enclosures for the various types of meters but the manufacture of these is sub contracted. Most of the electronic sub assembly, PCB manufacture, and mechanical detail fabrication operations are also sub contracted.

The company commenced operations in 1982 and, during the past 14 years, has conceived a wide variety of moisture instruments. There are over 10 instrument types in the current range. All of the instruments are battery powered and, with one exception, all are hand held units. The exception is an instrument built into a 4 wheeled trolley which is designed for moisture detection on large flat roof areas.

A world wide market has been established for these products via various overseas distributors and agencies. To further extend these markets, Tramex often exhibit at International Trade Fairs in Europe and U.S.A..

The customers of Tramex products are generally people connected with the building trades such as surveyors etc. sales are therefore on an individual basis. However, such instruments for these professionals are becoming a necessity and ease of use is an important factor.

The market is governed by two major factors, price and ease of use. The new product addresses these markets.

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

The overall size of the market for moisture meters is estimated to be in the region of 15 million ECU per annum. At present, Tramex have about 12% of this market.

Currently, there are seven major competitors worldwide each has approximately equal market share. With the new development Tramex estimate an improvement in their market share. The competitors use similar technology to the present Tramex meters, the majority of them are located in the USA with one in Germany and one in the UK. Our competitor's instruments are very similar to Tramex's units in terms of features and price, although Tramex have the edge on non intrusive moisture instruments which allows them to be used on a greater range of materials, glass re-enforced plastic for example.

Some of these companies also manufacture related products such as wood drying kilns and have recently developed non-invasive moisture meters in competition to Tramex. To-date, Tramex have maintained a competitive advantage over these companies by their ability to provide, at relatively low cost, innovative and versatile moisture meters for a range of industries. We are able to quickly respond to provide an instrument as soon as a need has been identified although this may involve a complete redesign.

Monitoring and control of moisture is vitally important to a wide range of industries and the market is expanding. In many instances, lengthy and expensive measurement techniques involving chemical or gravimetric assessment of material samples are still employed. The replacement of these methods with suitable non-invasive instruments offers greater accuracy and large operating cost benefits to such customers.

Servicing these new markets often requires parametric modification of instruments to suit different materials, alter scaling, etc. With the current instruments, this can involve a complete redesign and thus, effectively, the setting up of a new production line.

In addition to the other improved features of the proposed product, the ability to carry out parametric modifications, alter user menus, libraries, etc., via firmware/software changes only, will greatly improve the competitive advantage by:-

- ♦ Providing a fast response to new market requirements.
- ♦ Reducing the number of instrument hardware types thereby enabling production cost benefits.

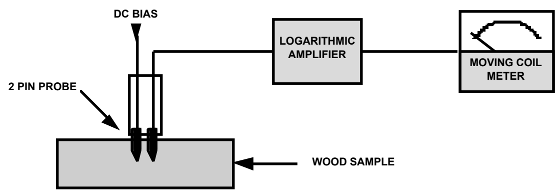
The data storage and computer interface facilities of the proposed product are new to the current market and provide a futher substantial enhancement to the competitive position. The Tramex strategic plan envisages future development of these features to suit other markets.

Tramex estimate that the steadily growing market for Tramex analogue moisture meters would likely peak around 1998/99 and then decline due to improvements and innovation by the competitors. Hence the strong motivation to introduce, with the help of FUSE, an advanced range of instruments based on microcontroller technology which will provide features offering the end user a major improvement in performance and operational efficiency.

5. Product to be improved and its industrial sectors

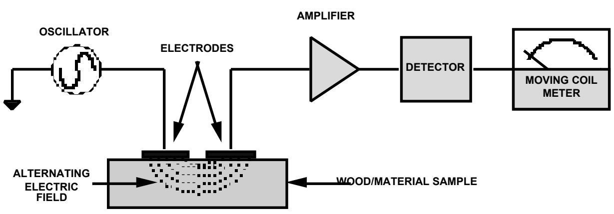
The Tramex range of hand held, battery powered instruments for the measurement of moisture in wood and other materials fall into two types, viz :- invasive and non-invasive. The application of the meters is extensive but the main industrial sectors are in the timber processing and building construction/inspection industries.

Invasive instruments (see schematic) utilise a probe with two sharp pins which are driven into the wood sample.
The resistance between the pins is, approximately, exponentially proportional to the wood moisture percentage. In a typical instrument, a DC bias voltage is applied to one pin and the resultant current from the other pin is monitored by a logarithmic amplifier to obtain a substantially linear output for display on a moving coil meter as a wood moisture % reading. The instruments can read wood moisture in the range of 7 to 40%.



BASIC SCHEMATIC OFANALOGUE (INVASIVE) WOOD MOISTURE METER

Non-invasive instruments (see schematic below) do not damage the wood or material being measured. They use two co-planar electrodes (mounted on the base of the instrument) which are lightly pressed onto the wood sample. The instrument employs a capacitive technique to penetrate the wood/material and measure the moisture content. A low frequency oscillator creates an alternating electric field between the electrodes causing an AC current flow through the wood/material sample. This current is amplified, rectified and presented as a moisture percentage reading on a moving coil meter. To compensate for the exponential relationship between the input current and percentage moisture, the amplifier, detector and meter scale are arranged to be non-linear, and switched ranges are often employed.



BASIC SCHEMATIC OFANALOGUE (NON-INVASIVE) WOOD MOISTURE METER

Simple analogue electronics are employed in both types of instrument, i.e., operational amplifiers, transistors, 4000 series CMOS logic parts, etc.
Whilst the current instruments are widely used, they have a number of shortcomings which are considered to inhibit market growth viz :-

- Readings can only be recorded by manual entry into a log book.
- The instruments are calibrated for a wood specific gravity of 0.5 (Douglas Fir) and a temperature of 20º C. Thus, for other wood species and temperatures, it is necessary for the operator to correct readings by referring to tables/charts.
- Measurement accuracy is limited.

At the time of writing the original AE submission, it was thought that the new instrument, embodying the microcontroller technology, should be a wood only unit including both invasive and non-invasive sensors. However, following a further market assessment at the commencement of the project, it was concluded that it would be better to base the new model on the best selling Tramex "Moisture Encounter" instrument (see photo below). The "Moisture Encounter" is a non-invasive instrument with 3 switched ranges which allow it to be used for moisture measurement on wood, drywall/roofing and plaster/brick.

It was considered that the market for an advanced design of multiple application instrument was much larger than that available to a wood only instrument and, in addition, the major competitors, who had hitherto largely concentrated on wood only instruments, were beginning to offer analogue instruments with multiple application capabilities. Thus, it was decided to alter the AE to add moisture detection of wall and roofing materials and target all the improvements at a multiple application non-invasive instrument.

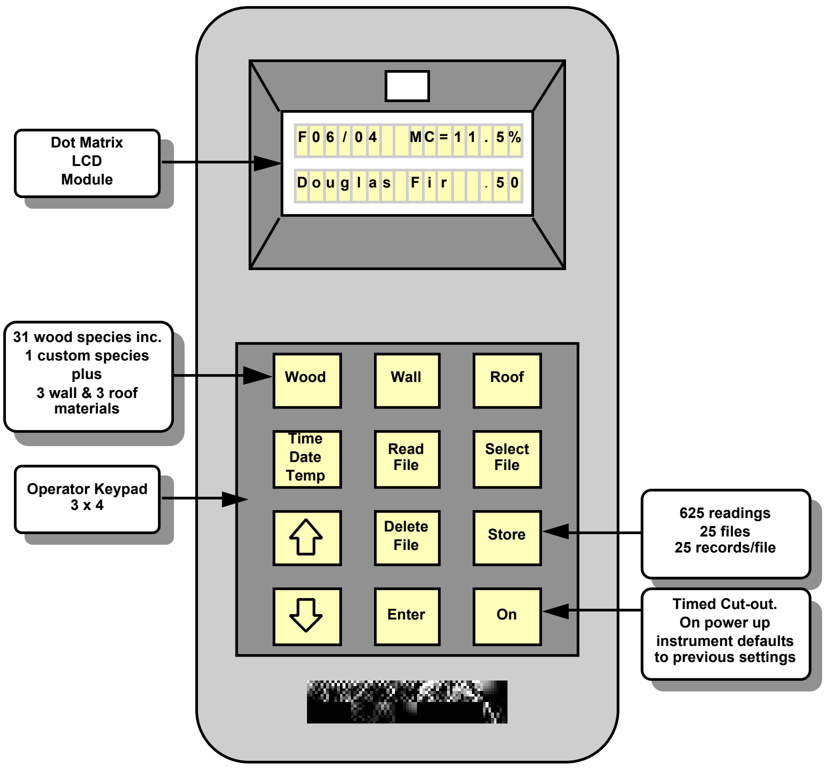
In addressing the shortcomings of the existing product, the AE will result in a multiple application non-invasive instrument, uniquely superior to any currently available from other manufacturers, and, as envisaged by the Tramex strategic plan, will form the processing core for redesign of other Tramex moisture meters and the basis for new designs. Tramex analysis of the market confirm that the ability to store and download the measurements at a later time to a PC thus eliminating the use of paper charts and records will enable them to gain a distinct advantage over the competition and provide sales growth.
In this context, knowledge transfer is essential to Tramex plans.

6. Description of the technical product improvements

The main features of the new, microcontroller based, product are summarised below :-

- Accurate measurement of the percentage moisture in wood (5 to 30%) with automatic correction for wood species specific gravity (0.3 to 0.9) and temperature.
- Moisture detection/measurement for a number of wall and roofing materials.
- Non-invasive capacitive moisture sensor.
- PIC microcontroller with in built A/D converter, RS232 and I^2C bus facilities.
- Dot matrix liquid crystal display (2 line 16 character).
- Non-volatile memory for libraries and storage of readings.
- Library of 31 wood species/specific gravities including one user adjustable scale plus 3 wall and 3 roofing materials (PC software has a base library of over 300 species).
- Storage of 625 readings in 25 files (25 records per file).
- Real time clock and temperature display and storage.
- Ability to recall and view stored readings.
- Ability to delete selected stored files
- RS232 Computer interface to down load stored readings and/or edit wood species/materials libraries

The new instrument, known as the "Survey Moisture Encounter" (SME), is similar in size to the existing "Moisture Encounter" (ME). It will be housed in a custom designed injection moulded plastic case. A basic sketch of the instrument facia is shown below.



A power supply slide switch and RS232 connector socket are inset at the top end of the case. The unit is powered by a 9 volt PP3 lithium manganese primary battery. A small PCB mounted 3 volt lithium coin cell provides a back up supply to the real time clock IC. Conductive rubber moisture sensor electrodes are mounted on the bottom face of the case.

Wood Moisture Meter/Recorder

The keyboard controls the operation of the device. Different gain settings as well as computation algorithm type for different materials can be entered. The libraries can also be selected using the keyboard and the user is guided through programme and selection procedures by messages displayed on the LCD display. Measurements can also be stored on Non Volatile Memory.
Some typical stored records, as downloaded to a PC, are shown below.

File No.	Record No.	Day	Month	Year	Time	ºC	Species	S.G.	% Moisture
1	1	24	Nov	97	18:39	22	Set User SG	.56	09.0
1	2	24	Nov	97	18:42	23	Ash Mountain	.68	07.0
1	3	24	Nov	97	18:42	23	Beech Europe	.70	06.6

625 records, organised as 25 files with 25 records per file, can be stored in the non volatile memory. The final firmware program comprised over 4222 lines of code (105 A4 pages when printed out) and occupied over 85% of the PIC16C74A 4096 byte program memory.
Stored records can be viewed on the LCD by pressing the Read File key and scrolling. Redundant files can be cleared with the Delete File key. The RS232 interface socket enables the instrument to be connected to the serial port of a PC. A "Survey Moisture Encounter" (SME) PC software package (not funded by FUSE) is being developed which will include the following facilities :-

- Ability to download and display all information held in the SME.
- Editable database library of several hundred wood species/materials.
- Double list database facility to display PC species library alongside SME library with "add/remove" commands to allow alteration of SME library.
- Connectivity with standard spreadsheet applications such as Excel.

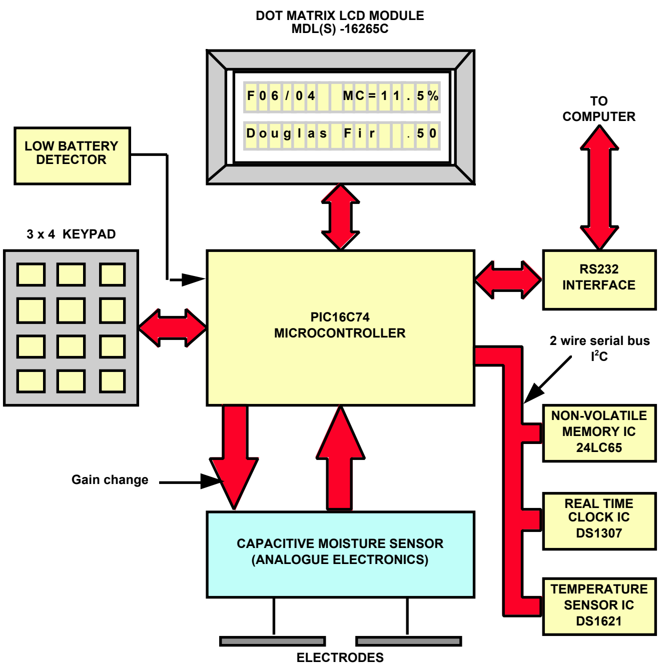
A functional block diagram of the "Survey Moisture Encounter" is shown below.

The core component of the system is an 8 bit microcontroller, the PIC16C74, which has a 4096 byte program memory and includes an 8 bit analogue to digital converter, 2 wire serial communications (I^2C bus) module, USART (RS232) module, and 3 timer modules.

With the exception of the keypad and LCD module, all of the components are mounted on one double sided, plated thru-hole printed circuit board.

PCB components total is 76, which includes 8 transistors and 12 ICs.

Manufacturing cost is estimated to be 25% more than the existing product, well within the target of 40%.
However, this is more than offset by the quantum leap in the performance and facilities offered by the new instrument which are unrivalled by any of the competitors products.



Functional Block Diagram of "SURVEY MOISTURE ENCOUNTER"

The photographs below show (1) a prototype model of the new SME instrument, (2) the SME printed circuit board and (3) the current Moisture Encounter with associated SG/temperature correction charts alongside the SME prototype which, as part of its many advanced features, obviates the need for correction tables/charts.

7. Choices and rationale for the selected technologies, tools and methodologies

The choice of fabrication technology was influenced by four major factors, viz :-

1. Tramex future development plans

Tramex future development plans envisaged the redesign of a number of instruments to provide improved accuracy, automatic SG/temperature correction, enhanced user operability, data storage and computer interface facilities. These plans required a low cost digital design technology suitable for low volume production (production rates for the "Moisture Encounter" average 400 per month but some of the specialised instruments are less than 10 per month) which, following the Wood Moisture Meter/Recorder pilot scheme, could be easily applied, with minimal external assistance, to the design of other future moisture instruments.

2. Economic considerations

Although initial assessment indicated that a new instrument, embodying the performance improvements and additional features outlined above, could obtain a higher selling price, it was evident that the manufacturing cost would increase. Following consideration of the market factors, distributor's margins and Tramex margins, it was adjudged that the maximum viable manufacturing cost increase was 40%.

It was also necessary to consider and make provision for the probable costs, additional to the FUSE funding, that would be required for PC software development, industralisation, IPR and marketing.

Thus, in determining the most suitable fabrication technology, it was important to minimise the subsequent manufacturing and industrialisation costs.

3. The functional requirements of the proposed instrument, viz :-

Analogue to digital conversion
Keyboard control
Mathematical computation
Ability to drive dot matrix LCD
Non-volatile memory
Real time clock
RS232 serial data interface
Low current consumption (below 80mW)
Ability to package complete instrument in small hand held case

Whilst it was possible to realise a number of the these functions by the use of separate standard integrated circuits, e.g., A/D conversion, EEPROM, real time clock and RS232 interface, it was apparent that a central controller was required to interpret keyboard commands, direct operations, carry out mathematical computations, drive LCD, etc. To reduce size, wiring interconnect and current consumption, it was desirable to integrate as many functions as possible onto a single integrated circuit.

4. Feasibility Study

The feasibility study carried out by the UK Bolton Institute.

A number of technologies were considered viz :- Complex Programmable Logic Devices (CPLDs), Field Programmable Gate Arrays (FPGAs), Application Specific Integrated Circuits (ASICs) and Microcontrollers.

CPLDs and FPGAs

Both technologies entail design at the discrete gate level and, even allowing the use of manufacturers macro blocks, functional integration of the Wood Moisture Meter/Recorder would have been limited. An external A/D converter would have been required and the mathematical computation functions would not have been easily implemented. The devices appeared more suitable for high speed logic functions than the low speed, low power consumption operation of the moisture meter. It was concluded that design by these routes would have required a high degree of skill and expenditure and they did not appear to be technologies that Tramex would readily transfer to future products with minimal assistance.

ASICs

Theoretically, it would appear possible to achieve a fully integrated design by use of an ASIC. However, this would have required a very high expenditure with a specialist design house and the technology transfer to Tramex would have been negligible. The expected volume as stated earlier in this section was estimated to be 5000 units per year so the very high ASIC development costs would have to be recovered over this small volume. This would result in an uneconomical selling price, pricing Tramex instruments higher than competitor's products thus damaging market share. More importantly, since the long term plan is also to produce a range of advanced instruments the use of an ASIC would continue to entail high costs and long design cycles for replication products.

Microcontrollers

A microcontroller system was considered the most suitable technology for the Wood Moisture Meter/Recorder and offered the most flexible approach for the Tramex future development plans. Key points influencing this choice were :-

- There are a large number of low cost microcontrollers commercially available and many include A/D converters, multiplexers, EEPROM and serial data I/O.
- There is a large range of peripheral integrated circuits available which make it relatively easy to extend system capability, e.g., increase memory size.
- Due to the low cost of these mass produced devices, microcontroller systems are economical for low volume production runs.
- Development tools, design assistance and training are readily available at moderate cost.
- In terms of technology transfer, the microcontroller hardware design was straightforward and, with suitable training, the ability for Tramex to design firmware to suit other instruments was clearly attainable.

Following preliminary study of microcontroller manufacturers literature/technical articles, coupled with comparison of device costs, ease of code writing, development tools costs and technical support available, Tramex were very attracted to the Arizona Microchip range of PIC 8 bit microcontrollers but were uncertain as to their ability to fulfil all the project requirements and to choose which type of microcontroller would be most suitable. With the aid of the TTN, these elements of uncertainty were resolved by arranging for the Bolton Institute to conduct a feasibility study specific to the project.
All aspects of the project specification were considered including accuracy and cost. The study concluded that a PIC design was completely feasible and recommended the use of a PIC16C74 microcontroller in conjunction with 2 wire serial non volatile (SEEPROM) memory chip/s (for data/library storage) and real time clock (RTC) chip. PIC16C74 features regarded as particularly suitable to the project were :-

- 4096 byte program memory which was roughly estimated as having sufficient capacity to contain the instrument operational code.
- 33 I/O lines , more than adequate for interfacing to keypad and dot matrix LCD.
- 8 bit, 8 channel, analogue to digital converter with sufficient accuracy to handle the analogue moisture sensor and temperature sensor inputs. [N.B. Subsequently a serial digital temperature sensor was employed.]
- 2 wire serial communications (I^2C bus) module enabling read/write to SEEPROM and RTC.
- USART (RS232) module to enable serial communication with a PC.

Most importantly, the feasibility study included a guideline cost estimate for the complete system which showed that the manufacturing cost could be contained within the Tramex viable limit, i.e. existing product plus 40%.

Design Methodology

A structured design approach based on simultaneous/concurrent engineering techniques was employed. It was considered that this methodology would give the minimum timescale to obtain a ***right first time*** complete design by ensuring that all aspects of the total product design were considered in parallel. It was key to the Tramex strategic plan that the new instrument entered the market shortly after completion of the Application Experiment. Thus it was important that, during AE development, full cognisance was given to all factors governing the design of the final product, e.g., case size, production engineering, manufacturability, etc.

These factors determined aspects such as the type of LCD display used, the keypad employed, the available space for the printed circuit board, battery type, etc., to provide a hand held instrument acceptable to the user whilst ensuring that the eventual product and its planned derivatives represented not only the best engineering solution but were also commercially viable.

This approach required that all design tasks were documented and, in particular, that the interactions between tasks were constantly updated and subject to regular design reviews. In practice, the monthly report and meetings with the TTN proved to be a very effective focus for these activities.

Extensive use was made of PC facilities to aid all tasks, e.g., project management, configuration control, digital/analogue circuit design and simulation, schematic entry, PCB design, software design and emulation, etc.

The design, particularly microcontroller firmware, was divided into a number of modules to aid portability to future instruments.

Analogue circuits were designed/developed with the aid of a PC Spice simulation package. This work proceeded in parallel with the firmware development and each module of hardware was breadboarded and tested with the firmware. Firmware development was considerably aided by the use of an ICEPIC emulator. Formal foundation training on PIC microcontroller firmware design was provided by the University of Paisley.

Considerable use was made of Arizona Microchip free design support services, PIC text books and various Internet sources of PIC information. On-the-job training was active throughout the project.

Although the knowledge increment was quite high, the risk factor for PIC microcontroller technology was low using this approach.

Test Methods

During development, tests were performed on the various modules confirming the robustness of the design, e.g., supply variations, temperature, "what if" conditions such as incorrect keyboard operation, etc.

Wood samples of known moisture content (assessed by gravimetric methods) were used to calibrate the prototype units. These settings were cross checked with calibrated analogue instruments.

The prototype units were also satisfactorily tested for EMC compliance at the Forbairt National Electronics Test Centre.

A manual production test flow, based on the use of calibrated dielectric/ground plane plates to emulate different moisture values, was developed. This technique is already employed for other Tramex instruments. Given the relatively low manufacturing rate, manual test methods were considered to be the most economical method.

8. Expertise and experience in microelectronics of the company and the staff allocated to the project

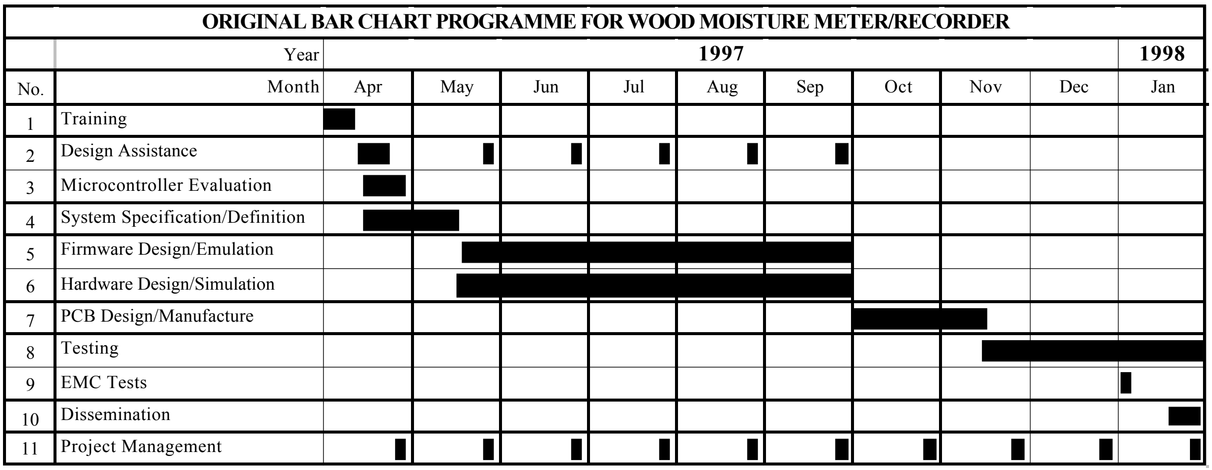
Prior to the AE, Tramex had no expertise or experience in microelectronics. The two engineering personnel allocated to the project, Jim McIlroy and John Ashworth, had electronics design knowledge and experience, mainly in the areas of analogue circuit design, analogue simulation, simple CMOS discrete logic circuits, EMC and printed circuit board design. Another member of staff, the final assembly/test technician, Darren Walsh, had some electronics knowledge but was committed to existing instrument production.

To conduct the AE and the Tramex future development plans it was apparent that knowledge and technical skill in the design of microcontroller systems, particularly firmware design, had to be acquired.

Having successfully brought to market several new instruments since commencing business in 1982, the company had acquired appreciable experience in handling development projects and thus did not perceive any skills difficulty with AE project management.

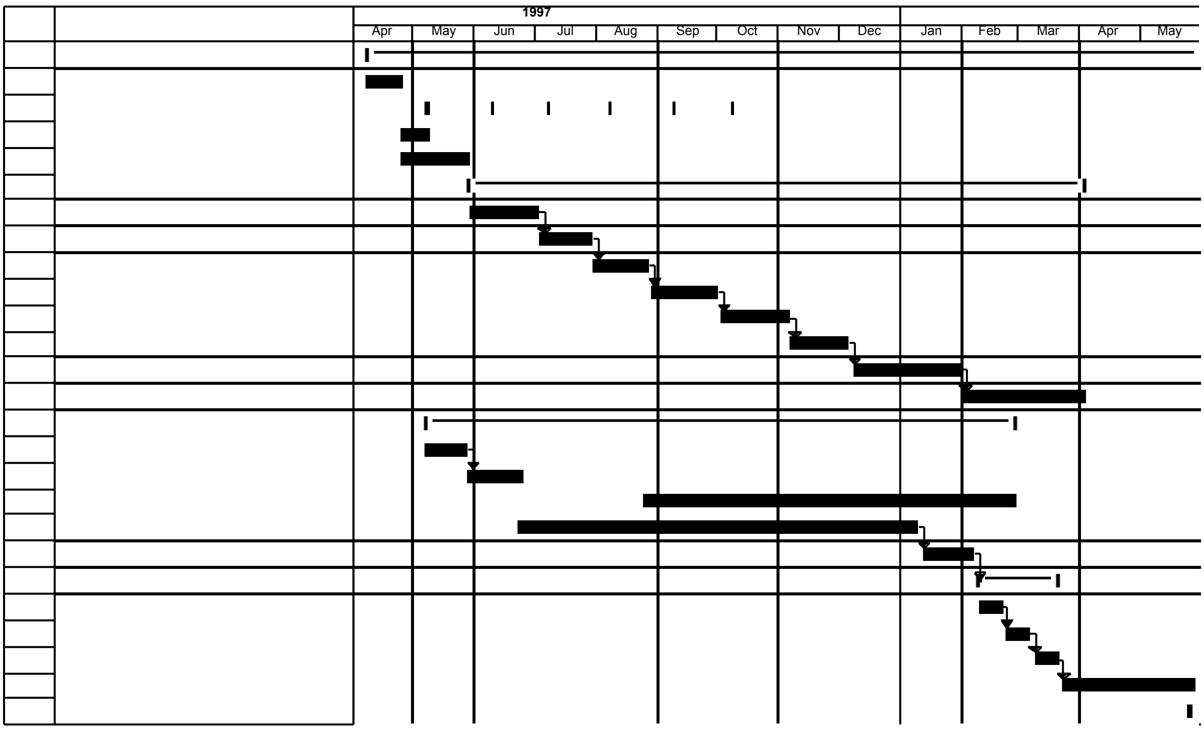
9. Workplan and rationale

The original bar chart workplan is shown below.



Although the AE development closely followed the bar chart pattern and a consistently steady level of technical progress was maintained, the timescale had to be extended from 10 to 14 months, due largely to firmware design problems.

The actual project Gantt chart, which gives a more detailed breakdown of the activities carried out during the 14 month timescale, is shown below.



Notes on the individual tasks are given below.

<u>Task 1: Training.</u>

The original training plan was based on three 2-3 day courses at the University of Paisley. However, after attending the first 2 day introductory course on PIC microcontroller technology at Paisley, it became apparent that various on-the job training tactics were proving very successful and could be more easily timed and applied to the meet the specific needs of the project. These tactics included :-

- Study and practical experimentation utilising the considerable amount of free information and assistance available from Arizona Microchip in the form of PIC data books, project application notes, sample code, development tools software, technical support services, Internet web site, etc.
- Attendance at two local 1 day Arizona Microchip PIC seminars.
- Use of the many Internet sources of PIC information.
- Use of PIC text books and a PIC project training breadboard.

The sample code modules proved particularly useful since they included example routines directly pertinent to the project, e.g., keyboard scanning, LCD, I^2C bus, RS232 and mathematical functions.

Tramex found the on-the-job training methods to be very effective in delivering a high level of technology transfer and establishing a sound foundation for future PIC projects.

Task 2: Design Assistance.

Whilst the original plan allowed for 15 days design assistance from the University of Paisley, the knowledge derived from on-the-job training regarding the quality of free design support services available from Arizona Microchip and their local distributor rapidly led to the use of this method for obtaining design assistance. In addition to an Microchip Email technical query service there was also access to a PIC design expert (author of one of the PIC textbooks) employed by the local Microchip distributor.
As stated in Task 2 Microchip has a very good web site with a bulletin board containing many examples of coding. These not only were a good training tool but also excellent for design assistance since the code was able to be cut and pasted into the Tramex code and used directly with small changes relevant to the Tramex application.

Task 3: Microcontroller Evaluation.

Although the start was delayed by 2 weeks, due to a later than expected date for the Paisley training course, this task was satisfactorily completed within the planned duration.

Task 4: System Specification/Definition.

As with Task 3, the start of this task was also delayed. Otherwise, the activities, which included drafting of a specification for the instrument, establishing the initial hardware configuration and planning the project in detail using a Gantt chart, were completed within the planned duration. This task was completed with the help and assistance of the TTN who emphasised the need to consider all aspects of the project including “Design for Test”, Design for Manufacture” and to consider the hardware and soft ware partitioning.

Task 5: Firmware Design/Emulation.

As the core of the new technology, firmware design was undoubtedly the most significant task of the entire project. It presented many difficulties, it also provided considerable stimulus and sense of achievement as each of the problems was solved and the firmware operating capability increased to meet the end objective. Tramex used some design assistance provided by the TTN during this phase, this comprised reviewing the schematics and coding to enable advice to be given to enable the most efficient hardware and software design. The design was also reviewed during the monthly monitoring of the project.
Due to various design problems, associated with the learning of the new technology and firmware coding problems the task extended to 40 calendar weeks. The resolving of the problem associated with the real time clock that caused intermittent data corruption when trying to read library data from the serial EEPROM via the I^2C serial bus also contributed to the delay. This was completely unforeseen by all parties and required considerable discussion with Dallas Semiconductor to resolve. They finally admitted to a design fault in their chip and released a corrected version of the chip. Interim, to allow development to continue, additional code routines had to be added to ensure that the DS1307 did not intermittently output onto the I^2C serial bus.
The delay associated with the firmware could have been shortened with more direct assistance but then the knowledge transfer would not have been as great thus jeopardising future replication projects that Tramex wished to pursue. In discussions with the TTN it was decided that Tramex should continue to solve the problems themselves with design assistance.

With the exception of the unique Dallas real time clock problem, it is considered that many of the problems were associated with the large size of the firmware program and the time taken for a First User to assimilate and acquire experience of the new technology. Firmware development was considerably aided by the use of an ICEPIC In-Circuit-Emulator. All of the firmware design was carried out by Tramex.

Task 6: Hardware Design/Simulation.

This task, which included breadboard design/construction, prototype package design, circuit design and simulation and overall circuit integration, was interactive with firmware design and, in consequence, was also extended in calendar timescale. Care should be taken in scheduling tasks, and, in particular, it has been found that software tasks are often underestimated. Analogue circuit design was greatly assisted by the use of a Spice simulation PC software package. All of the work was carried out by Tramex and the task was completed within the original budget.

Task 7: PCB Design/Manufacture.

PCB design was commenced immediately after the completion of the circuit design/simulation sub task. Although RS232 firmware and prototype package design activities continued in parallel, care had been taken in planning the revised Gantt chart programme to ensure that there was minimal risk of this work affecting PCB design. A standard case and keypad were used for initial testing, however, the prototype PCB electronics area was designed to suit the final injection moulded case. Apart from the manufacture of the bare PCBs, which was done by a local PCB manufacturer, the entire task was executed by Tramex within the original budget.

Task 8: Testing.

1. Once the hardware and software was complete a PCB was made. This was extensively tested. Several problems were revealed while testing this board, some of a hardware nature which included the drive capability of a ceramic resonator oscillator. The solution was to use a separate oscillator, for the PIC and moisture sensor transmitter. The PIC also had reset problems caused by loading variations on the supply. The PIC was changed to the newer version PIC16C74A which corrected the problems.
   Because of the above problems a Revision 'B' PCB was made.
2. Extensive testing revealed some firmware related problems :- these were all investigated and all the problems were fixed by small changes to the coding.

Testing of the 'B' model prototypes, which embodied all of the above changes, was very satisfactory. The tests also included successful interfacing with a basic SME PC software package.

Towards the end of the testing activity, Tramex were able to obtain a special one-off model of the production case which had been manufactured from 3D CAD drawings using Stereo Lithography Apparatus (SLA) and a prototype rubber keypad. The SLA case was assembled with a 'B' model PCB and a keypad PCB designed by Tramex. This pre-production exercise confirmed mechanical compatability of all parts, e.g., battery, keypad, LCD module, ribbon cable interconnects, main PCB, etc., and overall tests on the unit provided satisfactory results.

Task 9: EMC Tests.

Two prototype instruments (interim Bopla case standard) were subjected to EMC tests at the Forbairt EMC Test Centre on Tuesday 26 May Both instruments satisfactorily passed all tests. This task, which involved Forbairt as a subcontractor, was completed within the original budget.

Task 10: Dissemination.

Three dissemination notes were produced as part of this task. The introduction of the Demonstrator Document requirement after the AE had commenced resulted in a labour budget overrun of 4.5 days.

Task 11: Project Management.

This activity was completed within the original budget.

10. Subcontractor information

University of Paisley, 67 High Street, Paisley, PA1 2BE, Scotland
Phone +44 141 848 3419

The University of Paisley has a long established reputation for the provision of short courses to industry. Tramex' needs were discussed and a course was tailored to these needs which provided training on the use and operation of PIC microcontrollers. The training was a two day introductory course which focused on the programming and features of PIC microcontrollers since this was device type chosen by Tramex for use in the AE and future projects. Similar courses were available from other organisations but the University of Paisley was chosen on grounds of flexibility, cost and ease of travel.

National Electronics Test Centre, Forbairt, Glasnevin, Dublin 9, Ireland.
Phone +353 1 837 0101

Forbairt is a semi state agency established by the Irish government to facilitate the development of Irish business and to provide a range of science and technology services and programmes in Ireland. Forbairt wes chosen because of their experience and reputation. Tramex had also previously used Forbairt for assistance on an earlier project and new their operation and method of working.The National Electronics Technology Centre (NETC), a department of Forbairt, gave Tramex advice on EMC issues and tested two 'B' model prototype instruments for compliance with the EMC Directive. Both units satisfactorily passed all tests. NETC advised that, if no electronic changes were introduced, it was probable that only ESD tests would need to be repeated on the production model (injected moulded case). If the ESD tests were successful, the SME could be EMC certified and CE marked.

11. Barriers perceived by the company in the first use of the AE technology

Based on market assessment and observation of development trends in portable instrumentation, the company's motivation to create a new advanced instrument range was already present prior to becoming aware of the FUSE scheme. However, there were a number of perceived barriers, essentially all knowledge related, that frustrated active pursuit of this goal, viz., :-

1. Lack of microelectronics knowledge.
2. Difficulties in trying to obtain technology information that could be interpreted in terms of the company's requirements and from which development and manufacturing costs could be assessed.
3. General impression that the costs and risks were too high for a small company with no microelectronics skills or experience.
4. Uncertainty about the development demand on labour resources with the essential need to maintain normal business and existing R & D support activities.
5. Doubts about loss of design control and becoming over dependent on outside design houses.

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

The barriers listed in the above section were overcome and were as follows:

Lack of microelectronics knowledge.

Initial attempts to acquire knowledge of microelectronics did find quite a lot of literature but it was, for the most part, written for those already skilled in these technologies and the extensive use of unexplained technical acronyms tended to heighten concerns about the prospect of ever gaining a foothold on the new technologies.
However, a breakthrough in overcoming this barrier was achieved when an information pack on the UK Department of Trade & Industry's "Microelectronics in Business" initiative was provided by the TTN. The package included :-

- A booklet which described each of the microelectronic technologies in easily understood language and gave some simple application examples.
- Leaflets containing photographs, brief project descriptions and profiles of small companies that had successfully applied microelectronics.
- A handbook directory giving addresses, telephone numbers and brief descriptions of support centres, consultants, design houses and various firms providing microelectronic services.

This information provided a key which, in effect, opened the door to a stairway over the barriers. The subsequent contact with the "Microelectronics in Business" Support Centre at the University of Paisley provided more relevant information and the encouragement to make a FUSE submission.

> Difficulties in trying to obtain technology information that could be interpreted in terms of the company's requirements and from which development and manufacturing costs could be assessed.

The whole project was discussed with the TTN when the TTN visited Tramex. This discussion encouraged Tramex to have a full feasibility study conducted on the proposed project. The feasibility study, conducted by Bolton Institute, confirmed the viability of the project and it also provided detailed costings of the project.

> General impression that the costs and risks were too high for a small company with no microelectronics skills or experience.

The TTN helped tramex with the FUSE submission document which included the generation of a detailed project plan. The project was broken down into small tasks and each estimated for cost and time to complete. By following the structured approach whilst creating the submission gradually dispelled the barriers of the risks and lack of skills, the latter dispelled by the training that was factored into the proposal.

> Uncertainty about the development demand on labour resources with the essential need to maintain normal business and existing R & D support activities.

The possibility of FUSE funding for an AE radically changed the outlook on financial risk and was a substantial inducement to carefully examine all aspects of the project and subsequent industrialisation prior to completing the submission.

> Doubts about loss of design control and becoming over dependent on outside design houses

During the FUSE submission phase, Tramex were attracted to the PIC microcontroller on grounds of learning ease and cost but, when a draft instrument specification was sent to three design consultant firms, all proposed Intel or Motorola microcontrollers and were dismissive of the PIC as a "professional" solution. The first preference of these firms was to handle the entire design, both firmware and hardware, their initial cost estimates were very high and it was difficult to get them to accept the vital importance of technology transfer to the company.
Further advice from the TTN and provision of microcontroller training and design assistance convinced us that the project was possible for Tramex. to complete and that the highest degree of technology transfer, retention of design control and minimal dependence on outside design houses was possible.

<u>AE Implementation Phase</u>
Whilst, as already described in previous sections, a number of technical problems had to be overcome during the AE implementation phase, none were regarded as barriers. This could be attributed to the extended preparatory phase which not only removed the initial barriers but pre-conditioned the company to the new technology. The main handicap was timescale but this was not a barrier.

13. Knowledge and experience acquired

Most of the knowledge was gained via on-the-job training and using Microchip's extensive web site. However, the two day introductory course on PIC microcontrollers laid the foundation for this "self learning". It came as a very pleasant surprise to Tramex that the knowledge necessary to develop microcontroller controlled products was much less than anticipated. We were able to progress after the two day introductory course.
New skills and experience acquired include :-

- Ability to specify and plan a complex project using microcontroller technology.
- Where to find the technical information to plan the project and complete the hardware. This knowledge will be able to be applied to other projects that may use a technology other than microcontroller technology.
- Ability to interpret data sheets/specifications for a wide range of digital devices, eg., PIC microcontrollers, SEEPROM, real time clock, digital temperature sensor, dot matrix LCD, etc.
- Ability to design the hardware and software to develop microcontroller system products including interfacing with peripheral devices and analogue circuits.
- Use of design tools including PIC Integrated Development Environment (IDE) MPLAB software package for creating/editing firmware code, simulation, emulation and programming devices and the use and importance of In-Circuit-Emulators (ICEPIC).

- Knowledge of Visual Basic acquired to create a basic PC software package to test the instrument RS232 interface.
- The scheduling and completion of the project has allowed Tramex to gain the experience to manage and complete complex microelectronic projects by applying a structured and detailed approach.

14. Lessons learned

Several valuable lessons were learned at all stages of the AE, viz., :-

Choice of Microcontroller
The experiences associated with the first FUSE submission provided a lesson on the importance of choosing a microcontroller family that fully complies with all of the company's requirements and the need to take independent advice on the choice of technology and manufacturer. Design houses have a vested interest in promoting their existing skills which do not necessarily provide the best solution.

PIC Information & Technical Support
The Internet was a great source of knowledge during the AE. Not only was information and technical support found on the PIC microcontrollers but also an enormous range of technical data on all aspects of electronics can be sourced via the Internet.

Project Timescale Estimation
By breaking down the project into small tasks the project can be estimated accurately but care should be taken to include sufficient time for learning the new technology. As a First User of microcontroller technology the company did not have any previous knowledge base from which to estimate the likely project timescale and external advice should be taken.
Unforeseen problems can occur as with the problem with the real time clock, showing that chips from vendors can have bugs, can cause schedule slippages. By adding a small contingency into the schedule these types of problems can mostly be accommodated. and care should also be taken to include holiday time etc..

The design tools that were purchased to aid the writing of the software were found to be invaluable in the development and debug of the code. If possible such tools should purchased at the start of a development.

A major lesson learned, however, was the need to plan the project in great detail at the start of the project. It is felt that this is absolutely necessary to enable projects to be kept to schedule and budget.
Overall, the company has derived considerable benefits from the lessons learned at each phase of the FUSE process, i.e., preparation of the proposal, technical annex issue 1, technical annex issue 2, execution of the Application Experiment and preparation of the Demonstrator Document.

15. Resulting product, its industrialisation and internal replication

The prototype instruments which were tested at the end of the AE phase embodied all of the features detailed in the specification of the new product. Assessed from a production standpoint, the performance of the prototypes was very satisfactory, however, much knowledge had been gained during the project of the capabilities of the hardware and software. During testing it became apparent that some useful additions/improvements could be made to the firmware, e.g., :-

- Introduction of different scaling algorithms for each of the 3 wall and the 3 roof materials.
- Revision of RS232 code module to improve and enhance compatibility with PC software package.

Several details of the case design are required to be finalised for the production product together with the keypad rubber membrane.
The subcontractor for the main PCB assembly has been selected and these boards in the new case with the enhancements in the software will be production tested. This test plan is being developed and necessary documentation such as the operating manual and documentation is being written.
The cost of the industrialisation of the Wood Moisture instrument is estimated to be 68 KECU which covers the costs of the injection moulded instrument case, PC software and the costs associated with applying for and gaining a patent on the instrument (the Intellectual Property Rights or IPR).

Tramex exhibit at International Trade Fairs in Europe and U.S.A., this will be the main method for marketing the new unit although samples and a set of brochures will be sent to each of our distributors. Advertisements in relevant trade magazines will also be used.
The industrialisation plan which is shown in the Gantt chart below shows in detail the schedule for the tasks for the industrialisation.

November and December have been allocated to debug any remaining problems in the initial production batch and resolve any issues associated with the other tasks. Thus, it is planned to commence continuous production and sales of the new instrument in January 1999.
This represents an improved time to market for such a product that contains so many new features and is so user friendly.

Internal replication is following two routes firstly it can now be seen that the whole range of Tramex hand held instruments can be improved and updated with new features by the use of microcontroller technology. Plans are being developed with detailed schedules to update these instruments.
Secondly a new application is in the process of being developed that was not possible with Tramex' old technology, this product is also associated with the building trade. The Fuse experiment has therefore allowed a complete revamp of Tramex' instruments and also opened up new applications for Tramex to exploit.

16. Economic impact and improvement in competitive position

The projected economic impact of the FUSE project is summarised in the tables below.

Relative Instrument Price/Cost Comparisons		
	Current Analogue Moisture Meter	FUSE Project Moisture Meter/Recorder
Ex factory price	1	1.25
% Manufacturing cost	50%	50%
% Margin	50%	50%

Wood Moisture Meter/Recorder

Sales/Profit – Past and Projected							
Year	1997	1998	1999	2000	2001	2002	2003
Analogue Meter Sales	6079	6250	6200	5800	5400	5000	4600
FUSE Meter Sales			400	1200	2000	2800	3600
Equivalent Analogue Value (FUSE sales x 1.25			500	1500	2500	3500	4500
Total Equivalent Analogue Sales	6079	6250	6700	7300	7900	8500	9100
Growth Rate %		2.81%	7.20%	8.96%	8.22%	7.59%	7.06%

Initial production, marketing and beta testing of the microcontroller based Moisture Meter/Recorder, designed and developed with FUSE assistance, is planned to commence September/October 1998. Based on past experience of new production initial build rates and market take up rates, sales of the new instrument for 1999 are forecast as 400 units rising thereafter by 800 per annum to achieve 3600 in year 2003. Previous market assessments have predicted that existing analogue meter sales would peak around 1998/99 and then decline. This prediction has been the main motivation for the new instrument. It is anticipated that, as market awareness of new instrument grows, the decline in analogue meter sales will follow the rate shown in the above table.
The advanced features and operational benefits of the new product combined with the flexibility provided by the new technology to address new applications by firmware and PC software alterations, will enable Tramex to establish a lead position for this class of instruments and thus increase the company's market share.

In addition to the 50 KECU FUSE funding, Tramex are investing a further 68 KECU to cover the industrialisation costs of the injection moulded instrument case, keypad, PC software and IPR. The payback period for the nett 118 KECU investment is estimated to be 2.2 years. Based on the 5 year forward projection shown in the table above, it is estimated that the new product will contribute an ROI (Return Of Investment) of 50% (average) per year. There will also be an ROI from replication projects.

17. Target audience for dissemination throughout Europe

The four digit Prodcom for Tramex is 3320, instruments and appliances for measuring, checking, testing, etc., the target audience for this type of equipment covers a wide range of applications in many industries.
This demonstration document therefore should be aimed at a target audience of companies in all industrial sectors producing equipment as described in Prodcom code 3320. These companies tend to be small in size who utilise poor methodology in defining and executing projects, often resulting in overruns in both time and cost. They are also starting from a low electronics expertise and base and this project shows how companies can make the leap to new technology.

In addition to supporting TTN promoted seminars, publications, etc., Tramex plan to give presentations on the project to :-

- Branches of the **Irish Small to Medium Enterprise Association** (**ISME**). ISME has a membership of about 3000 firms and operates an R&D section which would be very interested to receive presentations on the Tramex project. Their target audience would comprise a large number of small manufacturing companies many of whom are in the electrical/electronic sector.

- The Irish section of the **Instrument Society of America** (**ISA**) which also has the title **The International Society for Measurement and Control.** The local Leinster (provincial) branch of the ISA has 80+ members which includes many small/medium instrumentation manufacturers. The ISA are very active in the promotion of instrumentation in Ireland and in forming links with European bodies. They frequently organise technical seminars and would welcome presentations on the Tramex FUSE project.

- Selected seminars organised by **Forbairt** (now known as **Enterprise Ireland**) on R&D Management. Enterprise Ireland is a semi state agency established by the Irish government to facilitate the development of Irish business and to provide a range of science and technology services and programmes in Ireland.

Tramex is a member of ISME and ISA.