An Improved Quality Control System for Dairy Product Manufacturing

Microcontroller provides a return of 2,000%

Rachel’s Dairy Ltd.

TTN: University of Glamorgan Commercial Services (UGCS) Ltd
AE Abstract

Rachel’s Dairy Limited started as a farm-based business in 1982 and expanded into a purpose-built dairy in 1990. The company produces a range of organic dairy products, and is involved in all stages of the processing of these products, and in the related marketing and distribution. The company employs 58 people and achieves sales revenues of over 5 MEUR per annum. The industry sector occupied by Rachel’s Dairy is defined by the standard industry Prodcom code 1551 (Food).

The company’s product range includes organic yoghurt, crème fraiche and double cream. Rachel’s Dairy supplies these products to major chain retailers (the supermarkets), and via wholesale distributors to delicatessens, health food shops, small retail and some catering outlets. A limited quantity of direct sales are also achieved. The company uses commercially available food processing equipment to produce these products, and until the application experiment had no experience in using or specifying microelectronic products.

The production process for yoghurt requires precise control over the pH of the milk during the incubation and the subsequent blast-chilling process. The current manufacturing process at Rachel’s Dairy requires the use of periodic sampling using hand-held pH meters. This method is inadequate, and operator estimation of the required incubation time can lead to excessively ‘acid’ levels of pH in the final yoghurt. The batch of yoghurt must then be disposed of.

The rationale for the application experiment was to improve the quality control process by repeatedly monitoring the pH of the yoghurt during its incubation process to prevent this commercial loss. The improved monitoring of pH is estimated to result in a reduction in the current rate of wastage from 3% to 1%.

The technical objective of the application experiment was to replace the current pH sampling method with a continuous, in-line measurement and data logging method. The application experiment therefore involved the development of a microcontroller-based multi-channel pH measurement, display and data logging system to provide the following functions:

- Monitor pH in yoghurt continuously during the incubation process, and provide out-of-limit warnings.
- Log the values of pH over extended periods of time, and to transfer this data to a PC for later analysis.

The duration of the application experiment was 10 months. This was extended from the 8 months anticipated to allow for the more complex design undertaken, and the inexperience of the company in developing specifications which required longer to complete. The prototype development cost was 38 K EURO, and a further 12 K EURO was required for industrialisation.

The economic impact of the adoption of the improved quality control process is significant, and will produce not only cost savings but provide opportunities for increased sales by the development of improved supplier ratings with the major supermarkets. The projected payback for the combined prototype development and industrialisation cost is 10 months, and the rate of return on investment (ROI) in the first four years is estimated as 2000%.
Keywords and AE Signature

**Keywords:**
- Organic Products
- Dairy Products
- Yoghurt
- pH monitoring
- pH measurement
- Data logging
- Process Control
- Microcontroller

**Signature:**

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2  0181  551 0204 2  1551 2  15  UK
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1. **Company name and address**

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![Rachel's Dairy Logo](image)

2. **Company size**

The company has grown significantly year on year, and currently employs 58 people and achieves sales revenues of over 5 MEUR per annum (1999 figure).

3. **Company business description**

Rachel’s Dairy Limited produce a range of organic dairy products, including yoghurt, crème fraîche and double cream. The company is involved in all stages of the processing of these products, and in the related marketing and distribution. Rachel’s Dairy is unique in the UK in that they use only organic liquid milk in their products, not organic milk powder.

In April 1999, Rachel’s Dairy was acquired by the American company Horizon Organics and became part of a new company, Horizon UK. Rachel’s remains the only actual yoghurt manufacturing concern within Horizon.

The industry sector occupied by Rachel’s Dairy is defined by the standard industry Prodcom code 1551 (Food)

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

Rachel’s Dairy’s product range includes organic yoghurt, crème fraîche and double cream. The company supplies its organic products across virtually the whole of the UK. Approximately 97% of company sales are for yoghurt.
84% of products are presently sold through major chain retailers (the supermarkets). Approximately 10% are sold through the Company's network of 15 wholesale distributors, to delicatessens, health food shops, small retail and some catering outlets. 6% sales are via the direct retail deliveries, mainly within a 220 km catchment.

The company currently has approximately 10% of the UK organic dairy market and has just commenced exporting its products to Europe.

The estimated retail sales value of the UK organic dairy market in 2000 will be 67 MEUR. This, in comparison to the overall UK yoghurt market of 2176 MEUR in 2000 (Source - Eurolaunch) shows the organic yoghurt market to be small at the moment, but with exciting potential for expansion. It is suggested that the organic dairy proportion will increase from 3.0% in 2000 to 6.2% by 2004.

The main suppliers to the conventional yogurt market are the major UK dairies (Dairy Crest, etc), foreign manufacturers (Danone, Muller etc), and the supermarket’s own label products. No one company dominates the market for yoghurt in the UK, though Yeo Valley presently have the major share of the organic component of that market.

Rachel’s Dairy crucial advantage is that it is the only supplier of ‘authentic’ and ‘pure and natural’ organic dairy products within the national market, maintaining the ethos established by Rachel Rowlands from the company’s inception. Only fresh, pure, liquid organic milk is utilised, with protein and fat levels being raised solely by evaporation, whilst all competitors employ milk powder and other additives to bulk up their products. It is reckoned that this ‘edge’ will enable the company to maintain its share of a growing market.

The organic yoghurt market of late has expanded rapidly, which can be attributed to a large extent to the mounting number of health and safety issues currently affecting ‘conventional’ food producers. Along with an awareness of more environmentally-produced goods, the consumer is now demanding improved quality and value for money in the products on offer, and Rachel’s Dairy meets that demand. Moreover, there is increasing public interest in nutritional composition and ingredient listing, manifested by the huge rise within the diet/health-conscious sector. The UK organic market is therefore demand-led due to consumer health, environmental and welfare concerns. With the major retailers’ significantly increasing commitment to organic foods, this sector is now strong and growing.
Rachel’s Dairy’s sales growth is indicated in Figure 1. The growth rate in 1999 was 56%.

![Figure 1: Sales of Rachel’s Dairy Yoghurt (1992-99) in K Euro](image)

5. Product to be improved and its industrial sectors

The process flow chart for the production of set yoghurt is illustrated in Figure 2 (below)
and is described herewith:

Pre-treated pasteurised and evaporated milk is fed into an inoculation tank. The current process has 7 tanks, each of which can hold enough milk for 1,800 yoghurt pots. The milk in the tank is cooled and the required amount of starter is established by weighing before it is added to the milk.

The treated milk is then pumped to a filling machine that fills the plastic yoghurt pots. The pots are sealed with lids, before being stacked onto trays able to contain 6 pots. These trays are then stacked on pallets before being transferred to the incubation room. Each stacked pallet consists of 9-10 layers of the packaged products.

The pallet containing the pots of yoghurt is then incubated at 40°C for approximately 4.5 hours until the required level of pH is reached. This process produces the desired acidity level of pH 4.5.

When the desired pH level is reached the pallets are placed in a blast chiller and rapidly cooled to a temperature of +2°C. The yoghurt pots are subsequently transferred into an overnight cold store at +2°C - +4°C. After a final product pH test the pots are over-wrapped, and then distributed to the company’s clients.

The critical process control parameter for the yoghurt fermentation process is that of pH. To ensure the desired level of control required by the company, routine pH sample checks are implemented. This testing is achieved using a hand-held pH meter operated by a quality control technician. The pH level is checked:

(i) When the pots are initially filled.
(ii) Prior to incubation during the pallet stacking process.
(iii) On a sample basis throughout the incubation period.
(iv) At the end of cold storage period, and prior to distribution.

The current sampling process is destructive in that the pots sampled must be disposed of afterwards, and is random in that the ‘sampling’ intervals are scheduled by experience and expectancy alone. The result of this imprecise testing process is an inadequate level of control over the yoghurt manufacturing process, resulting in higher levels of reject products than is desirable.

The reason for the development of the microcontroller based system to monitor pH is to reduce this wastage level. The parameter improvements to be delivered using the improved microcontroller based data logger system include those identified in Table 1 below:
### Table 1: Parameter Improvement

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Current Value</th>
<th>Improved Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process Waste</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>pH Recording Interval</td>
<td>Random</td>
<td>Regular, Set by User to Period (typically every 5 minutes)</td>
</tr>
<tr>
<td>pH Recording Events</td>
<td>Maximum 8, performed manually</td>
<td>Maximum 512, performed automatically</td>
</tr>
<tr>
<td>pH records</td>
<td>Kept manually</td>
<td>PC records available.</td>
</tr>
</tbody>
</table>

The incubation chamber loaded with a pallet of yoghurt is illustrated in Photograph 1 below.

![Photograph 1: Inside of Incubation Chamber](image)

6. **Description of the technical product improvements**

The objective of this application experiment was to enable Rachel’s Dairy to monitor more accurately the level of the yoghurt’s pH throughout the manufacturing process. This will enable the company to reduce levels of waste product, improve product quality and gain additional sales.

For example, intervention in the process is required to initiate chilling at the correct point in time, which is dictated by the pH reading. Reliable indication of pH and the correct point of intervention are both vital. In addition, an abnormal rate of change of pH could indicate a problem requiring investigation before the normal intervention point.

With the manual method, at least 1% of the pots were sampled for pH and all these were then scrapped. Repeat measurements increased this wastage. The only pots which were accessible were those on the top or at the edges of the pallet. With the microcontroller-based system, it is envisaged 8 in 900 pots would have the probe inserted. However, the lids do not need to be
removed each time a reading is taken which in practice reduces the level of pots wasted by this destructive testing process. Access to pots in different parts of the pallet stack is now also possible, enabling the sampling rate and positions to be optimised, giving further improvement in process control.

The application experiment therefore involved the development of a multi-channel pH measurement and display system with an integral data logging facility to assist in the improvement of the company’s pH quality control process.

The pH data logger system is described in block form in Figure 3.

![Figure 3. Block Diagram of the pH Monitoring Equipment](image)

The pH monitoring system is based on 3 major module types, viz:

1. The master unit, which provides communications to the other units and the PC, and provides the data archiving and display functions.
2. The slave units which interfaces the Remote Transducer Boards (RTB) to the master unit using RF communications links. A maximum system would have up to 16 of these units.
3. The Remote Transducer Boards (RTB), which provides the analogue data interface to the temperature sensor and pH probe. This unit is designed to fit within a yoghurt pot to measure in process parameters. Up to 8 of these units can be connected to one slave unit.
The complete design solution is therefore highly modular, and allows from 1 to 128 pH sensors to be monitored. The system also monitors temperature for each valid pH sensor input.

The RF communications link between the Master and Slave unit was introduced to allow the communications to be performed so that the master unit could be located outside the incubator room and the slave unit inside the room.

The RF communications link is a one way link from the slave to the master unit. This reduces the cost of the commercially available 418 MHz serial data transfer units compared to the cost of transceiver units. The system design is developed such that each of the slave units and the master unit is synchronised by a real time clock (RTC). This allows each module to transmit in an allocated time slot (18 seconds in width). This prevents any data transmission contention problems caused by the potential for overlapping transmissions of data from the slave units to the master unit. A passive aerial enables transmission out of the cool room.

The complete system allows the following functions to be performed:

- The pH of yoghurt pots on several of the stacking layers of each pallet to be continuously monitored. A maximum of 128 channels will be provided on the instrument to allow pots at various positions to be monitored.

- A numerical display of pH for each of the monitored probes at the master unit. The equipment will provide a cyclic display facility consisting of probe number and pH level reading for that probe.

- Operator warnings when the pH level approaches critical pH levels during the incubation period. This facility will enable the operator to provide close monitoring of the pH as the end of the incubation period is reached.

- A data logging facility that provides a complete record of pH values for each probe. The system can maintain 512 samples (equivalent to 32 hours at a 15 minute sampling rate).

- A serial data transmission capability to allow the download of the data values logged in the equipment to a central PC for the maintenance of quality control records.

The system will allow measurement to 0.01 pH unit of accuracy in the required range of 3.0 to 7.0 pH.

The master unit is based on an 8031 microcontroller device, and provides the following functions:

1) System configuration facilities to set up each slave unit prior to the use of the system. This set up process involves:
   
a) The identification of valid slave units for the configuration (note that each slave unit is uniquely identified using a binary wire link code), and only accepting data from these units.

b) Slave unit set up (including the set up of the real time clock) using an RS 485 hard wired connection to each board provided for the set up application only.

c) The facility to control the sample interval in minutes (minimum 1 sample every 5 minutes per channel).
d Set up of the alarm levels for the pH measurements. An audible warning alarm to alert the operator if the pH level in any of the monitored channels approaches the critical level for the yoghurt is then established.

2) An RF receiver to receive the data from each of the slave units in turn.

3) Data archiving facilities based on the storage of temperature and sampled pH values for each channel selected by the user.

4) An RS 485 serial data transmission facility, which is used for the slave unit set-up and to enable the transfer of the archived data values to a central PC for the maintenance of quality control records.

The slave unit is based on an a PIC 1663 microcontroller device, and provides the following functions:

1) Recognition of the unique hard wired code for the slave unit, and the use of this data and the real time clock value to enable transmission in the allowed transmit window as defined by the microcontroller software algorithm.

2) An analogue to digital conversion of the data received from the RTB’s temperature and pH output currents.

3) The transmission of data in the allocated time slot via a serial RF transmitter module to the Master unit.

The RTB unit is based on discrete analogue SMT components only. The function of this unit is to interface to the pH probe (which is soldered directly to the printed circuit board (PCB) and a temperature sensor, and to provide an amplified output current level proportional to the sensor values. This unit is connected by a cable to the slave unit. 8 such units can be connected to a slave unit.

The system circuit boards are illustrated in the following photographs.
Photograph 2: The RTB board and the pH sensor Probe

Photograph 3: Master Unit Circuit Board
The pH monitoring system meets all of the parameter improvement criteria identified in Table 1 of Section 5 of this demonstrator document.

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

The selection criteria for the appropriate technology to implement the improved quality control process were:

- Simplicity to use in the end environment.
- Reasonable unit cost for each equipment so as to allow several such units to be used for monitoring different batches of yoghurt.
- A technology that the company could manage, and that was low risk in its implementation.

Discrete device solutions were too unwieldy and space consuming, higher processing power component devices (such as DSP processors or high end microprocessors) were clearly over specified for this application, and FPGA and ASIC device solutions were not economical options from the design or fabrication viewpoint.

Three potential solutions to the improved process requirement for this application experiment were therefore, considered:

1. Commercially available pH measurement equipment.
2. Psion, or similar, data logger units with specific interface units for the probes.
3. A bespoke design based on microcontroller device technologies.

The results of this analysis were as follows:
**Commercially available pH measurement equipment.**

A wide range of available pH monitoring equipment was considered for this application experiment. The search undertaken revealed the fact that:

- Most pH monitoring equipment was designed for single channel use, and most of these were designed for laboratory use.
- Very few equipment were available with data logging capabilities, and these equipment were single channel solutions.
- No equipment was identified with display, alarm and data logging functions.
- Most systems were designed for room use, and could not be certain to operate successfully in the incubation area and then in the blast chiller.

The search therefore indicated that the company’s requirements could not be met by the use of a single pH measurement equipment. The use of a combination of equipment would be impractical as double the number of pH probes would be required, the space available of the pallet is limited preventing the placement of the several monitoring units on the pallet, and the need for multiple channel displays could not be easily resolved in such a multi-equipment configuration.

**Psion, or similar, data logger units with specific interface units for the probes.**

The use of industrial temperature data loggers was considered but rejected on the basis that:

1. The system would rely on the pre-processing of the pH sensor signal to convert this into a suitable format for interfacing to a digital logger unit. Some pH to 4 -20 mA systems for application in industrial environments were located but these were expensive, and the cost for 16 such units per equipment (and eventually 120+ in total) would be prohibitive.

2. Most logger systems provided limited single channel input capabilities, and could not provide the 16 channel input requirement for the system envisaged without external conversion to a multiplexed digital format. This would require additional bespoke designed hardware obviating the need to use the logger device in the first instance.

3. Display requirements essential to the operator monitoring of the process were not provided in these systems.

4. Alarm warning outputs were not available.

After considering the compromises in terms of reduced channels, lack of display facilities, lack of audible warnings and cost, the use of commercial logger systems was rejected.

**A bespoke design based on microcontroller device technologies.**

This design option allowed the following benefits to be derived:

1. All operational requirements could be achieved.
2. Physical size levels could be restrained to acceptable levels enabling placement on the pallet without major difficulties.

3. Costs of operation were reduced because of the compliance with the target specification for the unit.

This level of compliance with the desired requirements cannot be achieved by the use of commercially available systems. As this is essential for the improvement of the yoghurt manufacturing process quality a bespoke design option is essential to realise the required improvement.

The microcontroller device solution was therefore, selected for this application experiment after the rejection of alternative discrete and digital device technologies, and because the technology offered:

1. A programmable and flexible device solution.
2. Low cost device technology.
3. A high level of peripheral interfaces, including timers, integral analogue to digital converters, serial communications data transfer, and parallel digital inputs and outputs necessary to interface to external memory for data storage.

The operational location of the pH monitoring equipment within a sealed incubation room necessitates some attention being given to the communications link between the monitoring equipment / slave unit and the master control unit, the latter being located within an adjacent, but unconnected, laboratory.

Initially, this was anticipated to be a hard-wired link, but a decision was taken at an early stage to develop an FM radio link from the slave to the master, primarily to overcome the problem of multiple trailing wires through a busy and complex working environment. However, in designing the interface circuitry, a capability to enable a hard-wired link solution was incorporated. The selected frequency of operation was the approved 418 MHz low power band, and this provided up to 100 metres range under favourable circumstances. The system design was developed such that each of the slave units and the master unit were synchronised by a real time clock (RTC), which allowed each module to transmit in an allocated time slot (18 seconds in width). This prevents any data transmission contention problems caused by the potential for overlapping transmissions of data from the slave units to the master unit.

The selection of a microcontroller device option therefore required the selection of two devices; one for the master unit and one for the slave unit. The master unit required a capability to save data to external memory with a reasonable address range. This necessitated the use of a device with an external bus facility, and the 8031 device was selected for this task. The section of this device was based on the cost, and the common application of this device providing a wide range of sources of devices, design assistance and design support tools. The slave unit required a more compact design solution, and the PIC 1663 device was selected because this device provided a low cost, common family technology, and low cost development routes.
As execution speed or program memory size were not major constraints all software program development was undertaken in the ‘C’ language. ‘C’ language Cross Compiler / Debugger and Emulator facilities were used to support the development.

The system design incorporates several test pins into the circuit board, and uses various serial data interfaces to the PC to allow the operator to isolate faults.

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

Rachel’ Dairy produce organic dairy products, and the skills of the company are therefore related to food technology and production. The company employs graduate food technologists, but have no other formally trained development staff.

Rachel’s Dairy Ltd. has no previous experience of microelectronic product development.

The company allocated two members of its staff to partake in the application experiment:

- The company’s Operations Director acted as the Technical Manager for the application experiment. This individual had no formal engineering qualifications, but had acquired basic engineering skills and capabilities over several infrastructure developments undertaken by the company, including the development of the production infrastructure for the food manufacturing plant.

- The company’s Executive Aide acted as the project manager for the application experiment. Again this individual had no formal electronic skills, but had prior experience in the technical development and implementation of systems and processes.

9. Workplan and rationale

The application experiment consisted of the completion of several major work elements (work packages). These are described below. The timing for the completion of the various tasks is illustrated in Figure 4. The original time plan illustrated in Figure 4 was based on the rationale that the serial completion of each task should be completed prior to the start of the next logical task. This rationale was largely maintained in the conduct of the application experiment. Although perhaps not optimum, such an approach was regarded as advisable in view of the inexperience of the First User, enabling the company’s staff to focus on the acquisition of knowledge in one area at any one time.

The major work packages included:

Work package 1: Engineering and Project Manager Training

This task involved the provision of formal training of the company engineer and project manager in microcontroller development principles, and specific microcontroller device
details. Software design and program development using the C programming language was also covered.

The training task was completed very satisfactorily, although slightly behind schedule due to other demands. The training was split between Technical Manager and Project Manager, and was regarded by the participants as both effective and useful.

**Workpackage 2: Technical Management**

This task was undertaken by the Project Manager, and was entirely the responsibility of the company. The task involved the consideration of implementation options, the planning for the testing of the pH monitoring system, including its installation, subcontract management, and liaison with the FUSE monitoring staff to provide monthly progress reports.

The development plan was initially formulated as a bar chart, capable of being adjusted continuously as technical tasks metamorphosed and needs changed. The task introduced the company to the specific needs of the microelectronics development, but in general the task was completed satisfactorily because the organisational skills required were already well developed within the company.

**Workpackage 3: Specification**

The specification process involved the development of a functional specification for the pH measurement and display equipment, and the development of a software design specification.

The main responsibility for the development of these specifications lay with the design subcontractor. The functional specification development task involved detailing all the functions to be performed by the system, including the detailed performance limits, proposed design solution and the communications specification for each stage, and the data logging performance. The initial software requirements were also incorporated into the functional specification. This task was undertaken by the subcontractor, following briefings from the company, and subsequently iterated by a series of joint reviews to yield the final document that was formally accepted prior to the start of the design implementation stage.

The increased responsibility for this task accepted by the design subcontractor was required because of the company’s inexperience in the development of such specifications. The process of on the job training in specification resulted in a slightly longer time to develop the final document.

**Workpackage 4: Hardware Design**
The hardware design was primarily the responsibility of the design subcontractor. The task involved the following identified stages:

1. The selection of the pH sensor probe and the design of the analogue and digital interface circuitry required for the microcontroller interface. The pH probe selection proved more demanding than anticipated, with some difficulty locating suitable manufacturers; this was carried out largely by the company’s Project Manager. A very varied range of products, some quite specialist and unsuitable to dairy conditions were identified, and samples obtained to prove satisfactory performance in the final environment. The need to maintain signal integrity when in final environment required the use of a current output amplifier to generate a suitable output signal from the RTB unit to the slave unit.

2. The development of a communications protocol between the slave and master units based on an RF communications link. This required additional subcontractor design effort but was successfully achieved, although some trials with optimum antenna positions and size was required.

3. The hardware design of the circuit boards for the master and slave units were undertaken entirely by the subcontractor. The design basics and options were however, discussed by the company and sub-contractor originally before the implementation was undertaken. The master unit’s PCB was produced by the sub-contractor alone. However the company and subcontractor discussed and influenced the design and layout of the slave unit and RTB PCBs. The company engineer and project manager thence undertook the construction of the prototype hardware and, through this, gained considerable experience of specifying and ordering minor electronic components.

The role of the subcontractor in the hardware task was to take technical responsibility for the delivery of the hardware designs, and to provide training in the design solution and to develop the knowledge to build the PCBs.

The company Project Manager monitored progress, and with the company’s Technical Manager acquired the knowledge gained in PCB design, build and procurement.

**Workpackage 5: Software Development**

The subcontractor was again responsible for the detailed development of the operational software. This involved slave unit, master unit, and PC interface software programs. The subcontractor undertook the specification and high level design of each software component, although the company were involved in defining the initial parameters for the system and a subsequent review. The subcontractor performed the initial software coding and testing. The company were involved in trialling the initial software solution, and providing feedback for the modification for improvement. The revisions were incorporated by the subcontractor.

**Workpackage 6: Evaluation**

The first test stages used for the system focussed on test routines on the bench to evaluate the software / hardware integration, and the links to the pH and temperature sensors. Some
problems were originally apparent in the RF radio communications link, which was related to the presence of noise in the working environment. The investigation involved several trials with aerial and equipment placement to establish an adequate signal to noise ratio to enable the system to operate correctly. The final testing stage then required the company to apply the prototype equipment in the actual incubation room, and to demonstrate the performance of the system against the readings taken from the hand held, commercially available equipment.

The company’s engineers led the evaluation process, and the subcontractor assisted the joint investigations required to resolve any problems that were identified. The responsibility for the evaluation and acceptance of the final equipment was the company’s, and the company undertook the role of the lead in testing the equipment.

The role of the subcontractor in this task was to resolve identified problems with the prototype unit.

The planned and actual work package costs are illustrated in Table 2.

<table>
<thead>
<tr>
<th>Work Package Definition</th>
<th>Actual Effort in person days</th>
<th>Planned Effort in person days</th>
<th>Actual Subcontractor Cost K Euro</th>
<th>Planned Subcontractor Cost K Euro</th>
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<td>Engineer Training</td>
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<td>Technical Management:</td>
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<td>20</td>
<td>-</td>
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<td>Total</td>
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<td>138</td>
<td>17.29</td>
<td>16.9</td>
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</table>

Table 2: Work Package Definitions

The knowledge transfer process, as agreed at the FUSE contract stage, was focussed on the development of Technical Management and microelectronic test and maintenance skills. This was achieved through the interaction with the subcontractor and the support provided through the monitoring process provided by the TTN. The technical knowledge development process involved formal training provided by the training subcontractor, and through the interactions with the subcontractor, especially in the specification and evaluation phase.
**Variances:** The actual resources used by the company were lower than anticipated. The technology transfer aim was to develop management and test skills, and to attempt to gain as much design knowledge as possible. The resources allowed in the original plan allowed the company to be actively involved in the design activities. However it became evident that the technology step was too large for the company to become technical ‘experts’ in one increment, and therefore company resources under the Hardware Design and Software Design tasks were reduced.

The subcontractor costs were negotiated as a fixed price contract, and even though the subcontractor was involved in more design work, the subcontractor held to this agreement. Therefore there were no significant variances in the cost of this activity.

The actual and planned work programmes are shown on the following page in a time plan format. The deviations in the work plan were caused were as follows:

- **Specification:** This task took longer to complete than anticipated. The task required that several practical aspects related to the use of the hardware were evaluated in detail, and this required the sub-contractor apply extra time not allowed for in the original plan, although this did not affect the subcontractor cost. The additional discussions between the company and subcontractor required a longer elapsed time to sign off the final specification.

- **Circuit Design:** The hardware design task was more complicated because of the addition of the RF communications link. This required additional design time for the final development to be completed. Again this work was predominantly undertaken by the subcontractor, at no additional cost

- The software and testing tasks were delayed by the additional time required for the specification development and the hardware design task. The testing stage involved more company effort than originally planned, and was a major stimulus for knowledge transfer into the company. The tasks involved several iterations related to RF module placement etc. to achieve reliable operation, but a robust system was achieved, suitable for the production environment.
| Planned             | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 |
|---------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Microcontroller Training |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| System Design Specification |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Hardware Design      |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Hardware Self Testing Software |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Hardware Evaluation  |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Software Development |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Software Revisions   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Final System Evaluation |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

| Actual              | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
|---------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Microcontroller Training |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| System Design Specification |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Hardware Design      |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Hardware Self Testing Software |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Hardware Evaluation  |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Software Development |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Software Revisions   |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Final System Evaluation |   |   |   |   |   |   |   |   |   |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

Figure 3: Simplified Actual and Planned Work Programmes
10. **Subcontractor Information**

The company had no previous experience in selecting electronic design subcontractors, and therefore was heavily assisted by the TTN in devising the criteria and selecting the appropriate design subcontractor for the application experiment. The selection of a design subcontractor was complicated by the remote location of the company (on the west Wales coast and accessed only by rural roads).

The selection criteria identified by the TTN were therefore:

i. An excellent track record in developing a range of microcontroller based measurement and data processing equipment.

ii. The flexibility to undertake the design specification amendments required when dealing with a first user with no prior electronic experience without recourse to changes of subcontracts at every stage.

iii. Prior experience of working with very small companies, thereby indicating the flexibility required in (ii) above.

The company selected as its preferred design sub-contractor ESD Consultants Ltd, following the advice of the TTN. This design sub-contractor provided the company with exposure to an organization, and to a particular individual, with a proven record in developing microcontroller based products for a wide range of applications, and to a design sub-contractor with a previous teaching background. This latter factor offered the company a knowledge transfer service that would facilitate the development of company expertise in microelectronics technology.

The subcontractor, ESD Consultants Ltd., had previously designed products based on a wide range of microcontrollers, including the 8051, Motorola 68HC11, PIC 16 and 17 series, and Hitachi H8/3000 series of devices. This provided the company with a subcontractor that consider fully all of the potential device implementations for the pH measurement and display test equipment, and to provide the company with advice as to the implementation route and design methodologies to be used.

The one disadvantage of the selected subcontractor was geographic distance. The identification of an available, local subcontractors with the skills identified was not possible. The extended travelling distance of over 150 kilometers, required extra planning to overcome potential problems. However, the choice of sub-contractor proved felicitous. The contact and the management were handled flexibly, bearing in mind the geographical constraints. Exchanges with the design sub-contractor were mostly therefore electronic in nature, but regular, if infrequent, personal meetings were also held.

The company and subcontractor entered into a formal subcontract. This subcontract was a fixed price contract, and the subcontractor kept to the negotiated price even though design changes required some additional effort. The ownership and intellectual property rights (IPR) of the subcontract deliverables were the property of the company under the terms of the subcontract.
11. **Barriers perceived by the company in the first use of the AE technology**

Certain initial barriers to introducing microelectronics technology into Rachel’s Dairy were regarded as significant, and are itemised below:

**Knowledge Barriers:**
- Lack of knowledge in this engineering area.
- Lack of knowledge and expertise in the areas of microelectronics construction, testing and maintenance.
- Lack of exposure to electronics suppliers.

**Technical Management Barriers:**
- Lack of experience in dealing with electronics specialists.
- Lack of management expertise in specifying the scope of work for microelectronic projects.
- Lack of contract management experience in the area of microelectronics.

**Financial Risk barriers:**
- Difficulties in defining the level of risk associated with the development program, and therefore in factoring the level of risk into investment decisions.

The range of barriers faced by a company such as Rachel’s Dairy was therefore very wide, and probably characteristic of small food producing companies throughout Europe. In practice most of these were overcome by adopting a flexible and pragmatic approach (see Section 12).

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

The steps undertaken to overcome the barriers are described below:

**Knowledge Barriers:**
- *Lack of knowledge in this engineering area* The knowledge barriers faced by the company have been partially reduced by going through the FUSE processes of preparing the technical submission with the support of the TTN, and in the preparation of technical, planning, risk and cost assessments for this feasibility study. This enabled the company to benefit from the advice of the TTN by providing an initial input into the company’s knowledge in these areas and demystifying the subject.

- *Lack of knowledge and expertise in the areas of microelectronics construction, testing and maintenance* The barriers faced in this are have been found to be capable of being resolved by the application of combined and, in some cases, little recognised expertise from a number of managers and staff within the company. The support of the subcontractor was available when requested, and this advice removed the fear of undertaking this task with no support. Discovering the existence of such in-house knowledge has been an additional benefit.
• **Lack of exposure to electronics suppliers**  This barrier was overcome during the application experiment, as the Project Manager had to source a wide range of electronic equipment. This was assisted by the supply of suggested sources by the design subcontractor.

**Technical Management Barriers:**

• **Lack of management expertise in specifying the scope of work for microelectronic projects**  Detailed technical and management knowledge was developed during the application experiment. The FUSE application experiment protocols have provided a phased training opportunity and a continuing support structure from which the company benefited. This organisational sequence lowered significantly the pressures faced by the company in adopting microcontroller technology, by spreading out the issues to be considered over the application experiment, rather than having to address all the issues in advance of a standard commercial contract decision.

• **Lack of experience in dealing with electronics specialists**  The TTN’s continued presence and availability during the application experiment has offered the company an assurance of continued support in technical matters and management advice that has enabled the company to consider itself capable of handling specification issues, subcontract issues and component supplier interfaces throughout the application experiment. This ‘hand-holding’ presence is a key psychological support and has allowed the company to overcome the barriers that it faced.

• **Lack of contract management experience in the area of microelectronics**  Whilst the company is not an expert in this area at the end of the application experiment, it is not really considered a problem now. The company has benefited from the experience of working with the TTN and subcontractor to be in a position where it could handle such a project in the future with minimal support.

**Financial Risk barriers:**

• **Difficulties in defining the level of risk associated with the development program, and therefore in factoring the level of risk into investment decisions.**  The company was supported by the TTN in the development of the initial feasibility study into the use of the PH data logger, and this quantified the risk faced by the company. It is probable that the TTN, or other support centre, will be required in the future to provide assessments of costs and risks in new technology areas, but the company is now in a better position to manage this process.

13. **Knowledge and experience acquired**

The company anticipate that it would develop knowledge in the following areas at the start of the application experiment:

• Technical managerial skills required to accurately specify the product and to manage subcontractors.

• Test and maintenance skills for microcontroller based process-monitoring equipment.
These skills have been developed successfully. Although the testing skills have been developed during the application experiment, this area is one that will benefit further as more testing is conducted in the post-experiment, industrialisation period.

Subsidiary knowledge development goals consisted of:

a) Technology selection capabilities and the ability to appreciate the design and capabilities of microcontroller technology.

b) The ability to implement minor modifications to the embedded microcontroller code if required.

c) An appreciation of the hardware and software design approaches to be adopted, and the test methods and test solutions to be adopted in future microcontroller based projects, including communication options and the kinds of interface required at various stages in the system.

Goal (a) was successfully achieved. Whilst training addressed the ability to change and edit code sections, Goal (b) was not in practice achieved, as it was not greatly used or necessary during the experiment. Therefore, it is doubtful that the company could edit code without further guidance, as such knowledge and skills are only acquired by regular and repeat usage. Goal (c) was successfully achieved.

The outcome of the knowledge development process is therefore positive, and the company is now in the position to manage the development of such projects in the future with minimal support.

14. Lessons learned

The applications experiment is regarded as successful and will lead on to operational application of the system designed, or further refinements of this system. Several lessons were learned from the process of conducting of the experiment, and the following advice is presented for others to consider:

• Training: The company split the training between the staff members involved in the application experiment. The split training is both advantageous – in terms of two managers with some microcontroller knowledge, and disadvantageous - in terms of no one individual having the ability to address all problems. The other difficulty lies in the ability of the two participants to retain the acquired knowledge, when periods of the project elapse without it being actively applied. On balance, in Rachel’s Dairy’s context, the value of the training lies more in the Technical Manager and Project Manager having an informed understanding of the hardware and software, and an ability to perceive what might be required, rather than an ability to actually undertake either hardware modifications or programming without advice. The company advises other replicating companies to consider carefully the provision of wider training than just investing in one individual.

• Planning: The difficulty of planning, especially in estimating the time and cost to the various elements of such a project for a first user should not be underestimated. Though the company was able to draw on the experience of the TTN, there were still some deviations. This experience indicates that replicating companies should carefully consider the scope of the project before starting, and that all possible changes to the specification should be anticipated if possible. Possibly, one contractual mechanism is to have a contract for specification
development, and a fixed price contract for the development of the equipment to this specification.

- **Subcontractor Liaison:** The company, and the sub-contractor ideally need to be much closer geographically than was the case here. Where there is a greater need for detailed design knowledge transfer than had been established for Rachel’s application experiment, this distance factor would be very important. When the company is a shorter distance away from the design sub-contractor, more visits can take place in both directions facilitating a better appreciation of design decisions. Though modern e-communications allow relatively rapid exchange of instructions, views and data, they do not encourage the closeness and on-going familiarity with developments that site visits allow.

- **Documentation:** For a first user it is difficult to keep abreast of technical matters unless one receives regular exposure to them. This application experiment required a large leap in technical terms for the company. Unless very full documentation is provided, even matters of a trivial nature can produce insuperable barriers to progress.

- **Subcontracts:** This application has demonstrated the benefit of a formal subcontract. This is essential and the advice of a body such as the TTN in defining a subcontract is considered essential.

15. **Resulting product, its industrialisation and internal replication**

The prototype system functions correctly, and meets the original design specification. Testing established that the measured pH levels were consistent with values determined using the existing probe system as a reference.

The future industrialisation process is minimal. The prototype product produced is an end in itself. The only remaining industrialisation task relates to the continuing operational evaluation of the system to ensure it is fully acceptable for application in the process control environment. This process will prove the accuracy of the system against the existing commercial test equipment, and will identify any refinements to the system so that it might be considered for use in a new and much enlarged production facility currently being planned.

Operational evaluation of the system involves:

- Installing the electronic modules into robust housings
- Operator training
- Correlation between the measurements taken by the new system versus those by the old method
  1. from hour to hour during the processing of one batch
  2. from week to week to detect and compare any aging effects
  3. from one position in the pallet stack to another
  4. from one operator to another (using the manual method)
- Progressively replacing the old method by the new system, with a suitable overlap
- Conducting trials in the new production facility at the earliest opportunity
The time required to complete these remaining tasks is 6 months. The time scale is defined by the need to gain extended experience in the use of the system, before moving to full reliance on the improved pH monitoring equipment. The cost of this industrialisation process is estimated at 12 K Euro, being almost entirely labour costs.

Further replications within the company will be considered. The dairy manufacturing process continues to demand increasingly high levels of production process control to satisfy retailer requirements for cost reduction and quality improvements. Potential replication areas include monitoring chill and storage temperatures during in-house storage and during transport, and hygiene monitoring tests to ensure products meet health requirements. Logging of this information on a continuous basis might be required.

These examples illustrate the company’s growing awareness as to the benefits of adopting microelectronics and data archiving systems for its production processes.

16. Economic impact and improvement in competitive position

The improved control of pH values during the yoghurt manufacturing process will bring comprehensive benefits to the company, including:

1. Financial savings as a result of reduced wastage, resulting from improved product quality. The loss of a reject batch of yoghurt will represent a loss of approximately 1000 litres of processed milk. The total cost of lost product is therefore significant. Current losses caused by wastage (out-of-spec goods and product spoilage) equate to 3% of the company’s production. This figure can be reduced to less than 1% by consistently achieving within-specification pH levels. This can be achieved with the pH monitoring system, rather than depending on operator skill and application of the current manual method. This financial improvement is therefore quantified as 2% of sales valued at the cost of production. The cost of production up to this point in the process is estimated as 22% of the sales value.

2. Increased sales potential from satisfied customers recommending the product and through repeat purchasing. Final product acidity greatly influences product quality and customer acceptance, and poor quality performance would result in sales losses for a significant period.

3. Greater listing potential in major supermarket chains. Retailers pay great attention to customer complaints and require suppliers to consistently monitor complaint levels. A reduction in complaints, thus resulting in more satisfied customers and a reduction in costs in both businesses can influence greatly listing potential. Sales levels will expand as more supermarkets give Rachel’s Dairy approved supplier status.

The economic benefits of improved quality on customer satisfaction and in producing an improved supplier rating with the major supermarkets will be even more significant. The projected increase in sales of yoghurt in the future due to this factor will be at least 2% above that projected without the improvement. The forecast percentage increase in sales year on year has therefore been upgraded by 2% for each year, which will have a significant cumulative effect in view of the major expansion
that is planned. The financial benefit derived from these additional sales is calculated as the gross profit on these additional sales. Not only will the company therefore benefit greatly from this 2% annual improvement in sales, but it views this improvement in process control as a pre-requisite to the planned expansion, to prevent a proportionate increase in wastage and the accompanying management distraction.

The impact on sales of the improved quality control is illustrated in the following chart.

![Sales Relative to 1999 Figures](chart1)

**Chart 1: Projected Sales for Existing and Improved Process**

In addition, there are environmental benefits through the reduction in costs for the disposal of the spoilt yoghurt which is not pH neutral. This has not been quantified because it is small in relation to the other benefits, but it may have increasing importance in the future.

The increased profits forecast in the first full year of production will represent a payback period of less than 7 months for the investment cost of the development, which was 38 K Euro. The return on investment in future years will increase significantly as the level of sales growth produces larger returns. The expected rate of return on investment (ROI) is 2500% over 4 years.

The cost of the industrialisation process described in Section 15 is estimated at 12 K Euro. Including these costs extends the payback period to 10 months, but still shows an ROI of almost 2000% over 4 years.

Despite these clear economic advantages, it is thought that none of Rachel’s Dairy’s competitors have adopted such a system.

17. **Target audience for dissemination throughout Europe**

This application experiment demonstrated best practice in the following areas:

- Specification development, to reflect the issues relating to the increase in company sales turnover in assessing the use of the equipment in the new environment before the design was accepted.
The impact of the RF communications link allows the system to be adopted in a much larger, less manually intensive system.

• Sensor selection, which anticipated the need for the system to work with dozens of sensors, and the review and assessment of these in the future.

• Subcontractor selection and management which led to a successful delivery of the system.

• Evaluation, which involved the inclusion of plant supervisors and production staff to ensure that the system’s use was fully evaluated. This ensured that the production staff could be involved in the development process.

The target audience for the demonstrator documentation and related materials produced by this application experiment will include the General Managers and Managing Directors of organisations operating in the following industrial areas:

1. Food production - Prodcom Code 15
2. Agriculture - Prodcom code 0100
3. Fishing - Prodcom Code 0500
4. Craft Industries - Prodcom code 20

The application experiment offers the potential for replications in other food processing companies.