

Equipment Management Trial Final Report

This report summarises the work of the Equipment Management Trial. Supporting reports (Equipment Management Multi Home Trial Report and other documents held in the virtual office) provide additional information.

June 2005

Executive Summary

The Equipment Management (EM) trial was one of the practical initiatives conceived and implemented by members of The Application Home Initiative (TAHI) to demonstrate the feasibility of interoperability between white and brown goods, and other domestic equipment.

The trial ran from October 2002 to June 2005, over which period it achieved its core objectives through the deployment in early 2005 of an integrated system in trials in 15 occupied homes. Prior to roll out into the field, the work was underpinned by soak testing, validation, laboratory experiments, case studies, user questionnaires, simulations and other research, conducted in a single demonstration home in Loughborough, as well as in Universities in the East Midlands and Scotland.

Throughout its life, the trial faced significant membership changes, which had a far greater impact than the technical issues that were tackled. Two blue chip companies withdrew at the point of signing the collaborative agreement; another made a major change in strategic direction half way through and withdrew the major portion of its backing; another corporate left at this point, a second one later; one corporate was a late entrant; the technical leader made a boardroom decision not to do the engineering work that it had promised; one company went into liquidation; another went up for sale whilst others reorganised. The trial was conducted against this backdrop of continual commercial change. Despite this difficult operating environment, the trial met its objectives, although not entirely as envisaged initially – a tribute to the determination of the trial's membership, the strength of its formal governance and management processes, and especially, the financial support of the dti.

The equipment on trial featured a central heating/hot water boiler, washing machine, security system, gas alarm and utility meters, all connected to a home gateway, integrated functionally and presented to the users via a single interface.

The trial met its principal objective to show that by connecting appliances to each other and to a support system, benefits in remote condition monitoring, maintenance, appliance & home controls optimisation and convenience to the customer & service supplier could be provided.

The trial met this objective by:

- demonstrating that narrowband remote services from a variety of suppliers using equipment from different manufacturers, can be delivered to real homes;
- proving that communications with, and services related to, everyday appliances and home systems are deliverable with existing technology and relatively easy to achieve with broadband;
- finding that systems for the home environment need to be especially robust because of the nature of service demands and high customer expectations for reliable system integrity;
- identifying that customers want timely and meaningful data on energy consumption and are willing to interact with such a system in order to improve their home environment;
- identifying a range of potential service offerings for customers and demonstrating a selection of these for customer evaluation;
- showing that users are willing to cross over between loosely related services presented to them on the same home portal;
- finding that central user interface displays should:
 - include life saving alarms;
 - show information about damage to property;
 - give detailed information about electricity, gas and water use;
- finding also that:
 - central control of appliances is not popular;
 - data security is a major issue for respondents.

This is one of two main reports that form the trial output (the other, the Multi Home Trial Report, is available to EM Trial members only as it contains commercially sensitive information). A supporting library of documents is also available and is held in the virtual office hosted by Loughborough University Centre for the Integrated Home Environment.

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1 INTRODUCTION

During 2001 the idea of an Applications and Services led Initiative was aired and The Application Home Initiative (TAHI) was launched. It now has some 40 organisations as Members of the initiative that are working to bring new applications and services to home-based users. The aims and objectives of TAHI are applicable to Service Providers, Customer Facing Organisations and Consumers world-wide.

TAHI is a Company Limited by Guarantee that aims to accelerate the adoption of networked applications and services by connected home-based users. It is identifying the applications and services that people want and will pay for.

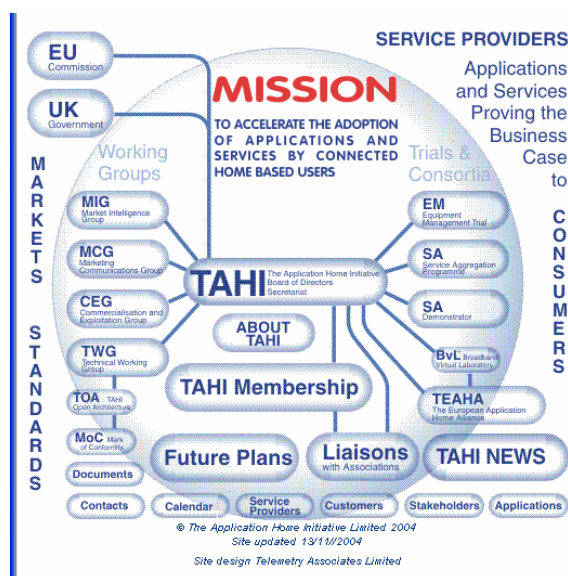


Figure 1. TAHI overview

One of TAHI's key objectives is to use practical trials to learn about the business models, logistics, costs and customer benefits that make up the business case for major deployments of a wide range of services and applications.

For this reason TAHI members supported the creation of a number of trial projects to test or exploit the take up of applications and services in a number of sectors.

Two of these activities, the Equipment Management (EM) and Services Aggregation (SA) Trials, have now completed their work. Other trials are in varying stages of progress. For example, across Europe, work is underway on Project TEAHA, funded under EU Framework Programme 6.

Through this approach, TAHI is showing both service providers and the users of services the scope of what the future will bring. It will increase awareness and speed the take up of broadband.

TAHI also has active working groups that are bringing understanding of the wants and needs of consumers, the benefits of services provision, and the architectures for delivery. Tahi members are discovering new ideas and ways of bringing new and better services to the consumer to the benefit of all stakeholders.

1.1 TAHI PROJECT WORKING GROUPS

The following working groups were set up to focus the full range of trial work and partner organisations. The EM trial drew on the expertise of these groups as appropriate in the trial.

Market Intelligence Group - understanding and statistics on the market place. Included in the MIG work is a group working on modelling the business and value case where many services are available to consumers.

Technical Working Group - developing the Tahi Open Architecture (TOA) and Mark of Conformity (MoC) and informing standards internationally. Included in the activities of the TWG the TOA work has a number of sub-groups associated with it.

Marketing Communications Group - delivering the promotional strategies of Tahi. This group is currently being established.

Commercialisation and Exploitation Group – promoting and exploiting the outcomes of Tahi activities. This group is currently being established and will build links between Tahi and the EU Commission.

Tahi has presented the Tahi Open Architecture as a way to manage the delivery of Services and Applications in European projects and larger initiatives and has received encouragement to take this work forward.

Membership of Tahi is open to any organisation that may gain a benefit from so doing.

2 AIMS AND OBJECTIVES

2.1 OUTLINE OBJECTIVES

The objectives of the EM trial, as outlined in September 2002 for the NEXT WAVE TECHNOLOGIES AND MARKETS third call, were as follows:

“Over a two-year period, the Tahi Equipment Management trial will seek to accelerate the interoperability between connected devices around the home and thereby deliver added value through the provision of information services to the customer/end user. The trial will show that connecting appliances to each other and to a support system, benefits in remote condition monitoring; maintenance; appliance and home controls optimisation; and convenience to the customer and service supplier - may be provided.

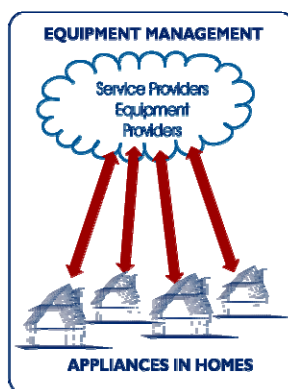


Figure 2. The Equipment Management Conceptual Model

The main applications envisaged are:

- *Remote diagnostics, control and maintenance of: washing machines; dish washers; cookers; central heating boilers; and refrigerators/freezers;*
- *Automatic meter reading and energy management;*
- *Security systems;*
- *Safety systems in the home, such as natural gas, smoke or CO emissions detection, water leakage from appliances or main pipes, abnormal appliance energy consumption;*
- *Back end services to carry out the remote diagnostics and equipment control, monitor conditions and optimise appliance/system performance;*
- *System and appliance interfaces with the customer.*

There are four main areas of research associated with the trial that will take place during the life of the project and will move forward in clearly defined phases and deliverables:

EM R&D 1: Equipment Interoperability Specification and Testing

Because white goods will be sourced from different appliance manufacturers, common versions of data acquisition language are required to interrogate appliances. This new language will form the basis of test specifications and procedures and will determine how interoperability measurements can be conducted e.g. by simulating different housing styles, patterns of use etc. This activity supports the eventual adoption of a Mark of Conformity.

EM R&D 2: Human Computer Interactions

There are many barriers to the use of new technology, not least the HCI issues. Easy to interpret, intuitive display of appliance information will play an important part of the EM trial. One option for example would be to develop clear, simple information displays on home systems via the home TV. The HCI element of the research will involve HCI considerations for the design of the home system as well as later product orientated user evaluations.

EM R&D 3: Home Network Management

Unlike in the workplace, there is no IT network support service in the home. The work would investigate the needs of a connected home, to determine the strategies required to configure, structure and support restricted-intelligence, interconnected, white goods. For example, equipment might be monitored and requisite action taken under fault conditions or when maintenance is due.

EM R&D 4: Data Acquisition and Information Management for Connected Households (Core Activity).

The main objective of this work is to develop a software based information management system and associated intelligent data unit technology for equipment management in the home environment. This will enable gathering and access of experimental data/information, whilst protecting commercial sensitivities. This core activity is applicable to other trials, as well as providing data to other researchers.

As with other TAHI trials, in year 1 the Equipment Management trial has two initial development phases leading to the initiation of commercial rollout via a 1000 home trial: the first phase relates to a single demonstration home in which all organisations taking part will scope out their involvement defining their roles, resources and outputs. The second phase is a 50 home trial, where organisations will use the demonstration home to gauge consumer reaction to the technology and the services offered.”

The proposal also defined the scope of EM applications as follows:

- *Remote condition monitoring, fault diagnostics, control and maintenance of equipment drawn from: -*
 - *washing machines;*
 - *dish washers;*
 - *cookers;*
 - *central heating boilers;*
 - *and refrigerators/freezers;*
- *Automatic electricity, gas and water meter reading;*
- *Energy management and optimisation of system efficiencies;*
- *Home climate control;*
- *Security systems;*
- *Safety systems in the home, such as:*
 - *natural gas;*
 - *smoke or CO emissions detection;*
 - *water leakage from appliances or main pipes;*
 - *abnormal appliance energy consumption;*
- *Back end services to carry out the remote diagnostics and equipment control, monitor conditions and optimise appliance/system performance;*
- *System and appliance interfaces with the customer.”*

The underlying theme of the trial was that although each application may be defined individually, none has an individual business case. Taken together, there are economies derived from the sharing of an infrastructure and this then makes the business case of the sum of the individual applications potentially viable. A key aspect of the trial was therefore to create an architecture which is generic and in which different devices, applications and services can be operated.

With the exception of home climate control, which was Honeywell's domain, the above applications were demonstrated to a greater or lesser extent. The trial did not depart from its core objectives although Dyson's entry caused the gateway to be fatter and require more memory and processing power than envisaged initially, in order to display local information about equipment status.

2.2 TRIAL DELIVERABLES

The original deliverables of the Equipment Management trial were to:

- Use a demonstrator and test facility to prove a TAHI specification which can be used for a Mark of Conformity;
- Create and demonstrate a home network using low data rate, plug and play technologies from a number of different suppliers;
- Create and demonstrate an infrastructure capable of supporting the network;
- Demonstrate the ability to manage remotely, fault identify and optimise the operation of white & brown goods, heating and security products in the home;
- Provide a test bed to facilitate further research in ambient computing and knowledge based Human Computer Interactions;
- Demonstrate an easy to configure user interface that is accessible to all kinds of users;
- Demonstrate interoperability of sufficient capability so that conformance tested products can be added and maintained on the network;
- Identify costs and benefits in the areas of capital/initial on cost to equipment, revenue from maintaining the network and infrastructure and any other associated costs;
- Gather information about the technical requirements and about customer behaviour relative to the offered applications;
- Provide continuing feedback from customers about the barriers, merits and difficulties associated with adopting new technologies, products and services;
- Evaluate the customer value propositions and service provider value proposition for applications that maintain and manage the customers' equipment;
- Identify the gaps in required new products and services associated with the interconnected home, to feed into future R&D activities of the NWTM Virtual Centre for the Integrated Home Environment.

Achievements against each above deliverable are given in section 3.3 below.

2.3 CONSORTIUM MEMBERS

The following 17 organisations were cited in the grant application. This Table sets out their initial roles and those that developed or ceased throughout the course of the trial.

Organisation	Expected contribution at start of trial	Contribution at completion of trial
Industrial Research & Technology Organisation		
Advantica	Testing & Verification process in support of Mark of Conformity. Gateway software. Support to field activities. Demonstration and test facilities. Support to gas alarm product application.	As at the start of the trial plus more extensive use of demonstration house; pivotal role in development of integrator residential gateway; support to gateway and security applications in the field; leadership of end to end systems integration; management of field trial activities.
SMEs		
Amino	Gateway design, prototyping, engineering and supply. Technical architecture development.	Led R&D on home networks and provided technical leadership on open architecture until their withdrawal in 2004 as a consequence of a board decision and management changes.
Extrada, formerly HomePortal	Back end system and XTN hub software.	As at the start of the trial plus gateway software development, field support to Multi Home Trial back end and leadership of business modelling activities. Technical leadership and link to Open Architecture.
Horstmann	Support for automated remote metering of electricity and gas.	As at the start of the trial plus trial leadership; provision of gateway hardware; support for water metering application; design and development of white goods monitors.
nSine	Powerline communications product application support.	Withdrew in 2004 as a consequence of company liquidation.
Olameter	Metering services and new business opportunities; financial management of trial.	Withdrew in 2002 before signing joint project agreement.
Telemetry Associates	Programme management.	As at the start of the trial plus financial management; support to Multi Home Trial.
Higher Education Institutes		
De Montfort University	Creation of data information and management system.	As at the start of the trial.
Ergonomics & Safety Research Institute (ESRI)	Design and evaluation of user displays	As at the start of the trial plus greater involvement in field trial and in creation of final report documentation.
Loughborough University	System simulation and emulation.	As at the start of the trial.
Heriot-Watt University	Use of user displays to influence energy usage.	As at the start of the trial plus greater role in energy matters.
Corporates		
Accenture	New commercial opportunities and creation of business model.	Withdrew in 2003 on back of Centrica's decision.
Centrica	Trial leadership; support to remote diagnostics of central heating boiler application; support to Multi Home Trial; exploitation of products and systems.	Passive role from 2003 following strategic review of products and services.
DSC Tyco	Support for security application.	Withdrew in 2003 before signing joint project agreement.
Dyson	Late entrant in 2003.	Gateway software; support to washing machine application; business case for remote diagnostics and equipment management.
Echelon	Powerline communications support.	Withdrew in 2003 before signing joint project agreement.
Honeywell	Support for Hometronic home environment control application.	Withdrew in 2004 because could not resource technical support for their product.
Invensys	Critical role on development of gateway software; support to remote diagnostics of central heating boiler application.	As at the start of the trial but effort transferred to retrofit iCom boiler energy monitor.
Panasonic	Support for brown goods applications.	Withdrew in 2002 before signing joint project agreement.

3 ACHIEVEMENTS

3.1 TRIAL OVERVIEW

Following extensive preparation, research, and development, 15 homes were retro-fitted with smart appliances and networked systems to assess how they fared in the real world environment, as part of a Multi Home Trial (MHT).

In participant homes the central heating/hot water boiler, washing machine, security system, gas alarm and utility meters were connected up to a home gateway. The system combined out-of-the-box technology with prototype products developed for the trial. The system this created is illustrated in the Figure below.

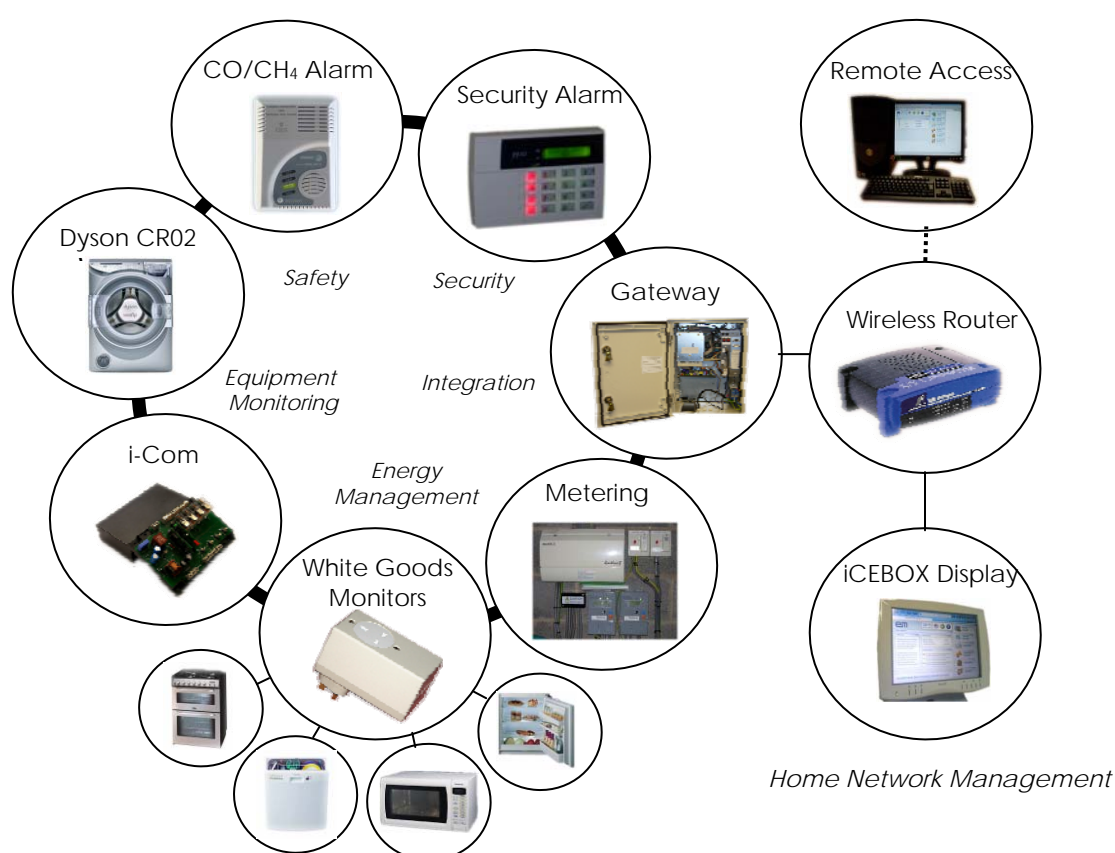


Figure 3. The Multi Home Trial smart system

Secondary meters for gas, electricity and water allowed for remote meter readings and meant that graphs charting household energy use on a day-by-day could be presented to the users via the interface.

White goods monitors were specially developed for the trial by Horstmann, to monitor and feedback detailed breakdowns of electricity use by appliance. It was originally intended that these modules would be fitted to existing white goods within the participant homes. However, technical difficulties meant that this component was not included in the MHT.

The iCom, a device developed for the trial, was fitted to the boiler to monitor the flow and return and hot water temperatures, and boiler demand.

A Dyson CR02 washing machine was modified for the trial. It utilised a powerline communication system to relay information back to Dyson and the homeowner via the home area network developed by the group.

The CO/CH₄ alarm and security alarm were integrated in the system and an overview of their status was provided in a central interface.

The residential integrator gateway was designed and implemented specifically for trial applications, with applications software running under an OSGi framework, on a single board computer.

All of this functionality was integrated and presented to the users in a single interface on an iCEBOX™, a countertop Windows CE computer that brings entertainment options together in one single device specifically designed for the kitchen. The iCEBOX communicated with the gateway via a wireless router with a broadband connection. Users and service providers in the trial could also access the home information remotely via various web browser screens. Some local, more detailed, information was also provided to householders directly from the gateway. The iCEBOX, manufactured by Salton, also incorporated TV, Internet, DVD/CD, FM radio, home video monitoring and appliance connectivity. It has a touch screen with stylus and a washable wireless remote control and keyboard. Whilst it had limitations to the requirements of the trial (for example, using Windows CE) and a number of alternatives were considered, it provided a central device that fitted the concept of the trial. Additionally, practical issues of availability and cost influenced the decision to include the iCEBOX.

3.2 ACHIEVEMENTS AGAINST EACH PROJECT DELIVERABLE

In the following sections, the achievements of the programme are set out against the deliverables of the project proposal and beyond. Overall though, the key conclusions of the field trial work are as follows:

- Although not intended for commercial rollout, the EM trial gateway was surprisingly resilient for a Windows system and once setup, was stable. Power loss and network loss were all reliably recovered and in some cases after a few weeks retry still recovered.
- The OSGi framework was highly stable and the remote management function very efficient. Device discovery within OSGi XML queries from the remote server are effective and interoperability mechanisms are inherent. However, a technical capability is required of device suppliers to implement such a system and this is an issue for all technology choices. There is a wide range of network interfaces available. Various alternatives to OSGi have similar merits.

- Generally, once commissioned and teething problems resolved, the equipment was reliable, although there were unexpected hardware failures. A mainsborne interference problem in one house remains unexplained. LON and EHS 'enrolment' mechanisms were found to be straightforward and realistic for an installer to perform with no operational issues and LON and EHS communications co-existed successfully on the same powerline network. Mains Ethernet was problematic though in some cases.
- Technologies to support product suppliers and service providers in implementing a wide range of applications in a defined infrastructure are well established. This suggests that service providers are able to deploy the types of service tested in the EM trial using available products and technology as long as these are based on a defined set of components and network connections that are independent of the customers existing home network or broadband connection. This may not be commercially viable on a cost basis and in most cases would need product developments to reduce costs. Deploying these services via the customers existing infrastructure is technically feasible but unlikely to be commercially feasible as the effort level and skill base required to install and maintain such systems will be prohibitive.
- Piggybacking on an ad hoc existing network to provide services to home devices currently requires significant costs in setup and support. Reliable wireless installation is not guaranteed because of device positioning. Not all wireless devices are suitable; applications need to need to find the optimum device for the required platform and keep the wireless channel open for reliability. There is always the contingency that cable may have to be used.
- The EM system was originally intended as dial up but broadband was chosen for expediency and useful experience was gained as a consequence: interfacing with the customer's existing 'arbitrary' network was not straightforward, there being myriad router, PC, network device types, settings and physical installation issues.
- The installer must evaluate each installation and adapt the system to suit, with the unfortunate result that the installer then 'owns' the network issues!
- Software reliability is dependent upon user actions, causing system changes that require investigation and resolution to maintain the service.
- Remote access to devices in the home from remote systems is complex and there are connection and Firewall issues to overcome.
- The industry should test its ideas against the TAHI trial experience to verify that technical proposals are feasible and worthwhile.

3.2.1 Support for Mark of Conformity

The trial aimed to use a demonstrator and test facility to prove a TAHI specification which could be used for a Mark of Conformity.

The main objective for the EM trial (in common with SA) was to carry out a test and verification process on devices developed for, and submitted to, the trial in order to ensure interoperability of the various system components.

A key aspect of this would be the application of the TAHI Open Architecture (TOA) that would provide a reference for Advantica to interpret into a realisable and testable solution.

The TOA provides an interoperable service open architecture to remedy the current situations where there are “islands of systems” where domain specific standards & architectures co-exist resulting into complexity in managing such systems.

The TOA aims to provide a service architecture for delivery of services via broadband which will:

- Clearly define responsibilities and relationships between various stakeholders.
- Allow service resources to be “mixed & matched” easily to aggregate services.
- Support different business models (e.g. pay-per-use, subscription, etc).
- Enable resource sharing between different services.
- Enable service providers to deliver their services to a wide range of connected home users regardless of their home configuration.
- Enable connected-home users to retain freedom of choice.

The TOA is represented in the Figure below.

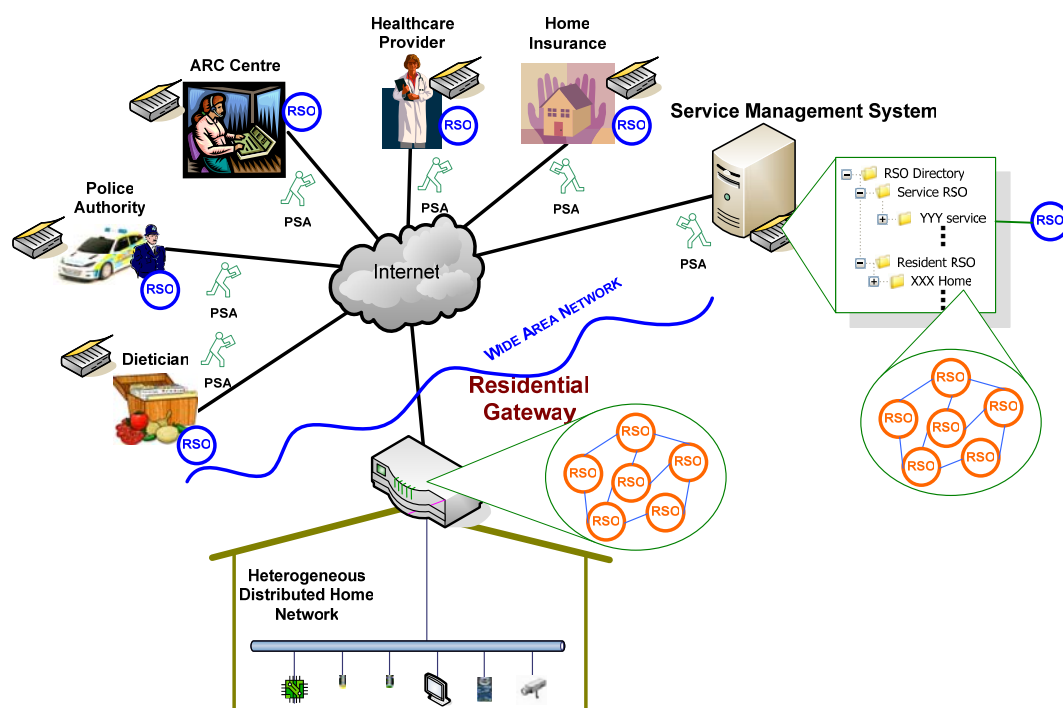


Figure 4. Representation of the TAHI Open Architecture

“Mix & Match”, “Mass Customisation” & “Choice” will be key ingredients for the success of service delivery via broadband. Interoperability is essential and central to such success and is required for all levels within the service supply chain – from device to system.

The TOA aims to provide an architecture of architectures within the public domain that offers a framework for interoperability between different resources (devices, systems & service applications) and supports the complete service supply chain into and from the home environment. The trial extends the current work on the TOA to meet these challenges. Wide acceptance and co-operation between organisations are essential ingredients for the success of interoperability.

The process of applying the TOA within the EM trial was to:

- Develop a series of interoperability specifications.
- Translate these interoperability specifications into a series of 'test procedures'.
- Develop test applications for devices to exercise functionality independently.
- Test devices and report results.

The experience of the EM trial ultimately deviated from this considerably for a number of reasons:

- Agreement on the detailed requirements of the applications to go into the trial was hugely protracted and, though detailed interoperability specifications were produced (and formed a key basis for the EM system design) the appearance of 'complete' applications was so late in the development as to make the type of testing originally planned unrealistic as this would put implementation beyond the end of the project finish date.
- Development of the open architecture by the TAHI Technical Working Group (following changes in Amino's involvement in TAHI and the EM trial) was also hugely prolonged and did not result in a testable architecture that could meaningfully be applied in a testing context.

The initial work on developing the interoperability specifications was completed and this formed a key basis for the EM trial system development.

The approach in the specification and design process was to start from an outline based on devices available and related application areas. From this a list of services to be provided and the devices they required was derived. A gateway architecture was then abstracted from this as this would be the application specific embodiment of the system in the home. The gateway architecture defined:

- Physical interfaces
 - Hardware interfaces to the various networks interconnected by the gateway - local and wide area.
- Network drivers
 - Software interfaces to each different network type used in the home.

- Device drivers
 - Software interfaces between the local applications on the gateway and the actual devices on the network. These abstract the detail of the device and the protocol to enable easier support from the application itself. A device may be an alarm, appliance, etc.
- Local applications
 - Software 'components' running on the gateway that manage the application behaviour at the local level (and provide the decision on what remote actions may be required in response to local events).
- Remote interface application(s)
 - Gateway software interface to remote applications running external to the home.

This architecture enabled partitioning the implementation to a level where the elements required to be developed or procured could be clearly defined.

The most significant development effort would be required in the applications themselves and it was important that these be thoroughly defined prior to development. Where there was a dependency on devices or software from more than one supplier relating to an application, then the development could be appropriately apportioned to different organisations and common interfaces between developments were clearly understood.

To reach this level of definition, each application was abstracted to a specific set of 'events' and 'methods'. 'Events' were asynchronous (generally automatically invoked) actions that would require an action or response from a bundle and 'methods' were functions (normally user invoked) that would require some action to be carried out and normally some data or parameters to be returned to the user. These methods would be invoked by the user interface which would be an application in its own right.

The definition created was translated directly into a set of software 'bundles' (applications) implemented within an Open Services Gateway initiative (OSGi™) gateway (though any other object oriented implementation would be possible from this). The definition included the remote service interface to the Extrada applications implemented via their 'glue' bundle on the gateway, enabling access from outside the home.

The trial used a number of devices of different types (both in function and interface requirements):

- Echelon LON (powerline) for the metering device.
- European Home Systems (EHS) (powerline) for safety.
- EHS (powerline) for the washing machine.
- Hardwired security panel interface.
- EHS (powerline) for the heating appliance monitor.

It had been anticipated that bespoke Radio Frequency (RF) protocol devices would also be used (from Honeywell) although trial membership changes precluded this. In addition a range of network interfaces (Ethernet and Wi-Fi®) were used.

The key issue of interoperability between these different application and communications types (which the open architecture and related methodologies attempt to address) was not a significant issue in the implementation due to the development of the interoperability specification and the use of the OSGi framework.

An implementation of the OSGi standard was used to create an environment in the home that would enable the different applications to interoperate and communicate with the required devices through appropriate network interfaces. An important feature of the implementation was Extrada's 'glue' bundle, an OSGi application that uses a method exposed by the application bundles to determine the capabilities of each device and provide this in an Extensible Markup Language (XML) definition to applications running on a remote server. This XML definition can then be used by remote applications to understand and enlist the services of devices in the home in a flexible and generic manner.

The OSGi framework was chosen for implementation of the gateway functionality because two trial partners already had experience of this technology so it was an easier development route than choosing unknown technologies. A number of the trial partners still had to learn this technology from scratch and this illustrates an issue in networked home technology that a considerable degree of appropriate skill and resource is required by any potential suppliers of these types of products. The OSGi standard provides mechanisms to discover new devices on the residential network and identify their capabilities and match this to applications available on the gateway. It also provides mechanisms to remotely manage applications available on the gateway and so to add new applications and update existing ones. The rich set of existing network interfaces and standard packages available in the OSGi framework mean that, once familiar with the system, development of applications can focus very much on the detail of the application and little on understanding the communications technology. OSGi had readily available interfaces for the EHS and LON protocols that would be required in the EM trial.

Although OSGi was used as the development approach, it was recognised that this may not be the most appropriate route for commercialisation.

The OSGi application development progressed reasonably well based on the original document, though some parts were not followed through (e.g. implementation of the Honeywell functionality). Aspects of the gateway development process is shown in the following Figure.



Figure 5. Gateway design in conceptual stage

The experience of using this technology showed that the OSGi standard and its implementation was mature, reliable and well thought out. It leads to the view that the need to define an open architecture that provides mechanisms for device discovery and description of services and devices in an abstract manner is unnecessary as there are existing technologies that can do this adequately for effective deployment of solutions. This does not recommend OSGi as being the only solution and there are others that fill a similar need and probably also provide solutions but were not evaluated in the trial.

It was also evident through the development both in the trial, and via experience outside the trial as well, that product developers and service developers have a great deal of commercial sensitivity with the detail of their product developments and exposing this via open standards is not necessarily in their interest. Open architectures can of course support this through manufacturer specific sections of protocols but the point is that for any worthwhile (i.e. differentiated) product offering there is going to be some specific end-to-end system development that does not have a need for totally open solutions.

The following diagram shows the original plan for the implementation of OSGi and gateway for the infrastructure to link devices in the home.

User Interface

Physical ports

OSGi

Diagnostics

Applications

Device Drivers

Network Drivers

Physical ports

Adapters

Connectivity

Devices

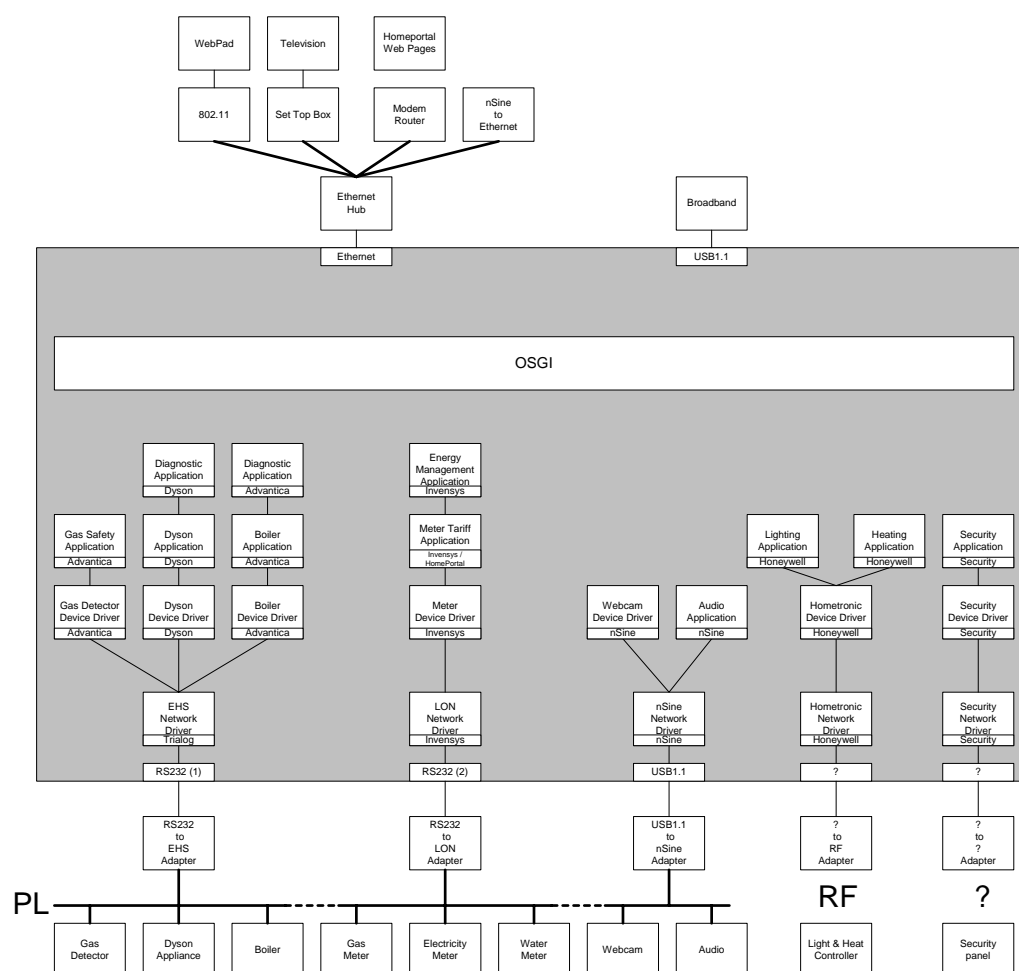


Figure 6. Implementation of OSGi in the EM home gateway

3.2.2 Plug and Play Networking

The trial aimed to create and demonstrate a home network using low data rate, plug and play technologies from a number of different suppliers.

The Multi Home Trial used existing technology wherever possible, something that would not have been feasible several years ago.

A lengthy pre-development phase was moulded into an overall system design detailed in the document EM80.1. This set out the detailed design of the gateway and network for the EM trial.

Network technologies used were based on those with which the development partners already had some experience. EHS and LON powerline protocols were used and it was expected that nSine, Hometronic and some security system interface would also be used, though nSine and Hometronic (Honeywell) dropped out of the project and security systems were connected via hard wired interface in the end.

The experience of this development was very positive. Both EHS and LON interfaces (hardware and software) were available for the OSGi framework used in the application development and so, with a little training, it was possible to build applications on this communications technology with limited detailed understandings of the technology. The integration of the EHS and LON drivers with the OSGi framework had been carried out very effectively by the suppliers of those subcomponents and it very much had the feel of established and stable technology. It should be noted that the OSGi understanding and application development is still a complex task!

The sharing of a single EHS interface on the gateway between three different applications was a concern for both Dyson and Advantica but the system handles this all automatically and these devices, plus the LON devices could all share common physical layer network and interfaces with no interworking issues identified.



Figure 7. Commissioning the EM system in trial home 7

Performance of the networks in the homes was also reliable though there were some specific hardware failures of various powerline devices themselves, which could be attributed to their prototype nature.

Installation of the powerline devices using a process where the gateway and device is put into 'address acquisition' through defined action on the device or gateway proved simple and effective on the iCom and safety alarm and on the Dyson washing machine and LON meter when these were working properly. It can be confidently concluded that (once the products are developed to a reliable level) their installation does not require substantial skill or training (unlike the gateway setup).

Wireless (WiFi) network connections were used between gateway and router in about half the installations and between iCEBOX and router in most installations.

A substantial amount of effort was required at the start of the project to find WiFi interfaces that would work properly with the gateway and iCEBOX. As the gateway is an embedded Windows XP platform and the iCEBOX a Windows CE platform, there were some restrictions on device type and trial and error showed which devices were best suited. This shows that such installations are by no means a case of choosing any apparently suitable device off the shelf.

A WEP key was used on all networks to provide some security on the network. In most cases the wireless networking worked well and installation and set up was straightforward. In some cases the positioning of the antenna was very critical and required some time and effort to achieve good location. Loss of wireless configuration in the router or gateway occurred a few times causing apparent failure of the wireless network. This was not immediately obvious to diagnose but generally re-entering the network key at the gateway (or router) resolved the problem. In one installation the wireless transceiver on the gateway itself failed. Generally it can be concluded that wireless networking provides a good alternative to wired cabling but requires some initial effort to find and prove suitable devices and cannot be relied on in all installations.

Dyson decided to progress a connectivity solution based around powerline networking technology. Several off the shelf solutions are available to implement this technology. Dyson selected an EHS based solution from Trialog chiefly due to the non-proprietary nature of the EHS protocol.

A standard Dyson CR01 washing machine was modified to include the EHS hardware and software developed to interface to the product. The architecture of the CR01 solution is shown in the Figure below.

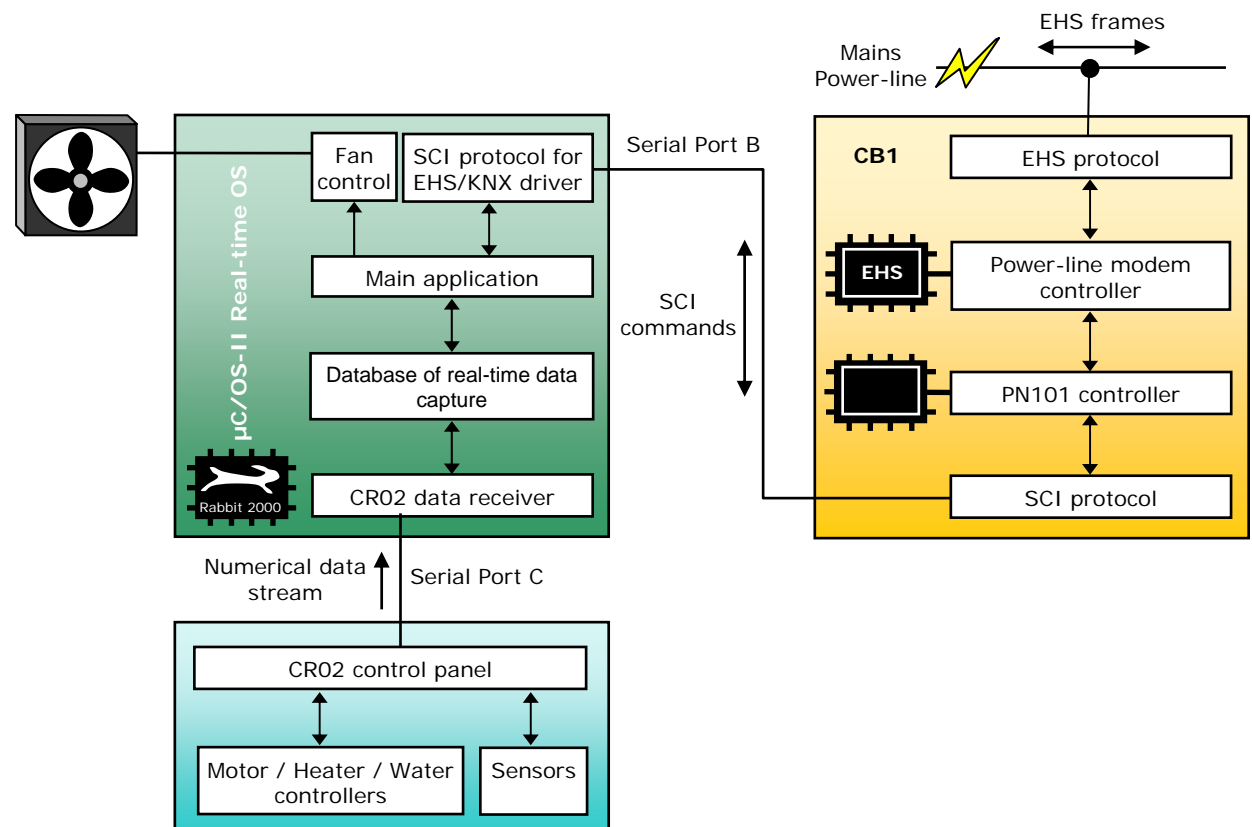


Figure 8. CR01 internal architecture

The washing machine communicated with the home network via the EHS protocol as shown in the Figure below.

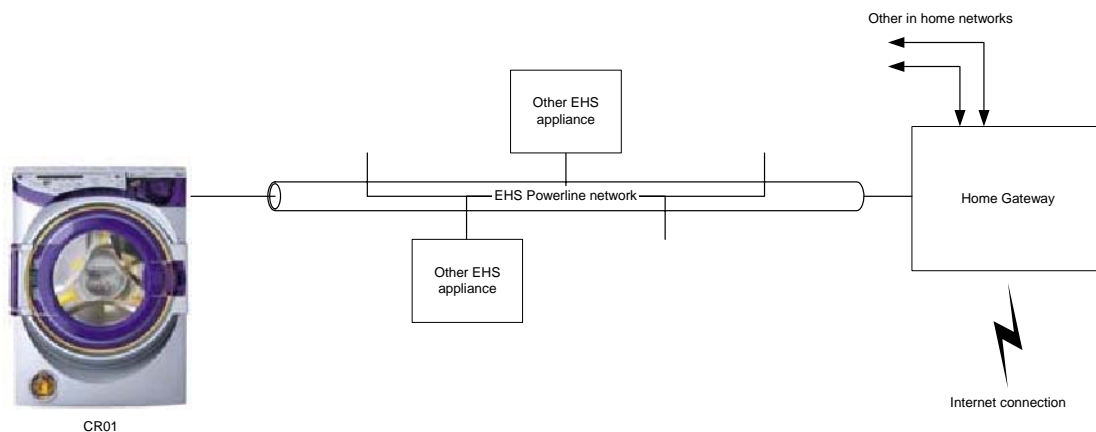


Figure 9. EHS network connection

The home gateway aggregated data from all networked devices in the home and communicated with external (internet based) systems in order to deliver services.

3.2.3 Network infrastructure

The trial aimed to create and demonstrate an infrastructure capable of supporting the network.

The trial's purpose was to provide the control and monitoring of equipment in the home, such as white goods, meters, security and home comfort. The trial began by focusing on the necessary architecture for delivering these services:

- Connectivity in the home and the concept and the management of the gateway.
- Local user interface (running on the gateway in the home).
- Remote access and management of the devices.
- Remote user interfaces for primarily service providers.
- Connection of manufacturers / service provider to the server hub.
- Data management – in and out of the home.
- Customer / equipment relationship management.

It was decided at an early stage to adopt the architecture below, showing the use case diagram for the EM system, identifying how the users and service providers interact with the system's software and hardware components. The architecture proved to be sufficient for the duration of the trial and only minor modifications took place. The main area where change took place was a decision that the gateway would have some (limited) capability to generate graphics for a local display without needing to be connected to the server.

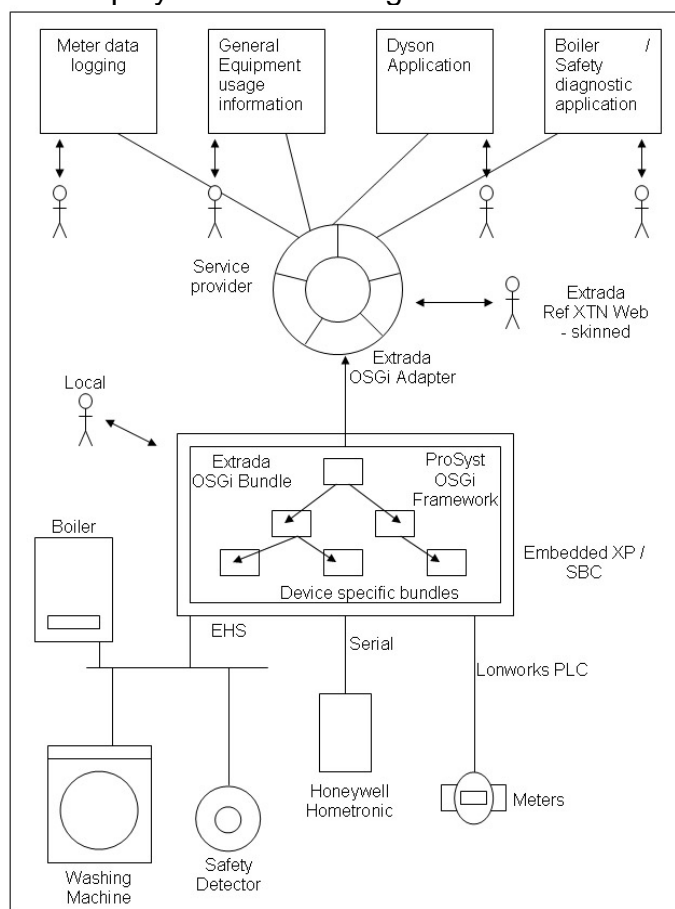


Figure 10. Use case diagram

The network and infrastructure for the EM Multi Home Trial was not initially seen as being a major area of development in that the intention was to use existing technologies for this. Its key elements were:

- EHS and LON home device networks for interfaces to appliances, meters and alarm devices.
- 'Hard-wired' connection between security system and gateway.
- Ethernet and/or wireless (Wi-Fi) connection between router, gateway and user interfaces (iCEBOX and the user's PC).
- Extrada's XTN™ hub as the basis of the server application communicating with the OSGi framework on the gateway via their OSGi 'glue' bundle.

It had initially been planned to use a dial-up connection for the remote connection from the home to the XTN hub and this was adequate in terms of bandwidth as no applications needed more than a few tens of bytes transmitted per day. However dial-up posed the problem of managing the dial up connection (i.e. when to dial in and how to buffer data until the connection was established). It was decided to use a broadband connection to avoid this problem and this gave the added benefit that the broadband connection would be a 'carrot' for participants to encourage them onto the trial. This extended the demands on the trial installation process to include integrating the TAMI home network infrastructure with the customer's network. The experience gained here was very valuable in understanding aspects of using each customer's IP network and broadband connection to provide device-based services.

Probably the major issue experienced in the trial setup was how to establish a communications channel from the gateway, through the customer's router and via the customer's Asymmetric Digital Subscriber Line (ADSL) connection to the Extrada server. Extrada's implementation was based on using a fixed (static) Internet Protocol (IP) address for the gateway, simple enough on a Local Area Network (LAN) or business network but the trial showed that this is not practical for residential customers unless they pay for an expensive broadband service with static IP addresses.

The fixed IP address worked fine from Advantica's ADSL line but this was a business line with 5 fixed IP addresses. The trialists used the 'Freedom2surf' service provider via BT ADSL that claimed fixed IP address assignment but these addresses seemed only to be visible within the Freedom2surf network and were not visible to the wider Internet. Also the routers used in the trial did not support any method of port forwarding to expose the gateway to a fixed IP address on the Internet. On top of this there were concerns about setting up such a configuration on customers' networks in case of opening up vulnerabilities on their system. This experience all showed that the use of fixed IP addresses for domestic users was rendered impractical on cost and implementation complexity grounds.

Domain Name Service (DNS) and Virtual Private Network (VPN) options were then pursued. Dynamic DNS created many of the same issues as fixed IP addressing as it still required a port forwarding approach in the router.

The use of a VPN connection was found to be the only feasible solution in the trial as this guaranteed a known and fixed IP address to the server. This approach also had problems in that the VPN connection would stop supporting data transmission after a while on many gateways, though would remain open and apparently normal. In this situation, stopping the VPN at the server end and relying on the auto connect approach at the client end would remake the connection successfully. A process of checking the VPN status and auto disconnecting at the server would be needed for reliable maintenance of this service.

The use of a VPN for gateway-server communications is not really feasible for commercial rollout as the requirement on server resources is prohibitive so this issue remains as one that would require a satisfactory solution for any significant implementation of this type of technology.

In addition to the remote connectivity issue the need to integrate the TAHI home network with the customer's network posed many problems, including:

- Many existing broadband connections are Universal Serial Bus (USB) based and not suitable for creating a network so a new router must be installed (and the cost incurred).
- Many home PCs cannot necessarily be networked without modification if, for example, there is no Ethernet adapter. This also adds cost as the PC must be adapted.
- Wireless communications are often not reliable (even amongst only 15 trial sites), as a position for antenna giving acceptable signal strength may not be locatable. In this case Ethernet cable must be laid, with resultant costs.
- Once the TAHI network installer had set up the customer's system then the trial effectively owned the network in the customer's mind and as a result many queries were routed to trial support though not necessarily related to trial equipment.

These experiences all make it clear that to install a home network for the purposes of providing services into the home (to devices in the home) has a substantial cost of ownership for the service provider as hardware and support effort costs are substantial. No lesser issue is the fact that a high degree of installer training, experience and knowledge is required to enable dealing with the huge range of variation in network device, PC and system issues.

The powerline networks posed no particular issues and were easy to install (where the equipment itself was working correctly!) and use of these network types with dial up connection would likely give a stable and supportable infrastructure adequate for medium data rate applications.

3.2.4 Remote Management

The trial aimed to demonstrate the ability to manage remotely, fault identify and optimise the operation of white & brown goods, heating and security products in the home.

The experience of development, test and implementation of the TAHI EM trial covered a number of aspects of diagnostics and remote management, as follows:

- The ability to diagnose component faults on equipment in the home (heating appliance, washing machine, CO/CH₄ alarm and security system) through equipment self-test and monitoring.
- The ability to monitor whether devices are communicating (or not) and perform some analysis of network performance.
- The ability to remotely manage the gateway software and update applications in the home from a remote location.
- Automated functions that will provide local recovery mechanisms where possible.

These are discussed in turn in the following sections.

3.2.4.1 Remote fault diagnostics

This is a reasonably well-understood area and Advantica (in particular) brought to the trial a large amount of experience on appliance diagnostics.

The bundles developed by Advantica for the heating appliance monitor (iCom), CO/CH₄ alarm and security system as well as Dyson's washing machine bundle all provided functionality to remotely and locally identify faults.

In the cases of the CO/CH₄ alarm and security system, these basically used the devices' existing self check fault outputs to identify faults and report these to the user via the Extrada and local user interfaces.

The heating appliance monitor bundle, which gathers data from the iCom, extended this further by including some diagnostic algorithms looking at the temperature and demand performance for the appliance to carry out some basic diagnostics, including ignition failure and heating performance issues, coupled with non-instructive measurement of central heating pump speed. The late delivery of the iCom restricted the ability to test these to the required level but the experience on the trial shows that the installation and commissioning of a retrofit appliance monitor is feasible. The most challenging issue was being able to connect a demand monitor to the appliance.

There were one or two cases of 'faults' identified by the Dyson application (not with the appliance but with the inlet flow) and the experience of this worked very well in that the user was taken through a process and was able to resolve the fault based on information provided via the local user interface. An example of this is shown in the following Figure.

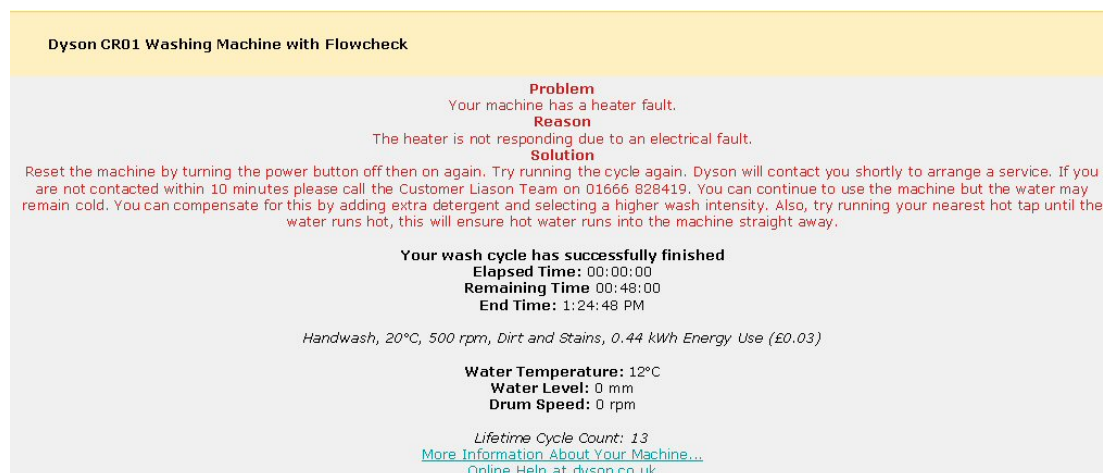


Figure 11. Appliance fault diagnosis screen shot

A CO/CH₄ alarm also failed though did not indicate this via its interface. Automated diagnostics cannot always be relied upon to identify all failure modes.

The experience also showed that in even the simplest devices, the integration of device intelligence and monitoring always enabled some form of diagnostics to be carried out and this is a beneficial low cost add-on to most conceivable home network scenarios.

3.2.4.2 Device communication status monitoring

Some basic functions were built into most of the applications to verify the communication status of each device and these were further enhanced and developed during the trial. These functions proved invaluable and essential in debugging various local and remote network issues.

The CO/CH₄ alarm, iCom, Dyson washing machine and Horstmann meter all had methods of showing whether the local device is communicating with the gateway or not (visible both locally and remotely). The gas alarm and iCom had a 'communications status' parameter. The meter bundle would not appear on the interface at all if not communicating with the meter and this could be enhanced to display a communications status. If the Dyson washing machine application lost its communication, the bundle indicated this fact. There were one or two initial problems with the implementation of some of these functions where the bundles tended to show devices were communicating when they were not. This shows that it is quite easy to (unintentionally) build an application that is misleading in this way if it, for example, displays the last data read from a device when communications had failed, as these data appear to be 'real'. The ability to display time and date of the last reading and a communications status should be proposed as fundamental in any user visible device management application.

As indicated in the previous section even basic intelligence available from home devices can be harnessed to develop diagnostic strategies. With the simple communications status information from devices, it was possible on the EM trial to identify if, for example, all devices on one network type (e.g. EHS) are not communicating. If they are not communicating, then probably the fault is with the EHS interface in the gateway and this fault was found at one location through exactly this diagnosis process.

At another location in the Multi Home Trial, all EHS communications were found to be normal but a meter was not communicating. The meter uses the LON powerline protocol and since it was possible to ascertain that the EHS powerline was OK, it was unlikely to be a fundamental powerline problem and was either the LON interface on the gateway or meter. In this case it turned out to be the meter that was faulty. If the other LON devices had been installed then this fault would have been clearly identified as relating to the physical meter and this would have been known without any local diagnostics.

In the early stages of the trial where there were significant application problems as well as some network problems it was found very useful to have a simple 'test' button function on the gas alarm. This enabled verifying in the home that basic communications and applications were running as it provided a simple way to perform an end-to-end action with a predictable result. It would be recommended that the functionality of any network device be such that the device is testable in some simple way like this. With the iCom, simply switching heating demand on or off or looking at temperatures provides this test function. On the Dyson washing machine application, changing the wash type achieved this.

3.2.4.3 Gateway software remote management

From a service provider perspective, reducing visits to customer sites to diagnose problems and for the (inevitable) update of software to fix problems or enhance features must be minimised in order to avoid excessive costs in providing networked services to customers.

The experience on the EM trial showed that associated technologies are already very well developed in this area and viable solutions exist. It has shown that the requirement that the TAHI Open Architecture addresses with Remote Service Object (RSO) discovery can be implemented with existing OSGi systems without the need for new standards.

The EM MHT used the existing Prosyst OSGi remote management functions (http server and remote console) to manage update of remote applications on trial gateways. The http server provides a repository where the gateway bundles (applications) are held and then these are distributed to chosen customer gateways via the Internet. The remote management functionality enables removal and addition as well as update of applications. Version numbers of existing applications can be checked and an extensive number of diagnostic and detailed management functions can be performed.

These functions were all used during the EM trial to update some alarm and security bundles on those gateways installed at the start of the trial (as these bundles were subsequently enhanced). The Dyson bundles were updated to add new functionality, though unfortunately this caused communications to stop on some appliances due to a problem in the Dyson washing machine prototype software. As the iComs were not available until after all gateways were installed it was not possible to install a tested bundle on the gateways prior to gateway installation and so all iCom bundles were remotely installed on to gateways prior to visits. This made the iCom installation very routine and all iComs successfully enrolled and communicated first time with the installation process requiring little expertise on the network side.

This experience showed that remote management is dependent on at least two aspects of the network infrastructure being in place:

- The network communications with the customer's gateway from the Internet must be working or there is no possibility of remote management (or diagnostics).
- Network devices must automatically handle enrolment with new applications in a reliable and predictable way.

The system used on the EM trial required a user to perform all of these actions manually but it would be entirely feasible to set up batch processes using the same technology to update and maintain a substantial user base to, for example, automatically maintain the latest versions of applications for a database of users.

3.2.4.4 Automated local recovery mechanisms

Considerable effort was applied to the gateway development and set up in order to provide a number of recovery mechanisms that would enable the gateway to recover from local errors. These predominantly used functions configured or fitted into the Windows setup and seem trivial in retrospect but ensured that the trial gateways operated reliably with only two user resets required.

Mechanisms included:

- VPN auto reconnect.
- VPN and OSGi framework automatically invoked on start up.
- Constant ping to local router to keep wireless channel open.

The VPN reconnection mechanism was particularly effective as communications were lost with most gateways for, in some cases, a few weeks after initial installation until the VPN problem was understood. At this point it was possible to disconnect these at the host end and allow the gateways to automatically reconnect after which reliable communications was achieved. This was with no intervention at the client (gateway) end of the system.

The following Figure shows the Extrada XTN reference screen for Trial Home 7, showing the type of information of value to a service provider and which can be selectively portrayed to the householder.

extrada xtn™ reference web User Manual Log Out

User: Account:

TAHI EM 7

My Content **TAHI EM 7**

TAHI EM 7

iCom Appliance Monitor

Enroled is	Yes
Demand State is	On
Demand Start Time is	13/05/2005 03:54:02
Fault State is	IGNITION_FAULT
Flow Temp is	56.0
Average Flow Temp is	20.1
Min Flow Temp is	0.0
Max Flow Temp is	57.0
Return Temp is	50.0
Average Return Temp is	17.9
Min Return Temp is	0.0
Max Return Temp is	51.0
DHW Temp is	42.0
Average DHW Temp is	17.4
Min DHW Temp is	0.0
Max DHW Temp is	54.0
Time Of Last Measurement is	13/05/2005 20:59:39
Heating Energy Increment is	74708.45
DHW Energy Increment is	229408.47

SecurityPanel

Alarm State is	Clear
Fault State is	Clear

Details

CO CH4 Alarm

CO Alarm State is	Clear
CH4 Alarm State is	Clear
Fault State is	Clear
Detector Status is	Enrolled

Dyson CR01 Washing Machine with Flowcheck

Your wash cycle has successfully finished

Elapsed Time:	00:59:45
Estimated Cycle Time:	00:00:00

Synthetics, 40°C, 1100 rpm, Dirt and Stains, 0.71 kWh Energy Use

Water Temperature:	21°C
Water Level:	2 mm
Drum Speed:	0 rpm

Lifetime Cycle Count: 98

[Online Help at dyson.co.uk](http://dyson.co.uk)

Figure 12. XTN Reference screen

3.2.4.5 Equipment Life Cycle Information Management System

A system was devised by De Montfort University which collects equipment life cycle data for enhanced service delivery to connected homes. These data can be used in different ways in many applications:

- Product development: data on failure modes and frequencies are good indicators for design modification to improve reliability beyond that achievable by laboratory tests or field trials.
- Appliance life monitoring: the system logs the input and output as well as the related actions of the appliance. Data logged at a defined period of time could be used for guarantee and insurance issues.

Furthermore, system efficiency could be evaluated by comparing the actual and expected outputs.

- Diagnostics and failure prevention: Critical parameters can be observed in order to raise alarms, activate counter measures and feedback to maintenance / service. Data monitored could support convenient, cost-saving maintenance. For example, service personnel could obtain operational data to facilitate diagnostics and deciding on rectification action such as part replacement. Remote diagnosis before a service visit could help identify the spare parts required to keep travelling cost down.
- Lifetime and reliability prediction: Prediction of remaining life of the main components and safety related components supports maintenance and end-of-life treatment. Guarantees can be provided based on actual use rather than a fixed time period.
- End of life treatment: data could be accessed and used to optimise the end of life treatment of equipment. Parts removed can be classified for treatment according to their life histories.

This system was created but has not been fully tested as part of the EM trial because of competing demands for resource. Gas safety data from the Multi Home Trial has been tagged and will be extracted from the gateways once they are removed from homes at the end of the trial. This on-going work will form part of De Montfort's continuing research activities.

The following Figure shows a screen shot from the system, demonstrating how a service provider could interact with on-line data relating to equipment in the home.

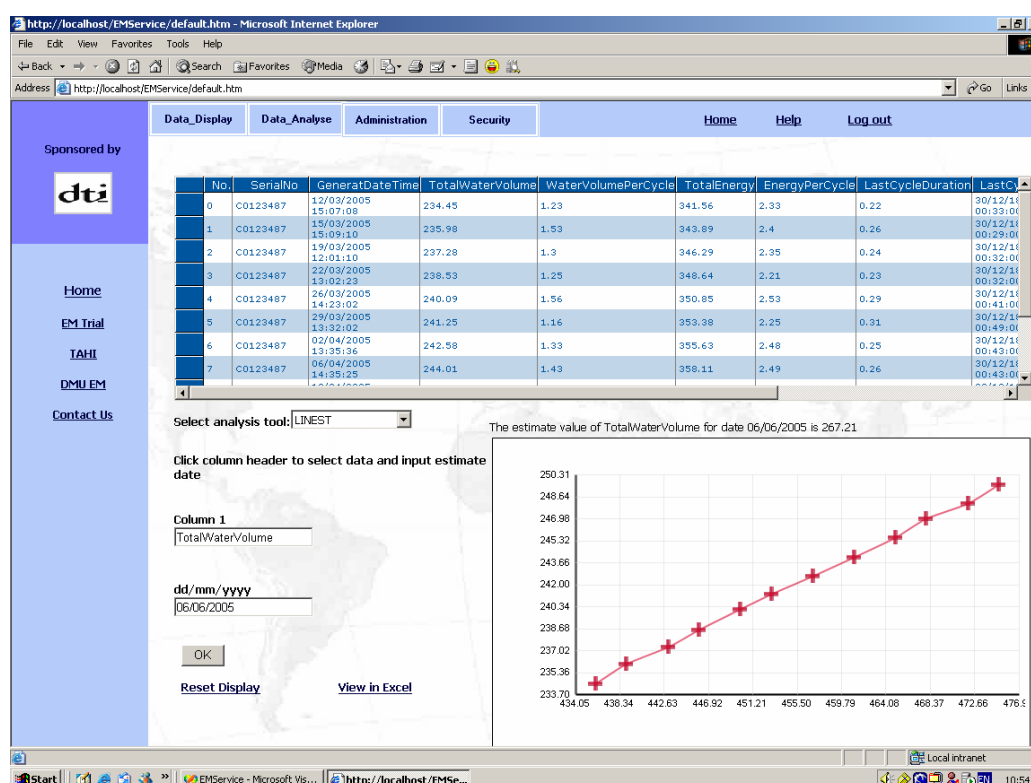


Figure 13. Screen shot from the Information Management System

3.2.4.6 Dyson Washing machine

The Multi Home Trial acted as a test bed for data collection from individual home networks. The home gateway collected data from the CR01 in each trial home. This information was automatically submitted to Dyson via email on a daily basis. These data provided product usage statistics, energy usage information and reports faults that may occur in the CR01. The following Figure shows a screen shot of the automated emails received from trial homes.

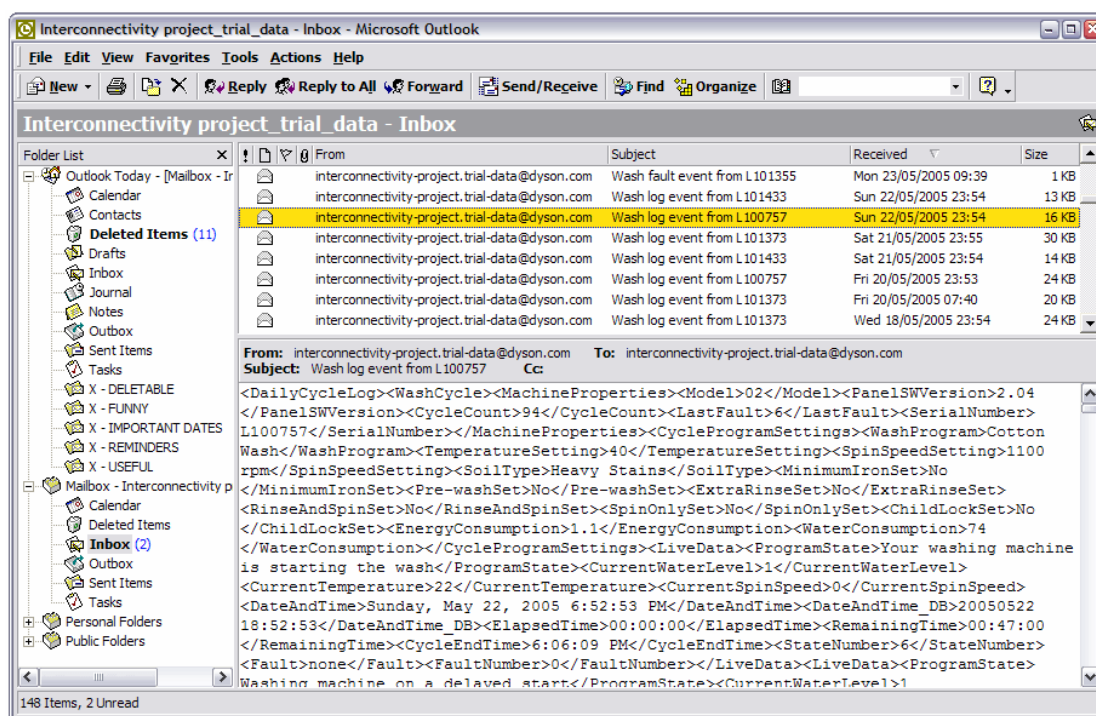


Figure 14. Data collection by email

The following figure shows a screen shot of the interpretation of this data at Dyson. Alongside this daily status report, the current status of each product in the field trial could be acquired via the Extrada web service.

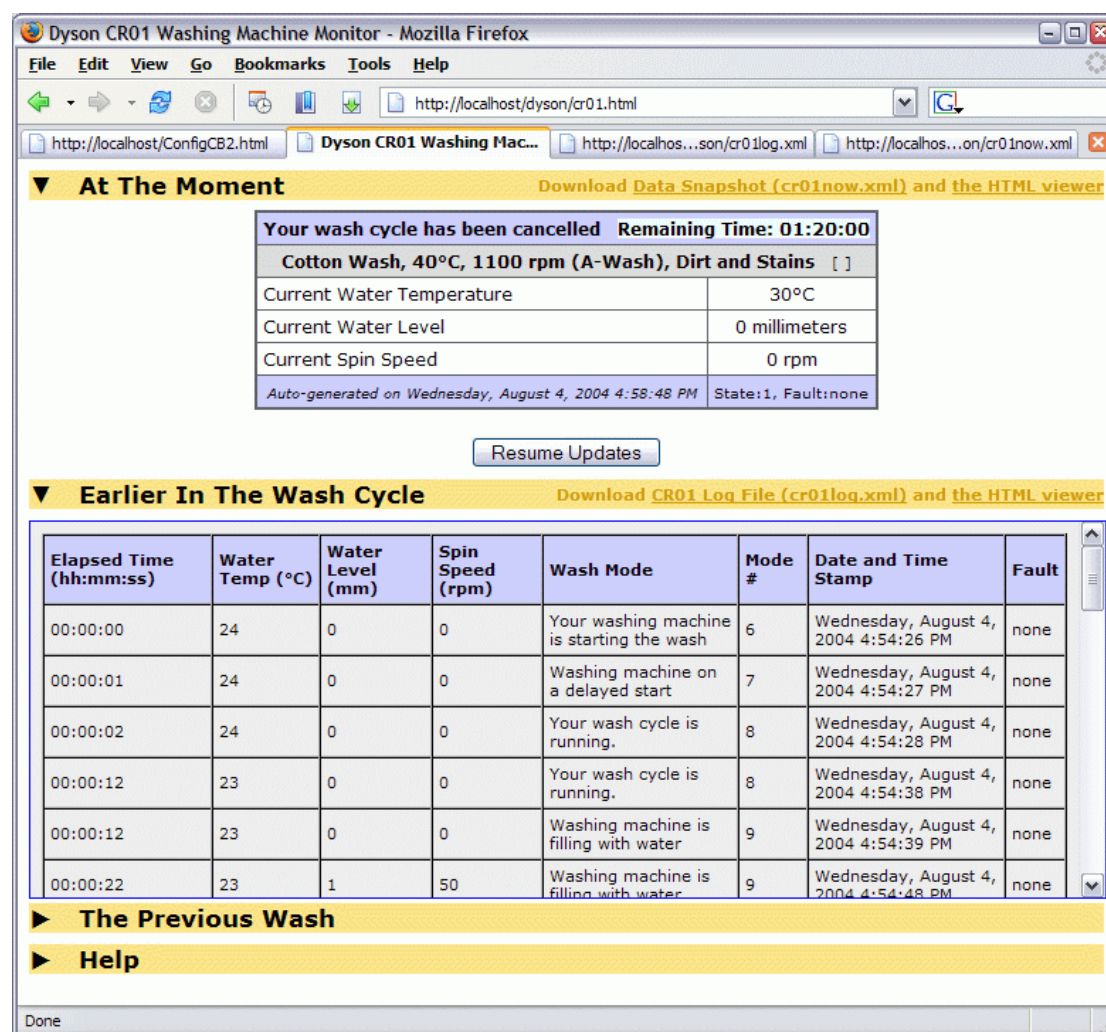


Figure 15. Data interpretation

The additional functionality provided by the networked appliance is shown in the Figure below.

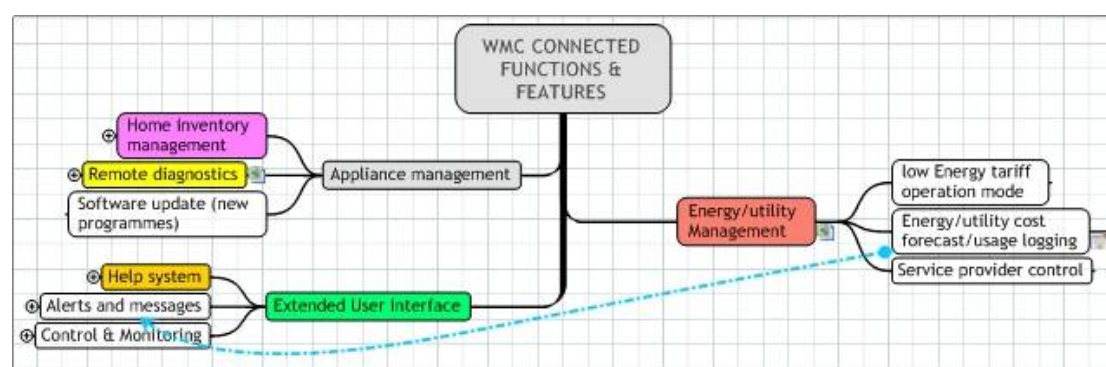


Figure 16. Connected WMC functions

3.2.5 Research Test Bed

The trial aimed to provide a test bed to facilitate further research in ambient computing and knowledge based Human Computer Interactions.

Loughborough University developed a flexible tool to support pervasive computing research for future home environments. The aim was to provide an emulation of future home systems which was as realistic as possible so that users interacting with the system would behave as though they were interacting with a real system. The requirement for this system arose because there are many ways in which to present a user interface and these will be highly dependent on the user types and the systems deployed in the home. To introduce changes in a production home gateway would be prohibitively expensive and time consuming. A solution was required where the process of refining the user interface could be more iterative and easily updated to reflect design changes.

The use of system simulators and emulators is commonplace in many industrial settings and has been demonstrated to be of great value. They make it possible to simulate future systems or architectural concepts before the enabling technology is in place. Consequently, system design options can be explored before time is spent on developing production hardware and software. This allows early design iterations and risk reduction work to take place before committing expensive industrial resources.

A test bed for the home environment enables the rapid prototyping of new devices and associated user interfaces for the home. HCI options can be refined without expensive time consuming effort of integrating with real systems. This is an important tool for consumer evaluations. Effects such as system latency, failure modes and user acceptance can be readily undertaken with the user interface prototyping system. The collection of devices and interfaces also serves as an animated system specification so that developers can get greater understanding of the more subtle aspects of the system design and its interaction with users.

The aims of the user interface prototyping tool were to:

- Identify relevant standards and best practice design criteria concerning design of smart user interfaces.
- Support contextual workshops (in a home environment) – focus groups / interviews / brainstorming in the home with families (attitudes, new ideas, problems, perceptions etc).
- Evaluative study of quality of service (QoS) impacts on a pervasive computing environment involving a ubiquitous user interface.
- Aid in the process of designing user interfaces for the home.
- Study interoperability of home environment systems within the context of a pervasive computing environment (user interface and network implications).
- Aid in the identification of important standards and issues that will cause access difficulties (ageing population and people with special needs).

The prototyping system will be used long after the trial finishes since it is not dependant on vendor supplied hardware or white/brown goods. This will allow further research to be undertaken and ensure the best of breed ideas emerging from the single and multiple home trials to be further evaluated.

3.2.5.1 Simulation overview

The system was based on a data driven model with a meta data structure for each device (in essence very similar to the TAHI Open Architecture model). System state variables were used to store state information and act as the interface between devices and user interfaces.

The User interface prototyping system comprised two main components:

1. Complete home system emulator – This is a representative functional model of the systems in a typical home (eg Central heating, etc). The aim of this part of the system was to provide functionally representative data in response to various user and system initiated actions. Instead of being a computer based simulator the home system emulator can allow the investigator to swap out a software simulation module with a communication module so that it can interface to real equipment if required. This feature allows the system to provide missing functionality that has yet to be provided by real hardware.
2. User interface prototyping system – This allows the systems designer to provide representative user interfaces on actual physical devices or allows simulation of future interfaces. It is possible to implement a wide range of user interface concepts so that human factors evaluations can be undertaken. Almost any user interface can be emulated by the system or integrated with it. This allows investigation of the impact of information presentation/interaction across a number of device types from personal digital assistant (PDA) sized units through to interaction on a TV. Non visual interfaces can also be accommodated. For example, a speaker independent speech recognition system has been integrated with the system as part of the work on the SA trial.

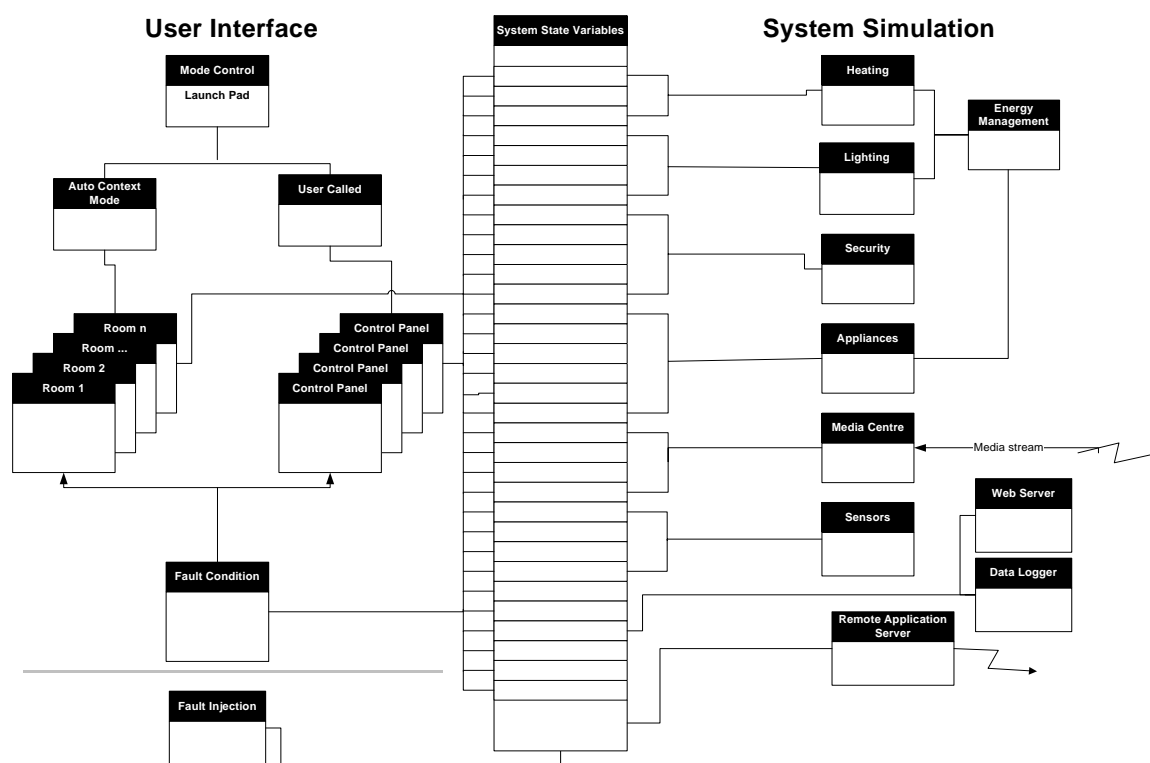


Figure 17. System diagram showing mapping of simulation onto system, with state variables in the centre

Additional functionality was built into the system to support the HCI evaluation process. For example, facilities for data logging of all user input and resulting system responses were provided. The whole system could be housed in a small footprint PC that can act as the home gateway. This made it portable and easy to install for trials in the test home. Interfaces to support powerline communication (e.g. X10 or other more advanced methods) ease the integration with the home systems and make it possible for the user interface simulator to control real equipment.

3.2.5.2 User interface prototyping process

The prototyping system was used to develop a generic central control interface for the home which was hardware independent. A fairly typical process for defining the user interfaces was followed comprising requirements analysis – system design – build – test – evaluation. The real benefit of rapid prototyping comes from iterating around this loop many times, each time round the loop the design is successively refined. This process was driven by establishing some driving scenarios for future home environments. These scenarios formed the basis for the requirements definition for the home system simulator and the user interface emulation. End user considerations were incorporated into the initial scenarios as well as the requirements defined by the vendors of white/brown goods. Whilst the form and functionality offered to the end user was particularly interesting to the researchers, the interests of the vendors of future home technology were also considered.

The simplified workflow process diagram is given in the following Figure.

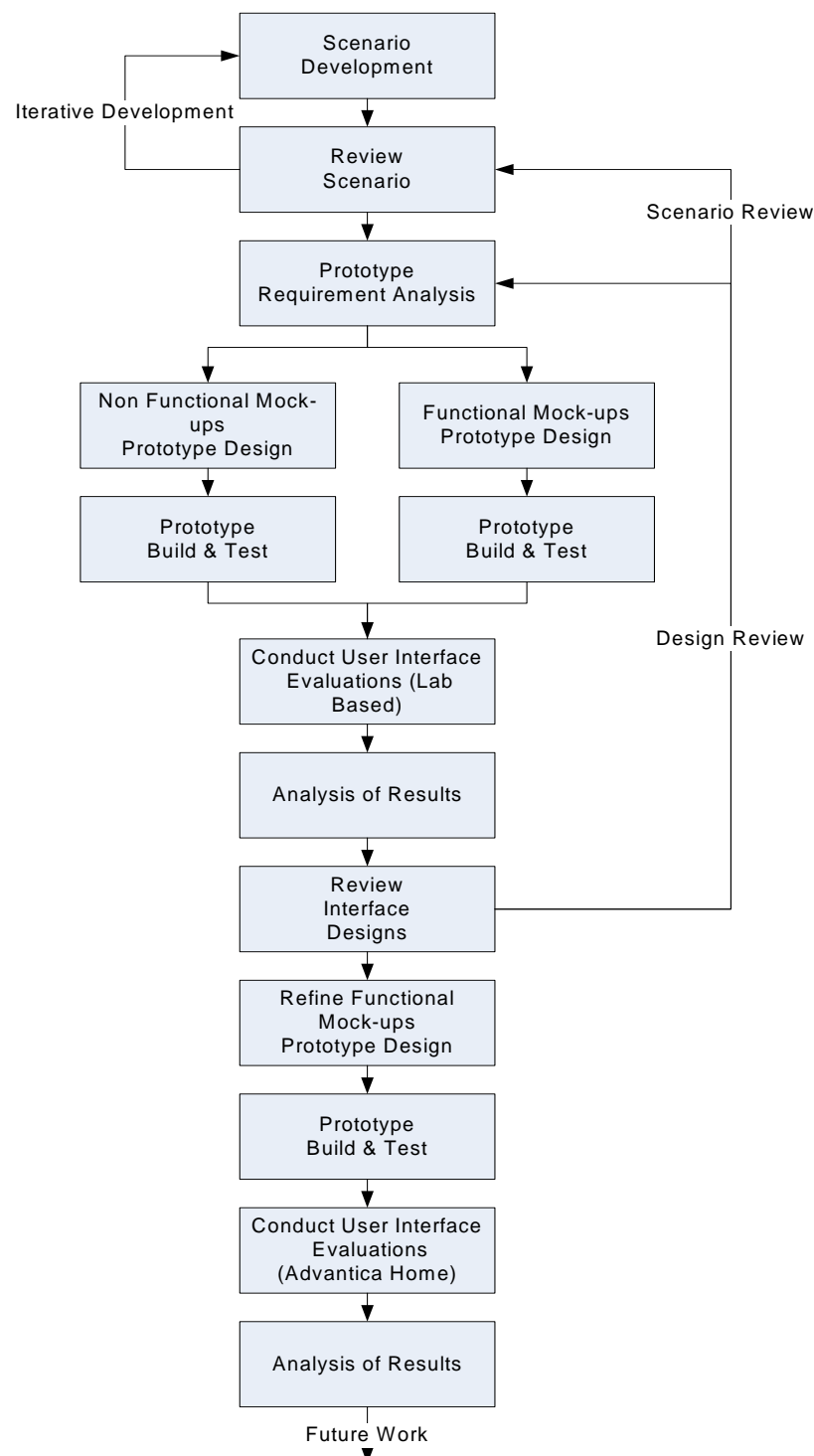


Figure 18. Workflow for User Interface Prototyping and Evaluation

The main steps include:

- Development of scenarios involving early prototypes - used to gain an understanding of problems, provoke new ideas and gain feedback for design refinement.
- Development of simple mock-ups - used to further assess attitudes, preferences, functional requirements and design ideas.

- Derive initial user feedback from general public exposure to the pervasive computing environment technology in the Advantica Demonstration Home.



Figure 19. The unoccupied test home at Advantica, Loughborough

Output from the trials will be used to develop more advanced prototypes for detailed exploration and interaction with users as part of Loughborough University's further work.

3.2.5.3 Role of the test bed within the trial

The user interface simulator was used in a number of ways to help define user interface requirements for future home systems. It has been particularly helpful in getting early understanding of user interaction issues as the design definition progressed. Loughborough University were able to animate parts of the system design specification using the user interface simulator. This meant that during the design review meetings with ESRI, Loughborough University were able to provide in depth knowledge of user interface issues with the underlying system functionality. The ability to interact with an underlying system meant that potential design risks could be eliminated. Many design review meetings were held between ESRI and Loughborough University. At the conclusion of each meeting it was possible to try out various suggestions and recommend alternative interaction strategies where appropriate. Issues such as screen size, resolution, interaction method (keyboard, on touch screen, minimal remote control interface and voice control) were evaluated in the laboratory before being proposed for in house demonstrations. As the iterative design evolved through lab based trials, subject matter expert reviews and further prototyping, it was possible to run a series of demonstrations and experiments within the trial house in Loughborough. An example page from the user trials is shown in the following Figure. The simulator was used to investigate the users understanding of icons and navigation functions within the generic top level menu structure for a central control panel for the home. The results of this work form part of the single home experiment series.



Figure 20. Example generic user interface

3.2.6 User Interface Design

The trial aimed to demonstrate an easy to configure user interface that is accessible to all kinds of users.

High-tech communication systems within homes involve issues surrounding the nature, function and design of human computer interaction and these have become increasingly complex. As machine-aided tasks become more a part of our everyday lives, it is essential for Human Computer Interface designs to be integrative, effective and efficient. From an ergonomics perspective, it is essential to take a human-focused approach to design user interfaces, so that the system is intuitive, reliable and easy to use. In order to achieve this, the user population, characteristics, requirements of the system as well as the system design itself (i.e. hardware and software functionality) were considered.

Following background research and supported by the other work of Loughborough University, the Ergonomics and Safety Research Institute (ESRI) undertook a series of development and prototyping stages in order to design the user interface for the Multi Home Trial. This included::

- Research to explore attitudes to new technology issues and equipment management systems, best practice in interface design, consumer behaviour attitudes particularly in relation to energy issues.
- Paper prototyping to map out the functionality of possible user interface designs that incorporated issues from the background research in conjunction with the known equipment offerings within the trial.
- Microsoft PowerPoint mock-ups to further develop the functionality of the end interface.
- Design and development of the look and feel of the interface.
- Expert evaluation of the trial interface and redesign where needed.
- Stage 2 interface design, as additional functionality became available.
- User evaluation of the interface via the Multi Home Trial.

This integrated with the simulation development, drawing on the design reviews and background research. It was not possible to use the UI prototyping tool in full, as this was not ready at the stage needed for the Multi Home Trial preparations. The UI development stages are detailed in the reports that support the trial, and an outline is provided in the following sections.

3.2.6.1 Background research

Research of the current literature relating to user interface design was supported by expertise from various project partners. This led to several activities to gain a better understanding of what consumers might want from an equipment management system, what were the most important features, what were considered as luxuries, how they might want the information to be structured and displayed. Underlying issues such as values, trust of technology, intrusion into the home and invasion of privacy were also considered. This allowed ESRI to build a picture of what should be included in the next stage of prototyping and how it might be structured and displayed.

3.2.6.2 Paper prototyping

Two stages of paper prototyping were conducted. System functionality was considered initially, using brainstorming techniques, visualised through the use of flip charts and Post-it[®] notes. Experts in usability and interface design from ESRI considered the various aspects of the system and the functions that a user may want to have available in their smart home. Issues addressed included:

- Who are the users? How would the interaction by the primary user vary from others?
- Is there information to which only some people in the household should have access? Are passwords or other security techniques needed to limit access?
- How should the system be set up from installation and how can settings be changed easily, e.g. from summer to winter settings?
- How much automatic control should be applied by the system?
- How could the system deal with conflicting requirements of householders, e.g. turning the heating up and opening windows?
- Is a central device sufficient, or are supporting local interfaces required, and if so, how might they be used?
- Should the system incorporate other facilities and services, such as email, personal diaries, document storage?

From this, a number of key functions were identified and alternative ways of organising this functionality were developed through low fidelity, hand drawn prototypes. Examples of these are shown below.

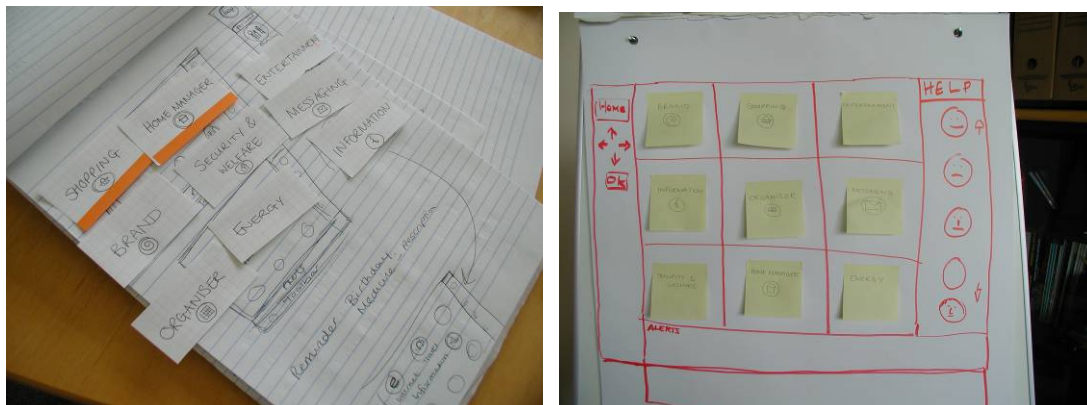


Figure 21. Paper prototyping examples

This allowed the research team to explore, in a quick but effective way, how much information might be contained on each screen and how the user might navigate through the information, as well as what information might be included. This stage allowed the researchers to consider a number of issues and as a result, identified the initial functions for the MHT interface.

The next stage was to refine these functions through the development of interface structure diagrams, which were first hand-drawn, then refined. Examples are shown below.

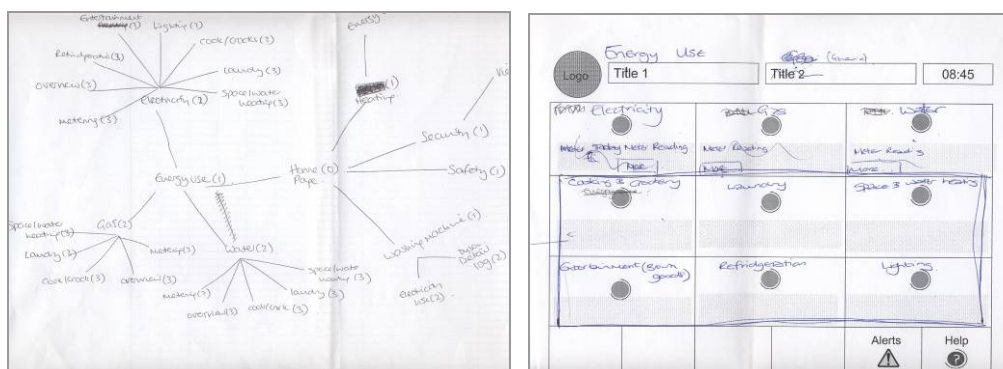


Figure 22. Interface structure diagrams

3.2.6.3 PowerPoint mock-ups

Mock-ups were then constructed in Microsoft PowerPoint to develop further the functionality of the end interface. This allowed the researchers to represent the interface structure, visualise the interface and to incorporate some functional navigation through the use of buttons and links. Examples are shown below.

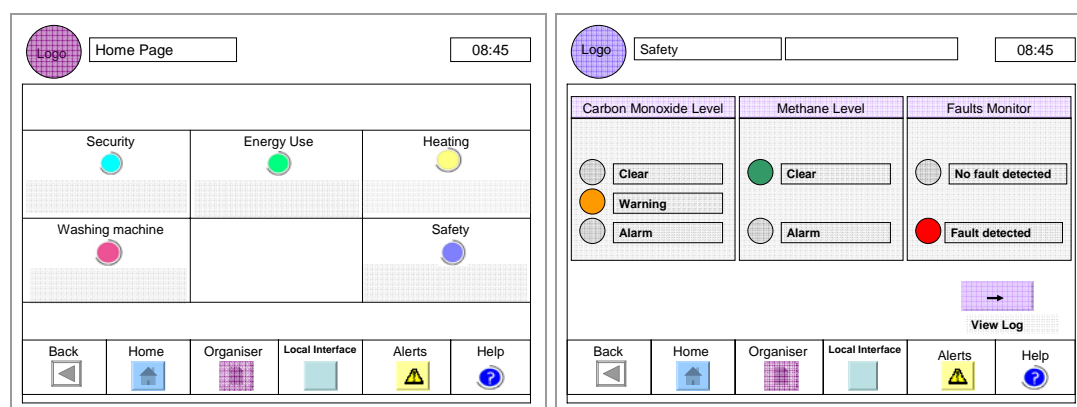


Figure 23. PowerPoint mock-up examples

This was a particularly valuable stage to allow the other trial partners who had not been involved in the user interface development to be able to test out the interface in a limited way and feedback comments where appropriate. As a result, a number of design changes were made. It is important to remember that at this stage, the final look and feel was not being considered; the function and inclusion of features was the focus.

It was also possible at this stage of the design development to identify exactly what equipment would be included in the final system and the nature of the data that would be output. In some cases, this shaped the interface design considerably – it was simply not possible to offer some features, and in other cases, more data could be shown to the user. The various revisions of the interface incorporated this developing knowledge.

Of particular interest to the trial was the energy information that could be provided to the consumer. Research into the best way to present this information, in order to stimulate energy saving behaviours, was conducted by Heriot-Watt University. The greatest number of energy-saving actions resulting from a display in the home will apply to those appliances with the greatest number of feasible energy-saving behaviours. On this basis, the development of 'appliance-specific' displays was recommended for the boiler, water taps, radiators, cooker hob, oven and grill. Alternatively, energy information might best be provided in activity groups (such as refrigeration, lighting, cooking and dishwashing, home laundry) to allow a concentrated comparison of energy use by several appliances. It was felt that a central display should be used to indicate information about total energy use, with consumption broken down into end use or appliance categories. Full details of Heriot-Watt's work are presented in the supporting reports.

3.2.6.4 Look and feel

Following the revision of the functional interfaces, the specific look and feel was developed, essentially its skin. It was also necessary at this stage to modify certain aspects of the interface where technical issues dictated. For example, a regularly updating display of energy usage would provide the consumer with immediate feedback, but it was only possible to display this information daily, even though it was updated every 30 minutes.

Examples of the interface that was installed as part of the Multi Home Trial are shown below.

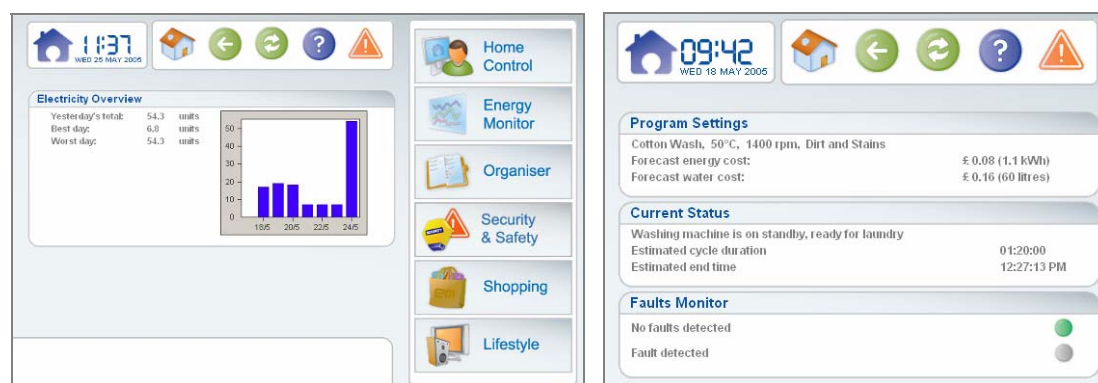


Figure 24. Multi Home Trial interface design

3.2.6.5 Expert evaluation of the trial interface and redesign

Once the interface was complete, it was re-evaluated using walk through scenarios to test its functionality and design. Where necessary, the interface was redesigned to incorporate the feedback from the trial members. Technical issues (for example, the time and date were not updating) as well as design issues (the gas usage should be in kWh not units) were implemented.

3.2.6.6 Stage 2 interface design

As the Multi Home Trial progressed, it was hoped that it would be possible to add additional functionality to the system, for example the white goods monitors, which would need to be reflected in the interface design. New screens were developed and designed in the same way as before, although the importance of the low fidelity paper prototyping stages was reduced and it was often possible to redesign from initial paper concepts to final design in one step. Unfortunately, these screens were not rolled out as the hardware could not be delivered in time.

3.2.6.7 User evaluation of the interface via the Multi Home Trial

Once a final interface was agreed, it was installed as part of the Multi Home Trial system. Participants were able to interact with the system through the interface and feedback about their experiences was gained at the end of the trial. This included comments about the interface design and functionality.

14 households took part in the evaluation, comprising 46 householders and as such, a mixed multiple case study approach to the process was adopted. Each case study provided rich information through the collection of detailed and descriptive data from participants. This was supported by the technical data collected for each household.

Building on existing expertise, appropriate evaluation techniques were used by ESRI, to ensure that maximum information was captured from participants over the full course of the trial.

This included ethnographic research methods, surveys, interaction accounts and interviews to provide both qualitative and quantitative data for analysis.

Participants were issued with 'participant packs' containing resources for collecting their experiences. The packs were designed to be stimulating and fun to complete, and allowed the participants to capture their thoughts, feelings and ideas in a concise and imaginative way.

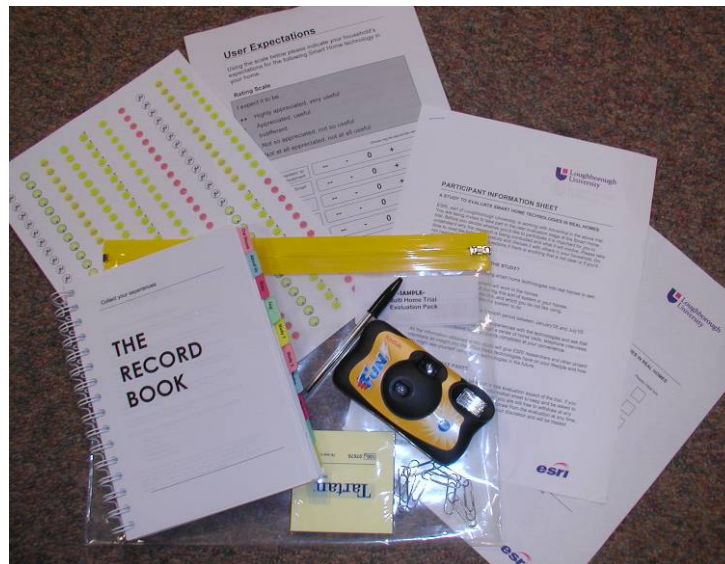


Figure 25. Participant packs

The main content of the MHT participant pack was an A5 spiral bound 'Record Book', which the participants used to keep a diary of experiences, personal records of interaction, a log of problems and a photographic record of the trial. Alongside this, participants were issued with Post-it notes, emoticon stickers and a single-use camera to use as they wished to document their thoughts, feelings and ideas.

Participants were free to jot any other notes and scribbles down that related to their interaction with the Smart Home technology. The Record Book was theirs to complete as they wished. They were the researcher's eyes and ears when it came to evaluating the user experience and were briefed to tell as much as they could; good or bad!

Figure 26. Completed sections from the Record Books

Participants liked the look and feel of the interface and found it to be well laid-out and easy to access. They liked the colourful interface design and felt it brought the system to life. They had found the interface easy to use and easy to navigate.

Most of the participants were regular users of the internet and as such, they were familiar with the internet explorer navigation. This did not significantly affect their ability to navigate the EM system, and they soon familiarised themselves with navigating their way around the touch screen device.

It was commented that there was very little content of use. It just appeared as 'a load of numbers' to the users, and with no kind of analysis it had limited value. They would have liked to have seen more patterns of household behaviour highlighted; this could have made the data more interesting as well as drawing out changes that could be financially beneficial to the users.

Participants had been disappointed in the usefulness of the energy data provided by the system. It was described as "dull and unimaginative", "a meaningless bar graph". Householders wanted to be able to see and interrogate their energy data, but the trial was unable to deliver the detail they required.

Initially, the participants had enjoyed the ability to watch the activity of their washing machine and see how much it would cost them, but the novelty soon wore off.

Although many participants commented that it was easy to find things, some reported that it was not always entirely clear where to look for information on certain pages as it was sometimes a little 'techy'. It was felt that an overview of the house presented at a top level, on the homepage of the system, might be useful. This could include some general information such as 'today is above average' so they would not have to search for information and deduce this for themselves.

Many participants would have liked to have seen the organiser and shopping functions populated by the trial.

The presence of local network pages in addition to the remote pages caused some confusion. They did not like the differences between the two sets of pages and found it difficult to navigate between them.

People did not like having to leave their iCEBOX in standby mode in order that it remembered their login details. This went against their instincts and seemed to contradict the idea behind the energy monitoring pages. If users wanted to turn the device off, they had to re-enter their login details each time they wanted to interact with the system. Although not intrinsically linked to the interface design, this is a problem with the hardware memory capacity which forms a barrier to free interaction with the interface. Having to login, reboot and reconfigure impedes the user experience.

Overall, people liked the look and feel of the interface, and thought the whole concept was "very clever" and "could be useful in the future", but the content and functionality of the system was "not quite there" with respect to the trial equipment under investigation in their homes.

3.2.7 Interoperability

The trial aimed to demonstrate interoperability of sufficient capability so that conformance tested products can be added and maintained on the network.

The whole aspect of interoperability is covered with in previous sections of this report specifically relating to plug and play networking (Section 3.2.2) and network infrastructure (Section 3.2.3).

3.2.8 Business model

The trial aimed to identify costs and benefits in the areas of capital/initial on-costs to equipment, revenue from maintaining the network and infrastructure and any other associated costs.

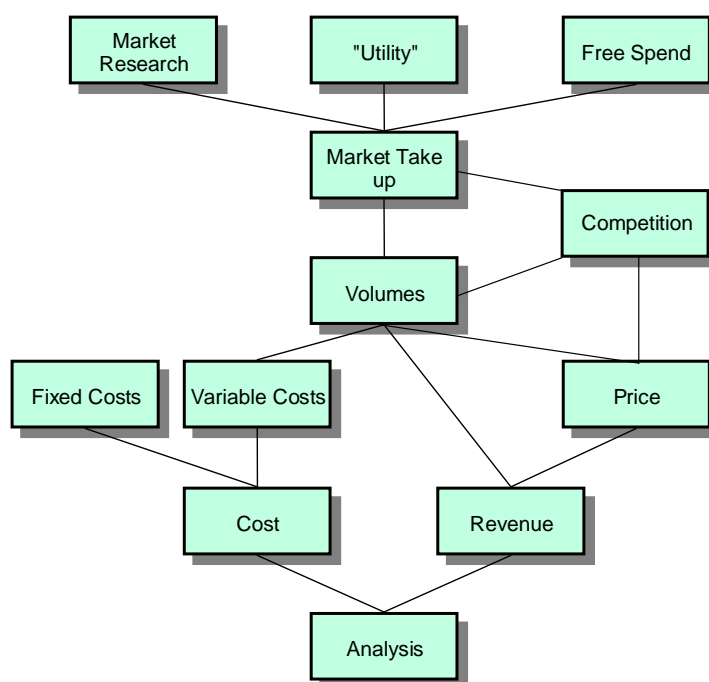


Figure 27. Business model flow diagram

Using the skills and experience of various TAHI members a set of nested spreadsheets and macros were developed to effectively build a model for single and multiple service applications. This tool at the simplest level is able to model the income and expense parameters for a single service. Also, there is the option to build in the assumptions on how much an additional service will influence costs and income and test various scenarios for this.

The business modelling tool provides a comprehensive income and expenses model for digital services. The purpose was to provide some essential business case information as a valuable output from the trials, which to some degree could be tested by the trials.

The model needed to cater for two kinds of service:

- Single Service Model – for an individual service such as meter reading, appliance diagnostics, security etc.
- Aggregation Model. For a combination of services offered using the same 'network'.

3.2.8.1 Market Model

To scale the costs and expenses the trial began with a model for the market, in particular the size and constituency. This was developed as shown below:

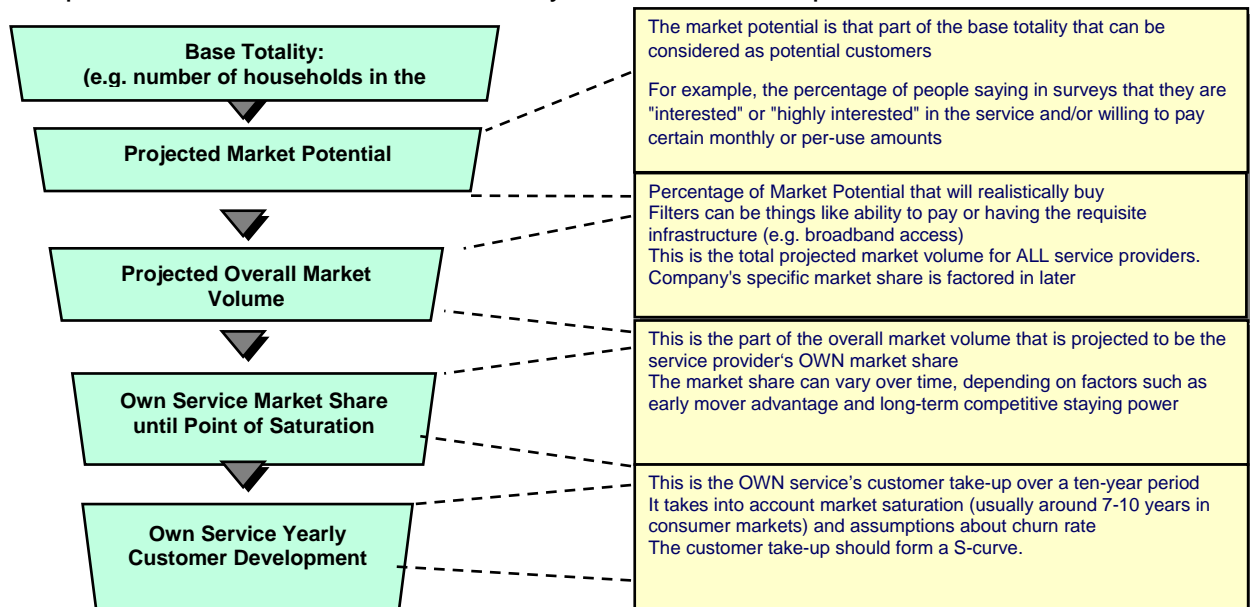


Figure 28. Market Model

3.2.8.2 Revue & Expenses Model

Next a revenue model & expenses model was developed. Revenues are structured according to:

- One-time revenue.
- Recurring revenue (flat).
- Recurring revenue (event-based).

The process is illustrated on the diagram below:

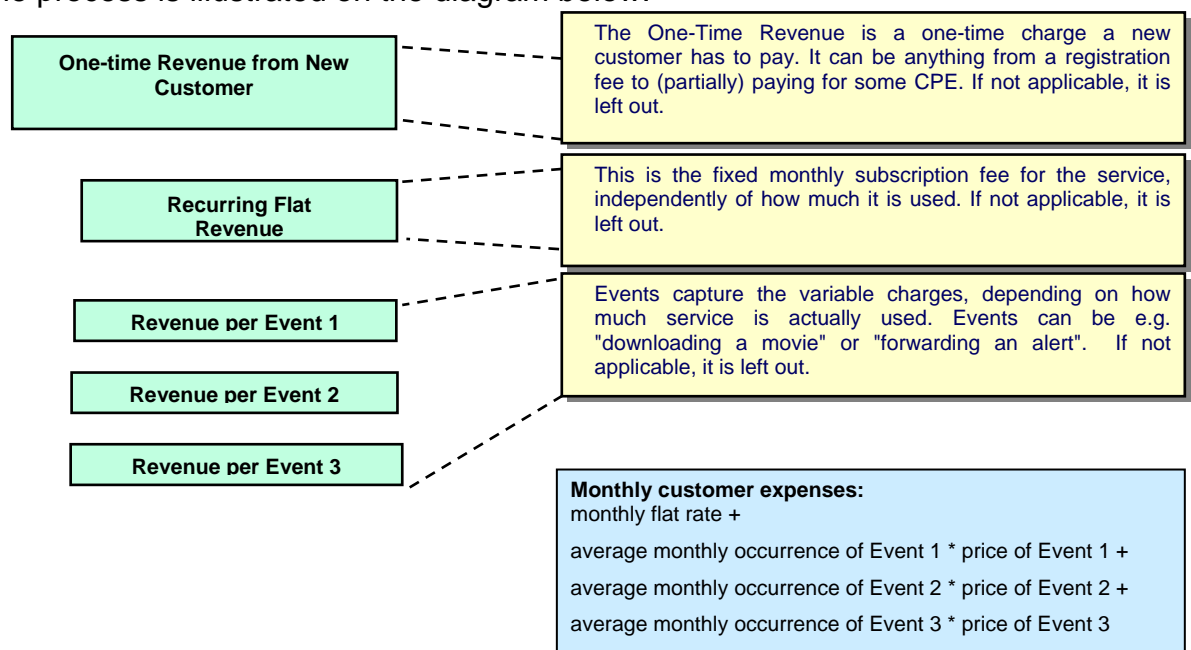


Figure 29. Revenue & Expenses Model

Expense types are:

- Marketing & sales.
- Customer care.
- Subsidies.
- Hardware & software.
- Operations service centre.
- Communication / event costs.
- Research & development.

These would need to be entered from known costs or estimates. For most of these there are reasonable estimates available based on analogous markets.

3.2.8.3 Financial Analysis

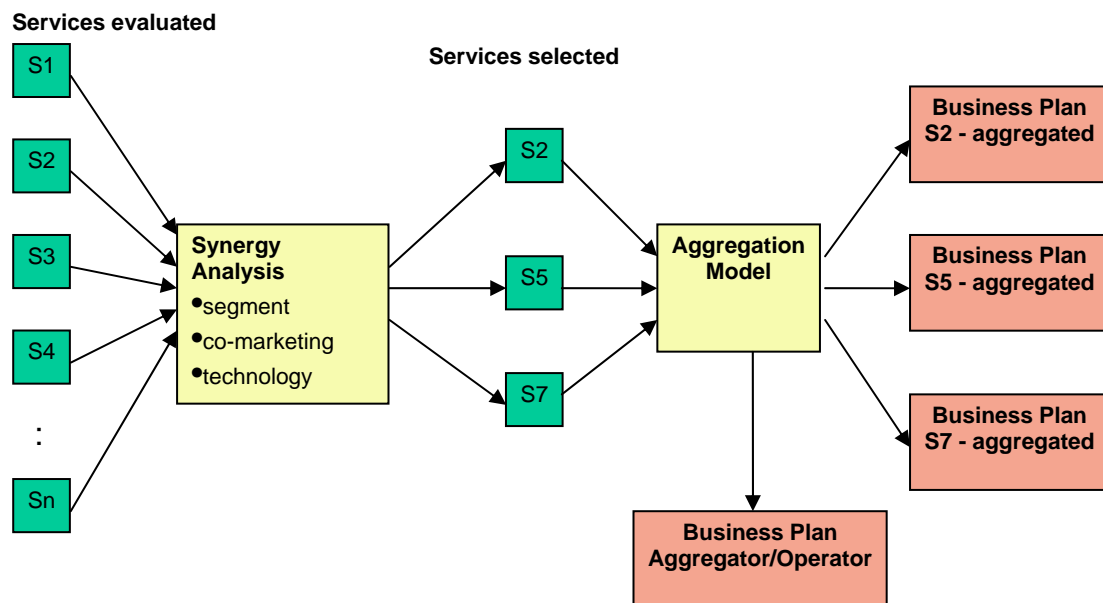
A financial analysis can then be performed. The financial analysis is taken over a ten-year period. This includes Earnings Before Interest, Taxes, Depreciation, and Amortization (EBITDA), cumulative cash flow and Net Present Value (NPV) is calculated. Discount interest rate and time-frame for NPV are variable.



Figure 30. Examples of Financial Analysis Data

3.2.8.4 Aggregated Model

For the aggregated model any number of services (S1 to Sn) are evaluated on a pair-wise basis for their suitability for aggregation. The process is shown below:



The three measures of suitability are

- Market segment fit
- Co-marketing / bundling advantage
- Technological / delivery synergies

For each measure a value from 1 to 4 is entered by the evaluator (e.g. experts), with 1="very low", 2="low", 3="high", and 4="very high". Through this analysis a cluster of services will emerge with an "aggregation fit".

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN			
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3	SERVICE 1					2	3	4																																			
5	SERVICE 2	2	3	4																																							
7	SERVICE 3	0	0	0	0	0	0	0																																			
9	SERVICE 4	0	0	0	0	0	0	0	0	0	0	0																															
11	SERVICE 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0																												
13	SERVICE 6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																										
15	SERVICE 7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	
17	SERVICE 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	SERVICE 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	SERVICE 10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
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Figure 31. Aggregated model

Customers for the aggregated services should increase due to aggregation, because:

- Churn rate decreases.
- More new customers are acquired due to co-marketing effects.
- These increases are calculated on the basis of estimated percentage changes relative to the respective single service business cases.

Customer take-up for the aggregator/operator is based on assumptions about the intersection between the customers for the single services, so per-unit prices decrease due to bundling, since the bundling proposition to consumers is: "The bundle costs less than the sum of the parts."

The following service expenses should decrease due to synergies created by the aggregation / bundling of services:

- Marketing & sales.
- Event costs (service events such as a communication / response).
- Research & development.

The following cost factors become common to all the services and are either borne by the aggregator or another third party. These costs will include:

- Customer care.
- Subsidies.
- Hardware & software.
- Operations service centre.
- Fixed communications costs.

The only increases in the costs of the individual services are the Business to Business (B2B) charges going to the aggregator / operator:

- One-time sign-up fees.
- Incremental, one-time capacity charges as customers are added.
- Monthly charges per active accounts.
- Percentage share of service revenues.

This makes it possible to model combinations of services and the effects on the business case.

For example, a comparison can be made between the viability of a service sold and delivered alone or as part of an aggregated basket, as shown below:

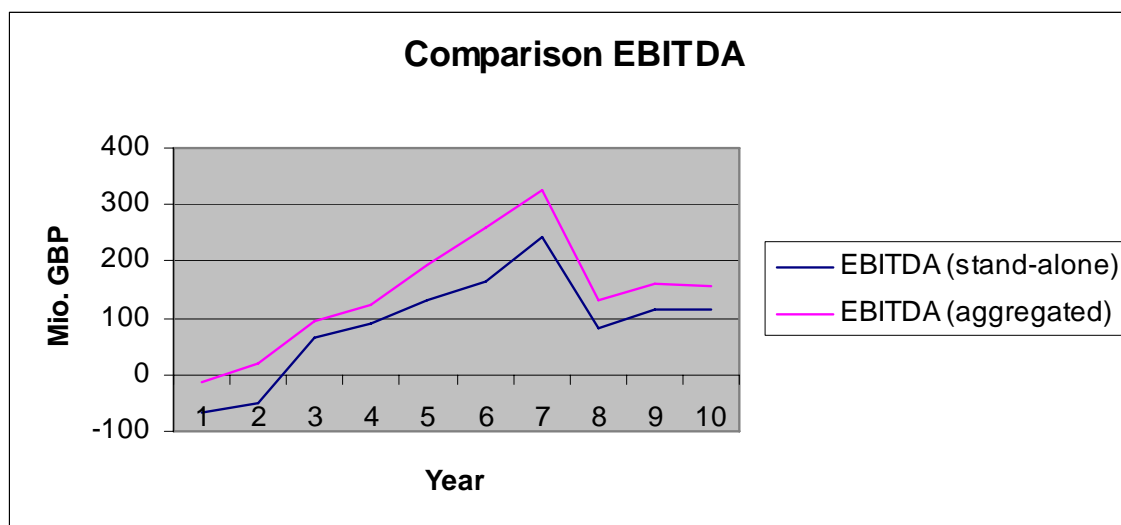


Figure 32. Comparison example

3.2.8.5 Front End

The model was created as a series of nested Excel spreadsheets but was later enhanced with a complete 'Wizard' to guide the user through the process in a user friendly way with instructions. The opening pages are shown below:

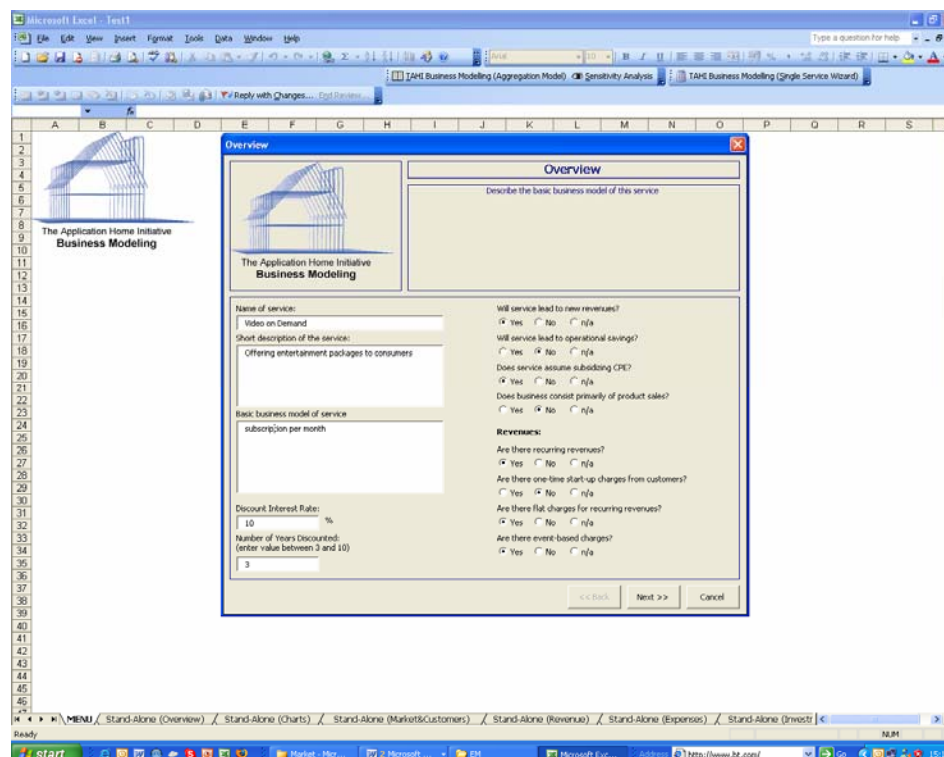


Figure 33. Business Model Overview screen shot

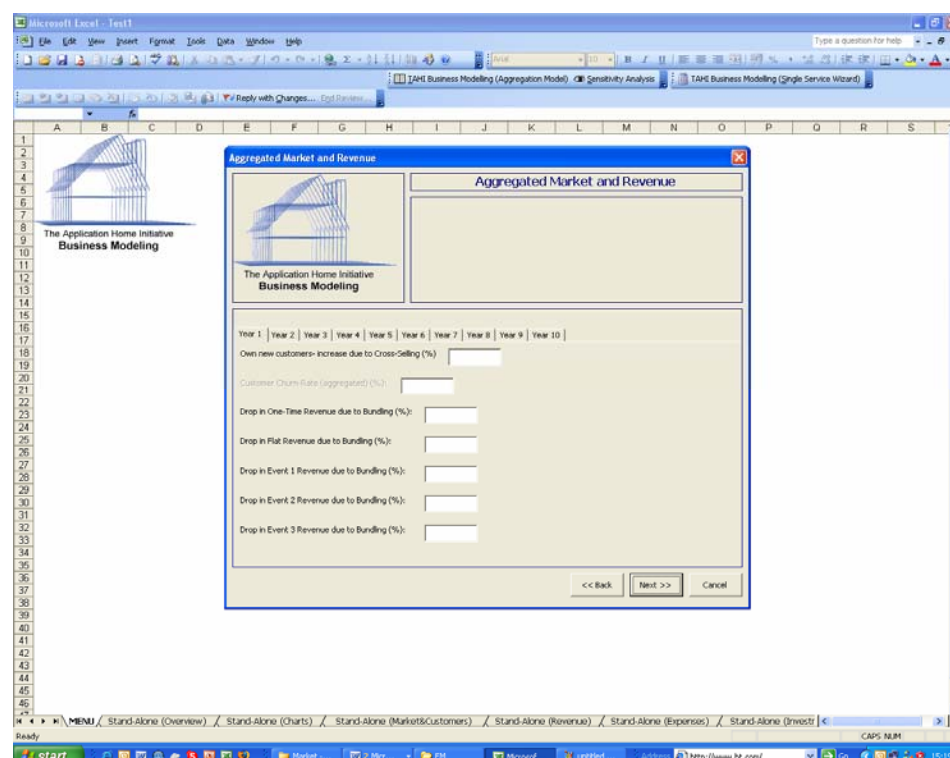


Figure 34. Business Model Aggregated Market & Revenue screen shot

3.2.9 Technical and consumer offerings

The trial aimed to gather information about the technical requirements and customer behaviour relative to the offered applications.

3.2.9.1 Technical offerings

Based upon the technology of the EM trial, the following potential services were identified by the trial. *Those actually implemented within the trial are featured in blue italics.*

Lifestyle Management

- Customer and/or service provider features to input/update lifestyle parameters.
- The system uses this general information to set the heating, lighting, security and other profiles rather than the user having to set each profile individually.
- Services Provider financial services related to the management of interconnected equipment.

Heating Environmental Control

- *Automated local control.*
- Automated system adjustment.
- *Customer manual control over local programmer.*
- Customer remote control over local programmer.
- Services Provider remote control over local programmer.

Energy Management

- Demand side tariff optimisation: Control of white goods against changing tariff profiles.
- Energy advice and energy saving tips.
- *Indication of user energy profile.*

Automated Metering

- *Remote access by Services Provider to read meter for billing, user profiling etc.*
- Customer billing of water; gas and electricity consumption.
- Dynamic management of tariffs by Services Provider.
- *Local access by Customer to view and manage metered charges.*

Diagnostics and Monitoring

- *Monitoring by Services Provider of excess flow of water and natural gas.*
- *Use of occupancy data to formulate emergency action as required.*
- *Condition monitoring, fault & service interval reporting to Customer by Services Provider.*
- Indication to Customer by Services Provider that product is nearing end of useful/economical life.
- *Automatic prompts to user.*

Lighting Management

- Local Customer control over chosen lifestyle profiles.
- Customer remote control.
- Services Provider remote control.

Safety

- *Reporting by Services Provider to Customer and appropriate authorities of alarms.*
- Local control by Customer over emergency shut off valves.
- Remote action by Services Provider over emergency shut off valves.
- Alarm reporting (to service provider or other remote entity) to include how many occupants are in the premises.

Security

- Local Customer control.
- Remote Customer control.
- *Reporting by Services Provider to Customer* and appropriate authorities of alarms.
- Remote action by Services Provider.

Real Time Clock

- Automated BST and time corrections.
- *Automated recovery after power outages.*
- Distribution of time display around home.
- Customer reminders/diary.

- Battery backed up on gateway.

Human Computer Interface

- *Provision of system status and information.*
- *Provision of product and services information.*
- *Local display.*
- *Remote display.*
- *HCI devices.*
- *User interface look and feel.*
- User interface 'islands'.

Product life cycle information management

- *Home EM services:*
 - *Equipment information.*
 - *Scheduling.*
 - *Notification.*
 - *Monitoring and diagnostics.*
- EM Services via remote service operator:
 - Marketing.
 - Design and development.
 - Service and maintenance.
 - End of Life treatment.

3.2.9.2 Consumer values

Having scoped out the potential functions and services the system could offer, it was essential to consider what the users actually wanted from this technology. It was important that the design process was not driven by the potential technical capabilities of the system alone. Visions of what technology can do are rarely based on any comprehensive understanding of need, and in some cases, are blatant technology push (Tweed & Quigley 2000). Research by ESRI helped to drive the process with a user centred approach. Researchers held focus groups with potential consumers and developed a photographic study of the home environment to capture user needs, values and expectations.

Focus groups were conducted with six different groups of participants to reflect a wide selection of society and gain a richer understanding of how people feel. The groups were presented with seven scenarios supported by guidance questions to generate discussion. The scenarios covered the topics of energy monitoring, equipment monitoring, appliance repair, security, home ambience settings and welfare monitoring. A full write-up of the focus group findings is presented in the supporting documentation to the trial.

Some emerging attitudes and issues from the focus groups are outlined below.

Energy use:

- 'Itemisation' of energy consumption would be beneficial not only in reducing energy wastage, but also in saving money.
- People did not like the Service Provider potentially monitoring their energy usage, it was felt they had a vested interest and people did not want to be continually 'watched'.
- A tariff advice system should be offered on an 'opt out' or 'request' basis.
- Emails were the preferred form of communication between service provider and consumer.

Equipment monitoring:

- Home owners should be alerted to decreases in performance or faults with appliances, but the alert should be contained within the home.
- The consumer must retain freedom of choice and have a decision in what action should be taken.
- People do not like to trust automated warnings and may seek an independent second opinion.
- People feel vulnerable to being misguided and misled into spending money on unessential maintenance or repair work.
- Having a household diary that engineers could view remotely should be avoided - this raised serious security issues.

Appliance repair - remote diagnosis:

- This was seen as a potential solution to the current problems that exist with numerous call-outs to repair appliances.
- Potential cost reductions resulting from fewer call-outs and reduced diagnostic time were well received.
- People did not like the idea of large companies coordinating alerts and actions.

Security:

- Important that the system is easy to set up.
- There should be a choice in where security alerts are sent – this should be set by personal preference.
- Preferred destinations for notifications of a break-in were; to the individual, to their husband/partner, to the police or a certified security firm.
- Cameras should not be located internally within the home, they should guard external doors and windows.
- Security system should mimic real-life when occupants are away on holiday.
- The system should react to external conditions.

Home ambience:

- Use of home ambience settings was viewed as a luxury or gadget.
- The concept was better received by the under 25s age group.

Welfare monitoring:

- Viewed as technology to benefit the older user.
- Could support independent living as a kind of 'computerised warden'
- System should be tailored to individual needs. This could include features such as, a fall monitor, heart rate monitor, medicine reminder service, and panic buttons.
- The system is dependent upon the quality of service that supports this functionality. It is essential that there is appropriate back-up in place to respond to any welfare alerts.
- Preferred locations for welfare alerts included: family, next of kin, primary carer, and social services.

The focus groups showed that people are responsive to the services that Smart Homes can offer. There were particular concerns over control, security and cost. These issues must be addressed if the Smart Home technology is to be accepted in people's lives.

The Photo study aimed to gain a realistic understanding of the context within which future Smart Home technologies are likely to be used and how this fits with people's everyday lifestyle and activities. The study utilised methods of ethnography within a domestic setting, where participants self-documented their thoughts and ideas and captured images around their home.

It was considered important to conduct a study in this area as it is within this setting of activities, interactions and constraints that these new technologies will enter people's homes.

A full write-up of the Photo study is presented in the supporting documentation to the trial. Key findings from this include:



People value people, space and memories most highly, rather than technology or physical possessions.



The items valued most highly were consistently described with feelings of comfort, relaxation and sentiment.



Technology and automation is viewed as saving people time and making household tasks easier, rather than adding value.



Some captured images of places or objects which focused on pride, appearance and prestige. Smart Home technologies may invoke the same feelings in some users and in this way, could find their way into people's values.



People do not display and share information in one single place; people often leave impromptu notes and messages left in context-specific locations around the home. A single, all-encompassing interface may not allow for this type of behaviour.

The findings from the photo study have implications for the design of future smart home technologies and should be carefully considered in order that the consumers' needs are not overlooked and a commercially viable offering can be developed.

Project partners, Dyson, also undertook research within this work package to identify consumer needs. Their work towards customer needs and behaviours are summarised in the Figure below.

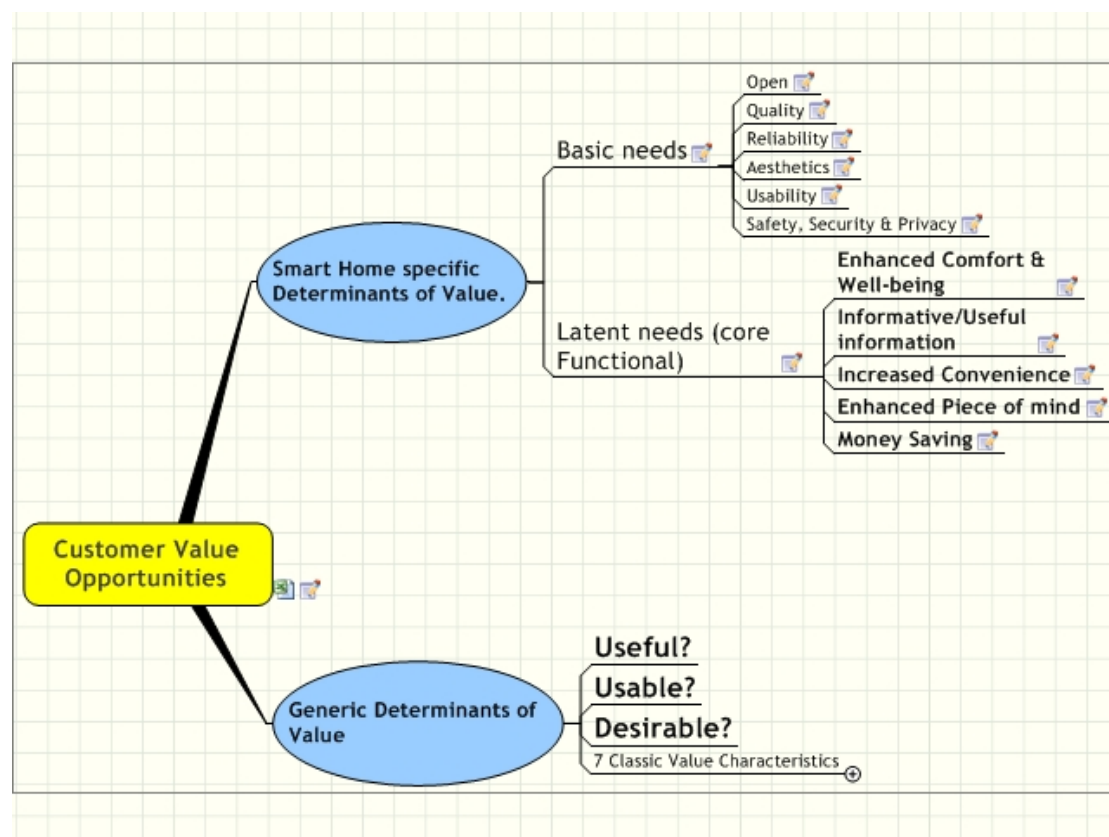


Figure 35. Customer needs and behaviour

Basic needs

These are needs which have been identified once the technology had been illustrated to potential user,; i.e. spoken concerns which, if not addressed, could lead to significant dissatisfaction - clouding the overall benefit of the technology. These were also identified through the analysis of the initial focus group investigation by ESRI. This also allows the subsequent definition of their relative importance.

- **Open:** Not anti-competitive, Allows freedom of choice and not be conducive to monopolising customer/business relationships.
- **Quality:** Quality of Service (QoS), Delivery, ease of implementation, excellence of execution (design and functionality), governed by an industry/consumer watchdog and appropriate standards.
- **Reliability:** To work all the time, every time.
- **Aesthetics:** Invisible networks and technology, seamless integration into the home.

- **Usability:** Intuitive UI - to use, set-up, 'tune', reconfigure and personalise.
- **Safety, Security & Privacy:** No additional risk to household safety (devices going live when not expected), No risk of invasion of privacy - identification theft, data protection issues.

Latent needs (core Functional)

These are the existing needs of a typical target end user. They exist in the lives of most people and it is these that the functions enabled by the smart home are designed to address. They may vary slightly from one market segment to the next - these can be weighted subject market segment definition and further targeted Voice of the Customer (VOC) research.

These needs were identified from ESRI's initial focus group investigation of a spread of demographics. Their subsequent satisfaction is the main focus of this technology/functionality. If these needs are addressed to a high level (high Performance) they can lead to high levels of satisfaction and even Delight (where the function exceeds expectation).

- **Enhanced Comfort & Well-being:** A better quality environment, enhanced sense of luxury, opportunity for Wow factor - able to create a sanctuary in your own home.
- **Informative / Useful information:** To be able to make better decisions, to have a better understanding, to provide helpful information - to reduce unknowns about your house.
- **Increased Convenience:** Reduced actions, easier to use, less effort (physical &/or mental), time saving - just faster.
- **Enhanced Peace of Mind:** Reduced worrying.
- **Money Saving:** Through the addition of the technology or system and the initial investment, it makes it subsequently easier to save money.

3.2.10 Customer acceptance

The trial aimed to provide continuing feedback from customers about the barriers, merits and difficulties associated with adopting new technologies, products and services.

Research by Heriot-Watt University revealed high levels of interest among consumers for detailed energy consumption information in the home and a willingness to pay for such services if facilitated by the TAHI approach. The survey results indicated that a central user interface display should be aimed at 18-35 year olds, and cost around £400 or £10 per month.

Features in order of preference should include

- Life saving alarms (e.g. for CH₄, CO).
- Information about damage to property (e.g. a water leak alarm).
- A security system with text messaging service.
- Detailed information about electricity, gas and water use.

However central control of appliances was less well received and data security proved to be a major issue for respondents (84% of respondents agreed to the appliance manufacturer or service provider accessing information about appliances securely via the web, but 93% wanted to be able to access all of this information).

Development of energy display technology on three levels was recommended:

- Local displays (appliance-specific and activity-based).
- Central displays (e.g. via a very smart meter).
- Hybrid displays (a combination of central and local displays).

The requirements of the user population will affect the specifications of any equipment management system. For the purposes of this trial, possible users were considered to include householders, visitors – occasional or regular, Installers, service engineers / maintainers, service providers and customer service / support workers. It is imperative that the needs of the householder, as customer to any service, are fully satisfied in order for the system to be a commercial success. Households are likely to be made up of single people living alone, groups of unrelated people sharing a house, couples, families (perhaps incorporating several generations), friends and relatives living with a family, etc. Within these broad groups there will be:

- Early Adopters - people who are interested in new technology and buy the new products to be first to have it.
- Families including people of many different ages.
- Younger and older people.
- People with disabilities either physical e.g. mobility or cognitive e.g. learning or a combination of the two.
- People who may be very familiar with technology and those who have no experience of technology.

The target customers for the EM trial products (home appliance remote diagnostics and monitoring) were identified as owner/occupiers, ABC1 consumers, 20 - 50 age group with young families. Two sub-markets were envisaged: the first is those who are cash rich but time poor and the second is represented by people to whom safety/security is important, who want to know what their outgoings are, and who tend to buy insurance products.

From the Multi Home Trial evaluation, a number of customer acceptance issues were raised. These included:

- Energy data needs to be reliable, and consistently presented in order that people make use of it. People would like to receive advice to complement the energy consumption and add meaning to their readings.
- Although money is the key driving force behind most energy saving behaviours, it was found that displaying breakdowns of energy consumption in monetary terms can also serve to de-motivate users. Pennies are not a big enough incentive; the benefits need to be perceived as significant in order that people alter their behaviour.

- Half day totals of energy use do not convey anything useful to the user. The data need to be sampled at more regular intervals so that it better reflects the results of their actions.
- The ability to interrogate energy usage over longer periods of time (comparing one year with another or one season with the previous) was considered to be useful.
- People do not want to have to log in every time they interact with the system. Having to log in forms a barrier to free interaction with the interface and impedes the user experience.
- People do not want to be tied into one manufacturer. They would like to pick and choose system parts from different manufacturers with an in-built ability to communicate with one another.
- If an organiser is to be integrated within the system, consumers would like to see it integrated with existing calendars, in particular their Outlook organiser at work. If it worked in addition to, and in isolation from existing calendars, diaries and organisers, people would not be interested in using it.
- Future systems should have a more interactive element. People want to use the system to control their home; just being able to monitor their home does not engage the users.

Full details of the responses from the participants are presented in the Multi Home Trial Report.

3.2.10.1 Legal issues

Legal work for the TAHI trials was managed by the Services Aggregation trial on behalf of both its members and those of EM. The work is summarised in a key paper by Jane Hill, a barrister, who has outlined the eight principles of data protection, focusing particularly on areas of concern relevant to developers and implementers as well as those responsible for the commercialisation of new technologies. This and other documents relating to the legal issues are held in the EM virtual office.

3.2.10.2 Security issues

Security issues were considered as part of TAHI; these have particular relevance to the Equipment Management trial. These security issues are critical to:

- Privacy of data relating to individuals.
- Trust, important for technology acceptance.
- Integrity, to ensure acceptable system behaviour.
- Safety, as security compromises can compromise safety.

Security is an issue to be considered early in the design of any smart home system, as bolt-on security is not always successful. Additionally, any security system must be usable, and the rest of the system including the interface, must interact fully with the security aspects.

Data Protection legislation provides a framework for certain safeguards to ensure personal data are not distributed inappropriately.

The trial considered where household data should be stored and how it might be transmitted both within the home and to outside networks and service providers. Customers may find it acceptable to allow routine data to be collated centrally, but if these data provide an unofficial source to identify patterns of behaviour. The communication and storage of personal data within and outside the house can provide a profile of a user which could be used as a biometric of the person. For example, knowing when energy usage is low to identify unoccupied properties, or when someone is alone in a house) then this would be unacceptable, regardless of the possible benefits. Issues are also raised about the accuracy of data if they are being used to make decisions relating to health and welfare. For example, the equipment management system could alert a health professional if household water usage dropped below a threshold. However, if the data are unreliable, this may trigger an expensive call and unnecessary alarm the householder. If errors are made, the issue of where responsibility lies may be significant. These examples demonstrate the need for a secure system, despite the costs.

Security measures must be usable, as users will reject them if they do not understand their importance or find them inconvenient to use. This means the HCI for the security aspects must be intuitive and fully integrated, like the rest of the system.

The development of a secure system must also consider the gateway's security, which will require adequate resource to cover the appropriate speed, memory and processing capability of the system. Wireless technologies, although convenient, open up possibilities for security breaches. Enabling good services that are easy to access provide the opportunity for inappropriate access. Data protection legislation adds an additional burden on the system. However, the importance of protecting personal data is paramount.

The use of cryptography improves confidentiality of data, but system ease of use conflicts with the need for confidentiality. For example, one touch confirmation may be favoured by the user, but a complex set of security fields better protects them. Where a system comprises a number of parts, it will always be the lowest common denominator that breaches the security. However, it is often the human that provides the weakest link in the system.

It is possible to define a secure system that goes beyond acceptable levels. Users may put up with a level of inconvenience or disruption in return for a working system. However, insecure data may be safety critical, for example, if it is to be used in health services decisions.

3.2.11 Customer value propositions

The trial aimed to evaluate the customer value propositions and service provider value proposition for applications that maintain and manage the customers' equipment.

Potential customer offerings have selectively been packaged to illustrate how the EM bouquet of products might be tailored to the targeted market using an aggregated services model.

These are presented in detail elsewhere in commercial confidence for the benefit of trial members.

Dyson undertook a brainstorm of business value opportunities; this is presented in the Figure below.

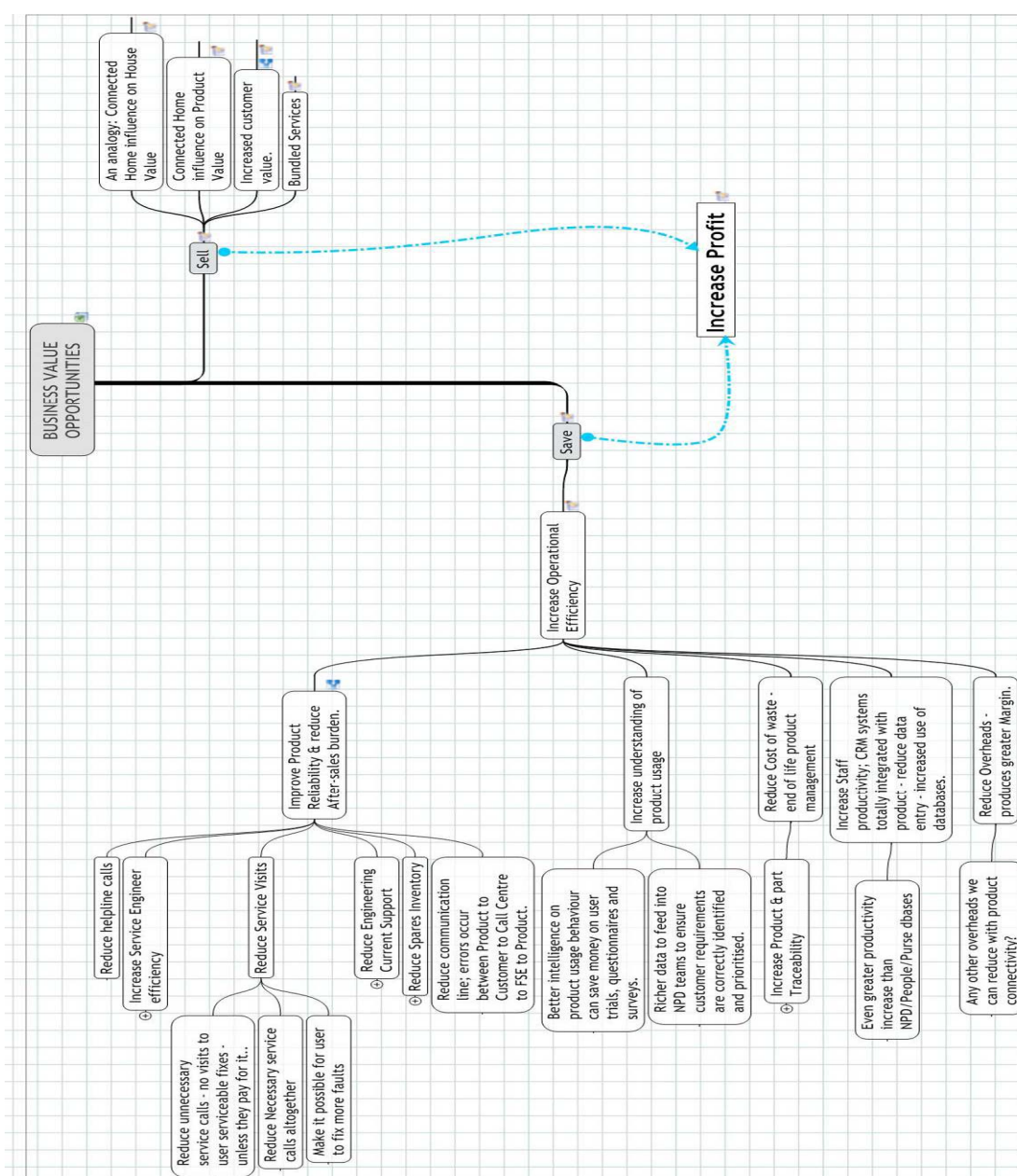


Figure 36. Business value opportunities

3.2.12 Future Research and Development activities

The trial aimed to identify the gaps in required new products and services associated with the interconnected home, to feed into future R&D activities of the NWTM Virtual Centre for the Integrated Home Environment.

The EM trial has identified exciting opportunities for the UK's domestic white and brown goods manufacturing sector. Despite the relative immaturity of some of the enabling technologies people seem interested in the use of smart home devices to improve their quality of life or just generally makes things easier at home in their busy schedules. Whilst the enabling technology behind future smart homes is being developed at a rapid pace, it is the intelligent application and integration of this technology that will make the difference to the home consumer. Just because the technology provider can make a 'useful' device it does not necessarily mean that the consumer actually wants to buy the 'new' invention. The EM trial has successfully shown where certain technology can be deployed successfully and also areas where further work is required. Consumer feedback is critical to the success of the market – instead of market push the structured approach behind the single home and Multi Home Trial provides clear consumer reaction and requirement for future home technology. This important feedback will show trial partners where to focus their future developments strategically.

The more obvious deficiencies in future smart home technology provision include:

Home Gateway

The home gateway represents a key link in the deployment of the integrated home technologies. The gateway provides the means to integrate all the enabling technologies in the home and also provide the link to the outside world. The lack of a clearly identifiable home gateway manufacturer in the UK currently is a significant factor that needs urgent attention. There are a number of companies who have some of the enabling technologies but these need to be brought together with a flexible software environment that is subscribed to by the systems providers in the home. The TAHI Open Architecture represents one attempt at providing a framework in which home appliances will be able to communicate with one another. This is still in an embryonic stage and considerable work is required to get the buy in from the wider market providers. There is likely to be a dominant presence in the EU in terms of home gateway standards and the US are known to be active in this area as well. It is clear that standards will emerge in this area but at this stage there is no obvious leader. Until some degree of standardisation is achieved this could lead to various standards and inter-operability issues.

There are clear market opportunities for the first in the field but this will depend on how quickly consumers will take up the technology. From a UK perspective it is unclear how a small UK based company will make an impact on the potential global market. Perhaps alliances with offshore technology providers may be an answer – the UK strength would be the definition and design of value added gateway software tailored for the UK market.

Unless a reliable and cost effective home gateway can be sourced then the future of smart homes will remain an issue.

Home Network Trades People

As soon as the gateway issue has been resolved and cost effective products become available the next hurdle will be the integration of these systems into the home. There will be a requirement to support new and legacy systems in the home and it will not be easy to interface the home gateway directly with existing systems.

The home will require 'wiring' up so that the various devices can communicate with one another. The EM trials have shown the complexities of supporting inter-operability between different communications standards. This has highlighted the need for highly skilled network competent engineers. It is likely that the networking issues that will emerge will be beyond the skill set of domestic electricians and trades people. Therefore, if networked enabled home technologies emerge there will be a need for suitably trained people.

Improved Access Control

The EM single home and Multi Home trials and other CIHE trials have clearly demonstrated the consumer's preference for easy to use interfaces. Though this was suspected at the outset, the trials have reinforced this view. Evidence has been obtained about which devices and appliances around the home need to be controlled. This information will help inform the design of future homes. The strong acceptance of speech recognition as a possible future interface was not expected. However, at this stage it is not clear whether the novelty factor is introducing this bias. Further work will be required to investigate the use of voice as a control modality. Speaker independent technology certainly eliminates the barriers usually associated with training conventional speech recognition systems. Further work will also be undertaken with improving the contextualisation of the commands used in the speech recogniser.

3.2.12.1 Major Challenges for Future Home Technology Providers

Privacy and Trust

Privacy and trust are key issues for the home consumer of smart home technology. As soon as devices are connected to an external network there will always be concern about system integrity. The use of wireless devices around the home also raises additional security concerns. Even though these problems will be surmountable, the consumer will tend to mistrust the system. Further work will be required to develop robust protocols that are resilient to external attack. However, as soon as one of these systems is breached the consumer is likely to reject external connectivity of these systems. Legal aspects remain an unresolved issue with person tracking – whilst it is acceptable to track a consenting adult it is another matter to track the behaviour of someone who is unable to make the decision themselves. The Services Aggregation Trial has looked at some of the legal and ethical issues but this will require further work.

Security

Security is essentially tied into privacy and trust but covers mainly physical integrity of the home system. As soon as the home system is connected to an external network it is vulnerable to external attack where someone could eavesdrop on the activities of the home owner. By looking for patterns of inactivity it is possible for an external person to improve their chances of breaking into the home undetected. Sophisticated attacks could also take place where the security of the home system is compromised and access to authorization codes and PIN could be extracted from the system. The need for low cost lightweight home gateways and protocols could actually increase the likelihood of such attacks taking place. The standards too would be vulnerable in the sense that they would be open and will need to be easily configured.

Multiple Occupancy

Multiple occupancy will not normally be an issue in future homes. However, if person monitoring is introduced to look after the well-being of a person then it will be necessary to introduce a person tracking system. Whether people will accept being tracked around their homes remains to be seen. Nevertheless, there will be instances where tracking is allowed (for example early release from hospital – precondition of being released) and technology to discriminate who is in a particular room will be required. Various solutions exist that need evaluating – these include Radio Frequency Identification (RFID), body sensor networks and intelligent tracking of people through activity monitoring.

User Acceptance

One potential main factor that holds people back with regard to employing smart technology at home is their lack of knowledge of it. This would be a problem in the future as well, even after all the technology becomes available. People, especially older people who would form a large proportion of the population, would resist new technology unless they have a thorough understanding of it. Therefore, just as there is a need for suitably trained engineers to install the systems there have to be educators to educate people by conducting workshops, seminars, TV presentations etc to educate people and familiarize them with the system and to build trust, which is currently lacking.

Content Ownership

To save on bandwidth there is the potential for media caches to be deployed in the home. These are 'black boxes' with large amounts of storage space. This may be used to temporarily store Digital Rights Management (DRM) protected media such as Video on Demand. It may also be used for semi-permanent storage of media recorded from digital TV/radio. Or it may be permanent storage such as music libraries, home video footage, etc.

Consequently, issues such as content ownership and reuse will need addressing. If the media cache becomes large then the issue of backup will be important for the home owner.

3.3 ADDITIONAL ACHIEVEMENTS

As the trial progressed, the partner dynamics changed, for example Dyson joined the trial and Centrica took a passive role. This had a number of effects. Firstly, there was a corresponding shift in emphasis towards energy monitoring and use, as Horstmann took over lead of the trial. As a result, there were a number of additional achievements within the trial:

- Heriot-Watt conducted research into attitudes towards energy use.
- Horstmann created the white goods monitors for collecting appliance energy data.
- Invensys stepped in with the iCom when Honeywell withdrew.
- Dyson undertaken work to scope potential service bundle packages for the connected home. A snapshot of this work is provided in the figure below.

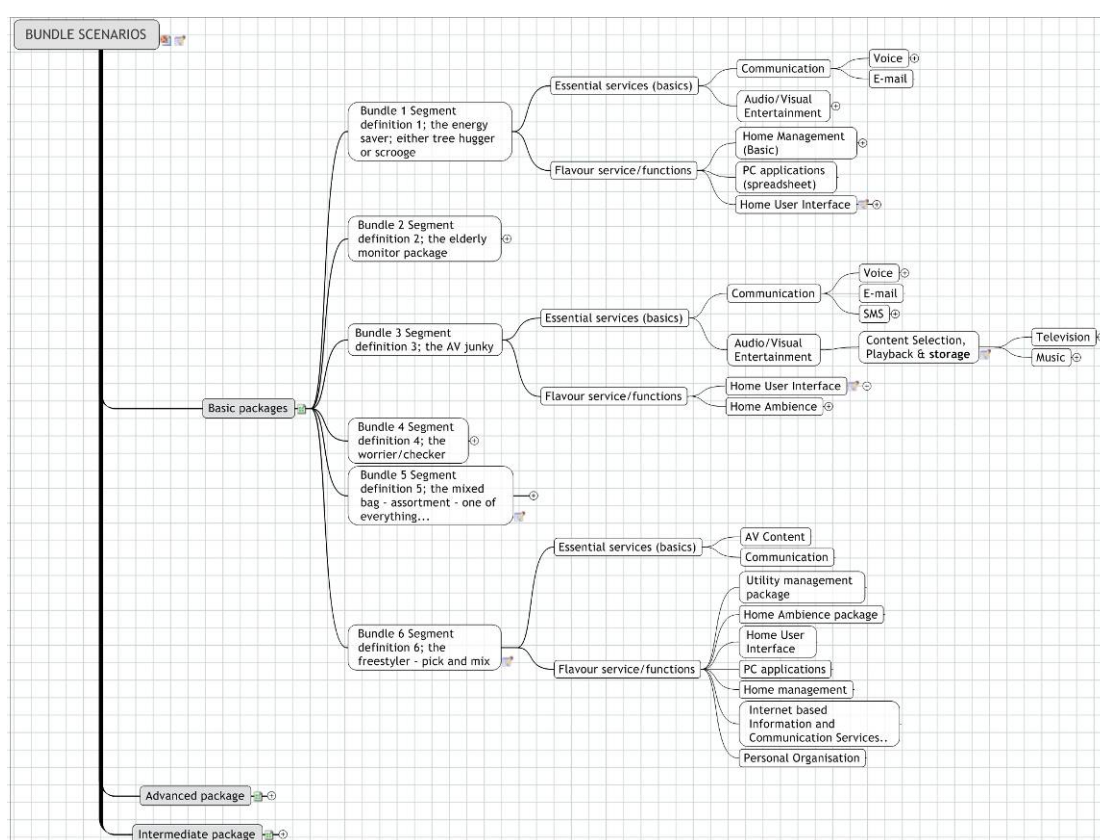


Figure 37. Service Bundle scenarios

3.4 KEY SUCCESSES

There were a number of key successes as a result of the trial. These can be separated into successes relating to the technical and research aspects as well as the trial process itself. These are described in more detail in the next sections.

3.4.1 Key successes – technical

The trial produced a number of technical successes, including:

- **Proving the technology in the home.** It was possible to design, develop, build, install and monitor an equipment management system in existing, occupied, non-identical homes.
- **Reliability of gateway and installation firmware.** This may seem a surprising view based on the number of problems experienced in the Multi Home Trial but for a prototype system of this type the TAHI EM installations were surprisingly reliable. Only 4 customer resets were required due to local system lockups and very few visits were required to resolve problems on gateways or devices (other at than at the first trial home).
- **iCom bundle development.** The iCom hardware arrived very late in the project but very good progress was made by Advantica in developing the iCom bundle and produced an application which was able to derive a wide range of data and diagnostic parameters from the available information. With the limited time available to integrate with Extrada, a mechanism was found to collect at least some logging data from these units. This should form the initial basis of development of retrofittable appliance monitoring devices of this type.
- **Remote management.** Monitoring and update of applications and management of the gateways and installed applications worked very well via the remote management applications employed in the trial. This proved that, with a stable platform and infrastructure in place, it is possible to manage such installations without need for many site visits.
- **Technology demonstrator.** Real time monitoring, usage data and diagnostic information were possible though the technology demonstrator. White goods installed in the home were able to transmit information over low data rate powerline networks. The demonstrator proved these data could be collated in the home gateway and disseminated over a wide area network via the internet protocol. The white goods data were presented to the end user via an intuitive web interface and via daily status emails sent automatically from each home gateway. The technology demonstrator proved the end to end transport of useful data over a wide range of network technologies.

3.4.2 Key successes – research

As the trial incorporated a number of Universities, significant research successes were made, to underpin the technical and commercial work. These included:

- **New research into interface design within the home environment.** As the use of any system must be considered in context, the trial provided an opportunity to develop research and understanding into the needs of consumers in relation to smart home technology. In particular the development of a user interface for the home environment was achieved, taking into account the context of use and users' expectations, both of which can be demanding. To support this, new evaluation techniques were developed.
- **Customer and commercial values.** The trial provided an insight into the values held by householders in relation to equipment management. Although the participant group was small, this research has identified, through real usage data of equipment, initial trends that can be further explored. The trial has also provided an infrastructure for the collection of these data.
- **Identification of problems with retrofit equipment.** The Multi Home Trial achieved an insight into retro-fitting smart home technology into existing, occupied, non-identical homes. In many cases this was an insight into the problems that can arise, but this valuable learning experience can be used by others in future development work.
- **Equipment life cycle data / information management.** A prototype system was developed for enhanced services delivery to connected homes, system demonstration and to inform future research and development.
- **A reference architecture** and detailed system specification / design was created as a 'blue-print' for future development
- **A generic equipment data specification** and associated XML data schemas were created for home equipment that will contribute towards future Mark of Conformity work.

3.4.3 Key successes – process

The EM trial followed the general principles of the established PRINCE project management methodology but because of the collaborative nature of the programme and the considerable differences in participant objectives, some of the rigour had to be relaxed and a more flexible approach adopted.

Telemetry Associates programme managed the Equipment Management trial from its inception in October 2002, and took responsibility for financial and virtual office administration from 2003. Key activities included:

- Start-up/initiation workshops were held, initially on a monthly basis, to ensure that all stakeholders had a common understanding of the scope, assumptions, constraints and interfaces.
- A Joint Project Agreement (JPA) was created and signed by participants as a contractual obligation in lieu of the dti standard document. The JPA had been developed and put in place in conjunction with the Services Aggregation trial and TAMI secretariat.
- A project template was created to encapsulate the ethos, objectives and anticipated outcomes.
- Work packages were defined and leadership allocated.
- The broad timescales for Phases I and II of the programme were set out and modified throughout the trial to take account of changing circumstances, flagged by:
 - Participant changes.
 - Monthly reviews and teleconferences.
 - Weekly teleconferences for key work strands where necessary – R&D and MHT activities.
- Individual parts of the programme were managed via tailored plans, sometimes revised weekly by teleconference.
- Roles and Responsibilities were agreed through service level agreements (Annexe 10s) related to the Joint Project Agreement.
- High level allocations of contributions and matching grants (where appropriate) were agreed, refined in accordance with work package responsibilities and balanced to meet the trial's evolving needs.
- A budget model was written and maintained, to record trial finances on a monthly basis by participant. This model was used to generate reports for monthly publication to trial members.
- Governance Procedures were defined, written up into management procedures and implemented.
- A distributed organisation structure was put in place across participating organisations.
- Steering group roles were defined and filled by representative organisations.
- Project managers were appointed in each organisation.
- Financial reporting processes were defined and implemented.
- Progress reporting processes were defined and implemented.
- A stage and grant sign off process was defined and implemented.
- A risk register was produced, maintained, managed through Steering Group and published in monthly reports.
- Project reviews (quality, time, resource, issues) were scheduled for work streams and pursued as appropriate for the duration of the trial.

- A documentation control process was created and implemented, with an index.
- A formal project change control process was created and used to communicate membership and budgetary changes to members, with the reasons for these and the resultant changes to the JPA.
- A virtual office was created to hold trial documents with access structured according to status (i.e. trial member>TAHI member>external), first on the web and then in the Leeds University Virtual Knowledge Park and now at Loughborough University. The full document register for the trial is appended.

The trial also successfully undertook team problem solving, an essential task in a multi-partner, collaborative trial. For example, the 'virtual' development and implementation team on the trial faced a substantial number of technical problems to overcome with equipment and software and managed to work very effectively, largely through email and teleconferences, to resolve most of the trial issues encountered. Ideas generated by individuals would be developed and tried by the group and showed how group problem solving can be very effective.

3.5 CHANGES TO THE PROJECT PLAN

The key changes to the project plan were mainly as a consequence of the withdrawal of participants, or changes to their priorities, as follows:

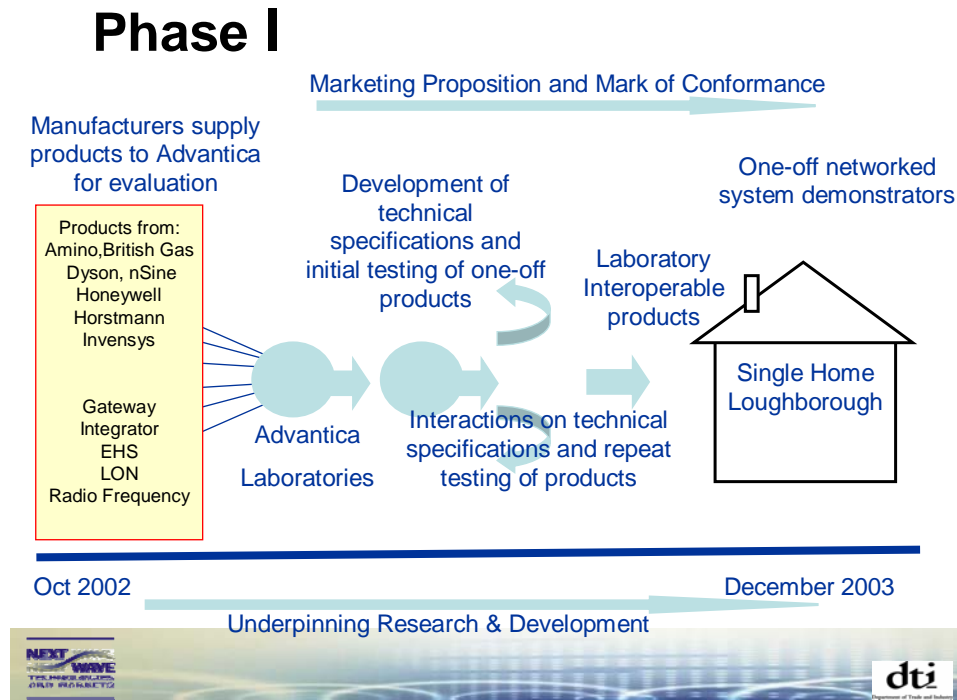


Figure 38. Phase 1 Work Plan

Amino decided early in the trial that they would limit their engineering input to the gateway and participate with a reduced involvement. This led to an early review of work packages during the period over which the JPA was signed. The consolidated gateway was developed instead by Horstmann, Advantica, Extrada and Invensys with support from Telemetry Associates, using OSGi as a development tool. Amino were responsible for leading the theoretical R&D work on home networks, which activity was completed to a satisfactory degree before Amino left the trial. However, the trial did not know at that stage how critical the practical embodiment of ad-hoc home networks would be to success in the Multi Home Trial.

Centrica's decision not to continue with its original commitment had a massive impact on the trial. The immediate effect was the loss of strategic direction from a large corporate likely to exploit the results of the trial's work. Horstmann became trial directors and took up the challenge of chairing the EM Steering Group. Additional resources were agreed with them.

Closely tied with Centrica's change of strategic direction, Accenture left the trial. They had conducted and coordinated the business modelling work, this then being picked up by Extrada, who created a new model in conjunction with the SA Programme and which included the all important "Service Aggregator" role as an intrinsic part of the model.

More focus was placed on demonstration. Phase I work up to August 2003 had identified an important need to pre-test the gateway integrator and interoperable equipment as a system, prior to installing this in real homes.

Phase 1a - SHE

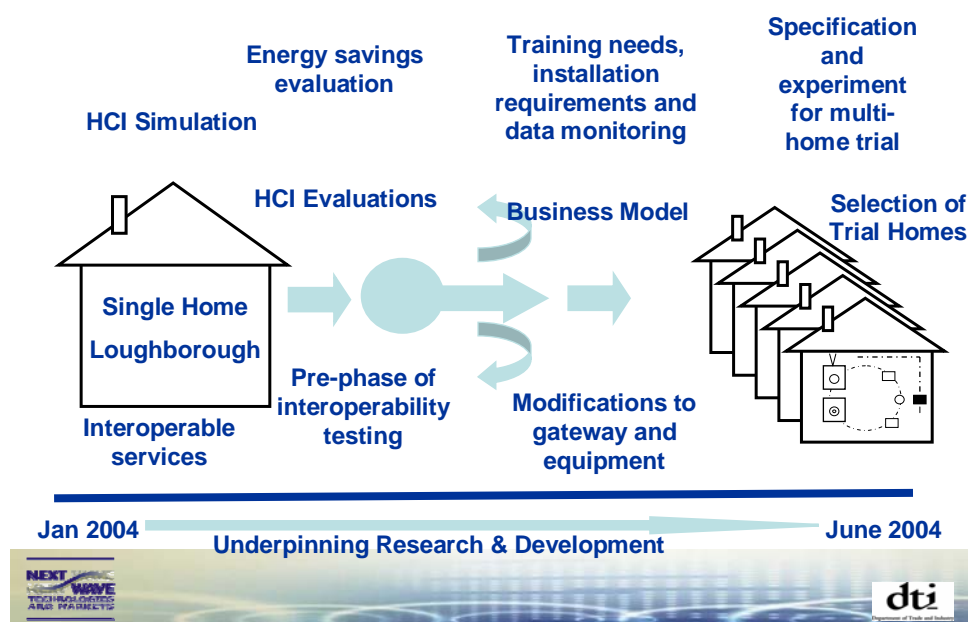


Figure 39. Phase 1a SHE Work Plan

Furthermore, the R&D co-ordination group had identified a number of experiments which although valuable, would be impractical in real homes. The break point between Phases I and II became blurred and an interim Phase Ia was created to reflect the need for continuing testing and R&D throughout the course of the trial programme, with interactions between the laboratory and field activities. The use of Advantica's test home was extended for the duration of the trial to conduct Single Home Experiments (SHE). Loughborough University picked up some of ESRI's SHE work. A new plan was created to take account of the above changes.

The late departure from the trial of Honeywell meant that the Hometronic environmental controller could no longer be included. With Hometronic withdrawn at this late stage, the trial had no possibility to demonstrate remote control safely within budget and remaining timescales. Instead, Invensys provided a prototype retrofit iCom device to monitor remotely the operating performance of the central heating boiler. Horstmann provided prototype retrofit modules for the measurement and optional control of electrical white goods. Heriot-Watt University extended their role to energy related elements of the Multi Home Trial.

Phase II

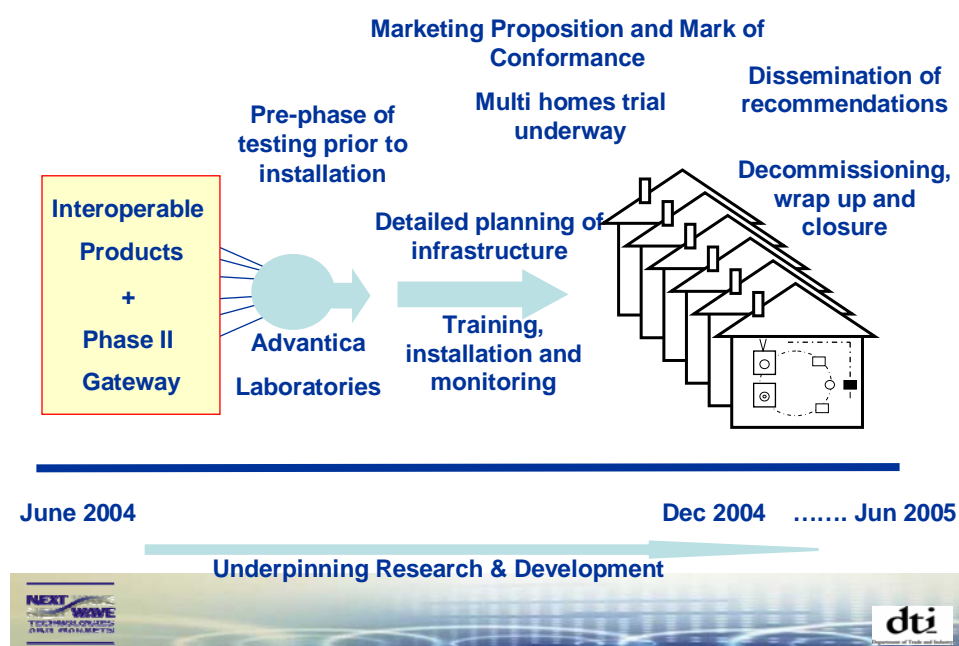


Figure 40. Phase II MHT Work Plan

nSine left the trial because they had gone into receivership. Their wireless power line product was not deployed, although other products have been tested during the Multi Home Trial.

With the loss of nearly £800,000 of industrial contribution from Centrica, plans for a 50 home trial had to be scaled back substantially and instead, case studies were conducted on 15 homes by ESRI. Instead of Centrica's contractors and engineers managing the field trial installations, Advantica did this and procured the necessary field trial equipment and trade services on behalf of the trial. Additional resources were agreed for Advantica and dti grant contingency funds were used to provide equipment where this was not included in existing commitments.

Advantica's experience from previous field trials was that essentially the same problems occur in most homes, and that the same learning can be achieved through running 2 or 3 homes in the trial. The Multi Home Trial backed up this experience. Although it was not possible to attain the original 50 homes in the trial, the 15 homes enabled the trial to maximise the amount of data received from the houses, in terms of installation experience, operational performance, raw energy data, and the customer perceptions of the technology.

Two houses were used extensively as pilot homes, with a third providing an additional test bed, although it did not remain in the trial for the full duration following significant technical issues. Many of the myriad technical issues arising in the field were investigated in the demonstration home, tried out in the pilot homes and then rolled out to the other field trial sites. The case study approach paid dividends in terms of learning.

3.6 CHANGES TO THE CONSORTIUM MEMBERS, ROLES AND RESPONSIBILITIES

Between October 2002 and the summer of 2003, the trial membership firmed up as the implications and commitments of the Joint Project Agreement (JPA) were realised and commercial decisions made. A 'Heads of Agreement' was used as a precursor to the JPA.

A number of organisations (DSC Tyco; Echelon; Olameter; and Panasonic) included in the funding proposal withdrew from the programme and were never party to the Agreement. In August 2003 a formal change note (EM53.1) was issued to document changes to participants, their roles and financial arrangements, that had taken place since the JPA was first issued.

Critically, this document recorded the financial impact of Amino's significant decision not to undertake the engineering of the gateway, and the consequences of this change. The note also dealt with Dyson's relative late entry to the trial.

By spring 2005 there were more significant changes recorded in EM123.3 and relating to Version 8.1 of the EM Joint Project Agreement (EM31.8) dated 22 March 2005.

- Accenture, Amino, Honeywell and nSine had withdrawn from the trial and all ceased to be signatories to the JPA.
- Dyson entered the trial.

- Centrica relinquished their leadership of the trial, adopted a new watching brief role, and made substantial changes to their initial commitments but remained party to the JPA.
- Advantica, Extrada, Horstmann, Heriot-Watt University and Telemetry Associates committed more disbursement and received matching grant budget to reflect their growing roles in the trial.
- Homeportal changed their name to Extrada.
- Advantica Technologies Ltd changed their name to Advantica Ltd.
- Publications policy was revised to facilitate publication during the trial's output phase.
- Telemetry Associates received a grant extension to continue to programme manage the trial until June 2005 and administer the contingency grant under EM Steering Group control, to ensure that funds were deployed effectively to priorities.
- In consultation with the dti, the trial 'end' and 'no obligation to pay' dates were extended by six months to 30 June 2005 and 31 December 2005 retrospectively, in respect of grant payments.

The financial position was reviewed and revised at each stage to reflect and manage these changes, and implementation plans drawn up. All budgetary changes were endorsed where necessary by the trial management (EM Steering Group) at its monthly meetings or teleconferences.

3.7 CHALLENGES AND OBSTACLES

The trial faced a number of challenges and obstacles, some of which were significant to the progress of the trial. In some cases, these challenges could be overcome through the input of additional effort by trial members, by redefining the trial plan or by finding alternative options within the plan. In other cases, it was not possible to overcome an obstacle and so the trial progress was halted temporarily and an alternative approach had to be found.

Particular challenges and obstacles included:

- The trial programme had to develop to keep up with, and make best use of, new technologies that developed along the way. These included broadband, wireless technology and digital TV, which were available at the start of the trial, but were not widespread in use.
- In the earlier stages of the project it was quite a challenge to determine what the EM gateway functionality would be and how to go about developing it. This was successfully overcome via the approach detailed earlier in this report (Support for Mark of Conformity).
- At the start of the 6 months allocated for the Multi Home Trial, a limited number of applications were ready and so the trial implementation was not a case of rolling out a proven solution. The trial implementation was staged so that the established and tested components were installed and then the newer components were proven in two pilot homes prior to roll out. Remote management was used successfully later in the trial to update installations with new applications. This approach worked well but required much more effort than installation of complete working systems from scratch but was unavoidable due to delivery timescales for some applications and components.

- Recruitment of participants for the Multi Home Trial was more demanding than expected. Early in the preparation for the Multi Home Trial, and following Centrica's withdrawal, it became apparent that a 50 home trial was neither possible nor necessary. As a compromise, a smaller, 15 home trial was conducted. Whilst it was recognised that this would not provide statistically valid data and would not incorporate a representative demographic sample, it could provide rich case study information through the collection of descriptive data from participants. It was also realised that many of the lessons learned could be discovered from only a handful of trials; additional houses would have contributed only marginally more new information.
- Evaluation methods had to be tailored to the home environment so that they were unobtrusive and engaging. As use of the system, as well as providing feedback, is discretionary, appropriate evaluation techniques had to be developed. This took additional time, but resulted in eliciting valuable data, despite the limited functionality of the system under evaluation. It was felt that the trial participants took the trouble to complete the evaluations despite not having many comments to make because of the evaluation methods; the participants saw that effort had been put into developing the record books, so wanted to respond positively.
- Technical difficulties delayed much of the user evaluation so it was necessary to complete the evaluation in a shorter period of time. This required researchers to be flexible and adaptable, and to mould the evaluation so that it did not affect or inconvenience any of the participant households. Ideally, systems should be completely robust before rollout. Even though the Multi Home Trial included relatively 'tame' participants, there were frustrations for them when systems were not working properly or in some cases not at all. In many cases, these failures were short-lived, but care had to be taken to ensure they did not override attitudes of perceived user value. By using more than one data collection methods, researchers were able to gain different perspectives from the participants and reduce the likelihood that data analysis could be biased by the nature of the data collection method used.
- Design and development of a suitable user interface in a working system is a major exercise. In order to make the technology successful (and providing something of real interest and use to the consumer), it is essential to use an effective process to providing an initial user interface which can accommodate developments to the design, without using significant resource. Whilst the trial developed a simulation which could incorporate interface prototyping, transferring this to the real system still took time. Additionally, the length of time taken to develop each aspect of the system meant that some parts were ready ahead of time, whilst others were not.
- The diversity of the skills, technology and operational capability needed to deliver digital services to the home means there has to be co-operation between these different companies to deliver end to end digital services. Standardisation, such as each piece of equipment carrying an IP address, would enable easier technical integration.

The trial had to overcome issues of non-standardisation in order to provide interoperability. Again, this increased the time and resource needed to reach a working system.

- Piggybacking on a customer's network to provide services to home devices currently requires significant costs in setup and support. The trial provided this setup and support, but it proved to be a time consuming task, as it essentially comprises a personal service to each household, with in-depth knowledge of the range of systems they had in their homes, their personal requirements and their capabilities.
- For this trial, the management of the parties involved was on basis of consensus between members. This is inevitable for a process of this nature but would not be a realistic way to commercially deliver real services. The two primary problems with this structure are that there is no simple decision process and when decisions are taken there is no powerful way to enforce them. However, in commercial rollout there may still be some of these less formal relationships and there were good learnings in the very least about how to get the best from them.
- A lesson common to almost all projects is that the planning and specification stages are the most important, both in defining what needs to be done but also getting buy-in from all the parties involved.

With the benefit of hindsight, the trial would take a number of different approaches to overcome, or ideally avoid, the challenges and obstacles set out previously. These include:

- Close collaboration between the Equipment Management and Services Aggregation Trials would have allowed for one combined system to be developed, with the equipment management aspects providing a platform for the aggregated services. Equipment management data would then have been offered as one of the services on this platform. As many of the project partners were working on both trials, but their input was separated under the terms of the Joint Project Agreements, two separate systems were developed. Close collaboration would have provided EM with real services rather than some dummy features, offering significantly more functionality to the trial system.
- The time taken to define and agree on the system specifications meant that much of the user centred work was delayed, waiting for clearer definitions before researching them in detail. In hindsight, this work could have gone ahead as part of a scoping study before the detailed specification, and may have helped to shape the system offerings and contribute significantly to the specification.
- A reduction in emphasis placed on the up front research, with earlier system prototyping would have allowed for better development and testing of the systems. This would have provided a more complete and robust system in the Multi Home Trial.

- The delay in agreeing a final system specification also meant that the time available for the Multi Home Trial was limited. Although this process may be considered inevitable with the range of project partners and the changes to trial membership, it highlights the need for one partner to take a strong lead in order to get effective progress early on in the trial. Whilst the direction may not be exactly as intended, this would provide the trial with a system to develop into the desired format.
- More expertise in Wide Area Networking would have been useful, as difficulties were encountered with this technology during the Multi Home Trial.
- The trial could have taken advantage of similar systems in use for building management in the commercial arena – there is a large cross over in technology and services delivered.

3.8 ADVENTITIOUS ACHIEVEMENTS

3.8.1 Broadband Use

When the trial was conceived, the take up in the UK of broadband was in its infancy and there were many areas in the country where the service was unavailable. Since then, the Government has promoted the regional growth of broadband and although not yet mature, comparison with other countries paints a forward picture for the UK.

The trial also needed broadband for data recording and monitoring, to research the equipment functionality and user data. Hence, broadband connectivity was adopted and narrowband connectivity placed in the “we know how to do this if ever necessary” category.

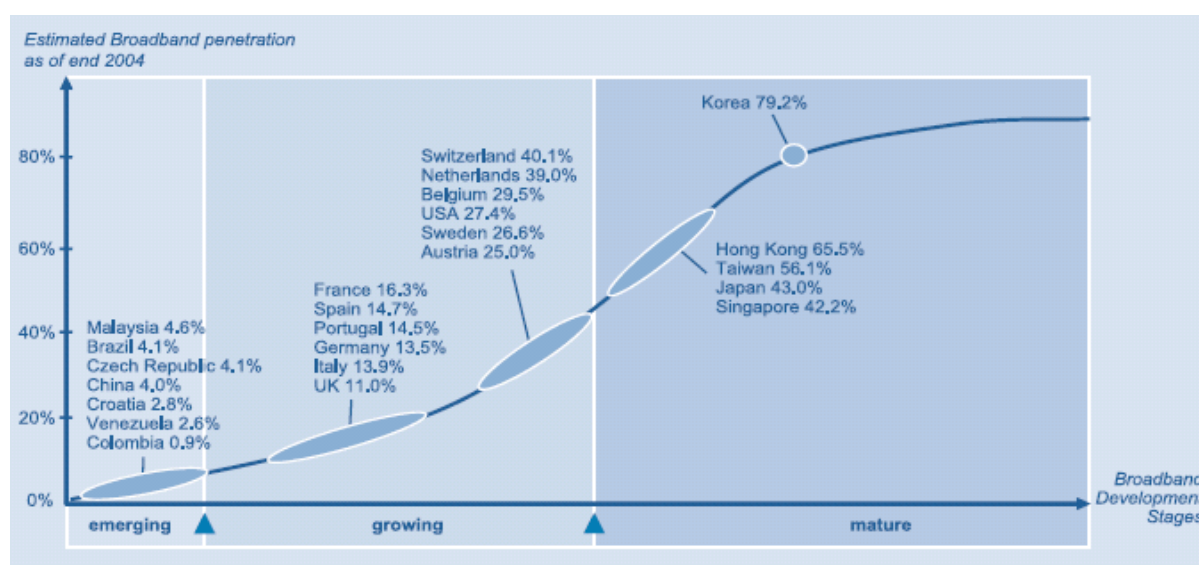


Figure 41. Broadband Development Stages (end of 2004)
(AD Little, 2005)

3.8.2 Wireless networking

Similarly, three years ago low cost wireless routers and wireless devices (RF, mainsborne) were not available readily in the high street as they are today. Hence, it made sense to show that the EM system could be integrated with off the shelf network components.

3.8.3 iCEBOX

This unit enables users to move between TV, radio, CD, DVD and internet access using a TV-like remote control and wireless keyboard. It also moves the internet access into the kitchen. The availability of this device at the appropriate point in the trial meant that the iCEBOX was chosen to represent the EM appliance displays.

3.9 PUBLICATIONS AND REPORTS

Key reports produced from the trial include:

Doc Ref	Document Title	Document Description
EM15.0.	Financial Governance Chart	Schematic outlining the agreed financial governance procedure for the trial, to be used in conjunction with the dti's established procedures.
EM20.0.	Project Proposal Issue 3.0	EM programme description based upon EM1, that forms the basis of the formal collaborative agreement (JPA) Schedule 4, "The Project Template". Also see EM31.
EM25.1.	Systems Integration Report v.6	System design for the integrated equipment under trial. Technical reference document written by Martyn Gilbert of Amino and reviewed by TAHI Technical Working Group.
EM30.0	Project Brief	Overview by Programme Manager of EM trial objectives as required by the Prince project management methodology.
EM31.7	JPA Version 7	Revised issue version of the EM Trial Joint Project Agreement, as signed by participants. Annexe 10 statements from each organisation are now held on the VKP (Reference folder). Project template (EM5) was not included as an annexe of the issued document or its predecessor EM31.6.
EM47.3	Trial Services & Products	Options for products and services to be offered to Customers under the Equipment Management Trial.
EM53.1	JPA Change Document	Formalisation of key changes to the JPA (EM31.6). Amendment to list of participants for leavers and Dyson's entry. Redefinition of work, with revised Annexe 10s.
EM54.03	Scenarios	Scenario work to support the creation of a new EM strategy following the announcement by Centrica that they were to withdraw from active engagement in the trial.
EM56.03	dMU Report on IDU/IMS Spec	Phase I DMU deliverable: report on the 'Requirements specification and reference architecture for IDU technology and information management system.'
EM59.1	dti Progress Review	First formal report to the dti, setting out the first year's progress.
EM67.1	EM Workshop	Notes from a review of work package progress since November 2003. Practical demonstrations of end to end applications through the gateway and an HCI simulation.
EM69.1	Dti Progress Review Note	Second dti review document, linked with the quarterly review of the Centre for the Integrated Home Environment. Period: October 2003 to March 2004. See EM59.
EM71.1	Amino White Paper on stand alone and aggregated content and services	Amino deliverable. Academic report containing worked examples of stand-alone and aggregated content and services. Conceived as critical element of the adoption of the TAHI Open Architecture to link the trial equipment to Pervasive Service Agents and Remote Service Objects. With new TWG leadership, the report does not have the standing it may once have promised.
EM80.1	EM Development	Key document by Advantica's John Bryce that defines the gateway

	Gateway Requirements Specification	and system requirements, including HCI requirements.
EM83.1	Aggregated Business Model	Excel model templates created by Mark Herterich of Homeportal, that links a number of business model spreadsheets for individual services. Enables sensitivity analyses to be conducted for aggregation options.
EM 92.1	Appliance Monitoring Node HCI Requirements	Specification by Horstmann white goods energy monitor, including message structure and display options.
EM95.1	Progress Report to dti March-July 2004	Third dti review document, linked with the quarterly review of the Centre for the Integrated Home Environment. Period: March to July 2004. See EM59 and EM69.
EM96.1	EM Trial Management Procedures July 2004	Streamlined version of trial procedures document, setting out financial and administrative governance.
EM100.1	Remote EM Services system for MHT.	Requirements specification from SK Chong of DMU for the remote equipment management services (REMS) system to support the Multi Home Trial. This document is produced with reference to IEEE Standard 830-1998 for producing software requirements specification.
EM102.2	Multi Home Trial Investigation Plan	Defines the investigations for the Multi Home Trial. It is a living document that will encompass the trial results as and when these are available, in addition to setting out the investigation objectives, methodology and process. The report describes investigations (as opposed to experiments) that will be conducted in the homes. Also now includes functional spec for MHT HCI.
EM104.1	Focus Group Evaluation by ESRI	Findings of a focus group study to gauge general attitudes and opinions toward Smart Home technologies and services Six groups of participants were presented with seven different scenarios to think about and some guidance questions to generate discussion. The scenarios were: Energy Use; Boiler Service; Appliance Repair; Holiday Security; Home Ambience; Break In; Welfare Monitoring.
EM105.1	MS Media Centre Evaluation by Extrada.	Evaluation of the Media Centre, a new software product from Microsoft combining home entertainment and computing on one device as an extension of what has been happening already in the PC world with the ability to play multi-media in ever-improving quality. The media centre could become a real and available means of delivering a control and service viewing interface to potential EM customers.
EM109	Heriot Watt Energy Questionnaire	Questionnaire to TAHI and external audience, seeking information on what equipment people would like in the home and what they would like this equipment to do. The questions focus on the use of energy and water and in detailed matters relating to energy-saving and water-saving.
EM110	ESRI MHT interface display mock up	Remote interface mock up for the Multi Home Trial produced by ESRI's Catherine Cooper. Extrada's local and remote interfaces will be based upon this visual specification.
EM114	MHT Householder briefing note	Briefing note written by Nikki Ranzetta of Advantica to communicate to prospective trial participants, the equipment that will be installed in their homes.
EM117	ESRI's evaluation of the EM trial equipment software and interface designs	A report describing the initial assessment and measure of success of the usability of the products in the trial at its inception, using a process of Heuristic Evaluation. This involved a set of specialists scrutinising the interfaces and evaluating each element of the design to judge its compliance with a list of widely accepted usability principles. In some cases, the designs of the devices were so simple that an analysis of heuristics was not appropriate. Under these circumstances, the evaluators have suggested improvements to the overall design of the device based on their knowledge of 'good design' and usability issues.
EM118	Progress Report to dti Aug – Oct 2004	Fourth dti review document, linked with the quarterly review of the Centre for the Integrated Home Environment. Period: Aug-Oct 2004. See EM59, EM69 and EM95.

EM121	MHT Risk Register	Register of hazards relating to the equipment being installed in 15 field trial homes, together with an assessment of likelihood, impact and the risk control measures to be taken.
EM122	MHT Infrastructure Plan	MS Project plan of the timescale and interactions for the delivery, installation and commissioning of field trial equipment.
EM123	JPA Change Document	Formalisation of key changes to the JPA version 7. (EM31.7). Amendment to list of participants for leavers. Redefinition of work, with revised Annexe 10s. Recognition of leadership change. Inclusion of revised publications policy.
EM140	Equipment Management Trial Final Report	External report summarising the history and achievements of the trial from October 2002 to June 2005.
EM141	Advantica Final Reports	Final reports by participant summarising their contribution made to the trial and recording IPR, software and other know how. A MHT. B Energy Audits. C Gateway final status. D Conformance Facility. E Testing & Verification. F Gateway Specification. G Gateway Build H Conformance Facility Requirements Analysis. I Review of Existing test facilities, experience, processes and equipment.
EM142	De Montfort University Final Report	Final report by participant summarising their contribution made to the trial and recording IPR
EM143	Dyson University Final Report	Final report by participant summarising their contribution made to the trial and recording IPR
EM144	Extrada Final Report	Final report by participant summarising their contribution made to the trial and recording IPR
EM145	Heriot-Watt University Final Reports	Final reports by participant summarising their contribution made to the trial and recording IPR: A Summary. B MHT method. C SHE Expert Advice. D Preferred Design. E Questionnaire.
EM146	Horstmann Final Report	Final report by participant summarising their contribution made to the trial and recording IPR
EM147	Invensys Final Report	Final report by participant summarising their contribution made to the trial and recording IPR
EM148	Telemetry Associates Final Report	Final report by participant summarising their contribution made to the trial and recording IPR
EM149	ESRI Final Report	Final report by participant summarising their contribution made to the trial and recording IPR
EM150	Loughborough University Final Report	Final report by participant summarising their contribution made to the trial and recording IPR
EM153	Equipment Management Multi Home Trial Final Report	Internal trial report summarising the infrastructure and field experiments in the Multi Home Trial up to June 2005.

A full list of publications and reports produced from the trial can be found in virtual office supporting this trial.

Additionally a short video was produced at the end of the trial summarising the achievements of both the Equipment Management and Services Aggregation trials.

3.9.1 Academic Papers

A number of academic papers are planned following the conclusion of the trial. These will disseminate the underlying research that is in the public domain and will be presented at Conferences or academic journals of relevance. Papers produced during the trial include:

Chong, S. K., Moore, P.R., Wong, C. B., Pu, J. (2004), *Equipment Information Management in Connected Homes*, 9th Mechatronics Forum International Conference, Mechatronics 2004, 30 August– 1 September, 2004, Culture & Convention Centre, METU, Ankara, Turkey.

4 RECOMMENDATIONS FOR FURTHER WORK

This trial has provided an excellent opportunity to develop and test equipment management systems in real home environments by bringing together small, medium and corporate businesses with universities. Without the support of the dti, this work would not have been possible and to maximise the trial's benefits, it is suggested that industry should test its ideas against the TAMI trial experiences to verify that future technical proposals are feasible and worthwhile.

Whilst there have been many achievements within the trial, set out in this and supporting reports, further work is needed to bring the system in its entirety to market. Some component parts of the work can be developed by the commercial partners without significant future research investment. Other aspects need more extensive research and development. These include:

1. Technically, the trial has proven that it is possible to create an equipment management system. The trial has also identified that the role of service provider (the '5th utility') who supports this system is considerable. Whilst individual equipment manufacturers are able to control their own provision and support, the integration of these components falls outside individual responsibilities. This 'superaggregator' is not an insignificant job and needs considerable further research into what it entails and how it might operate to ensure market acceptability.
2. The trial identified a number of significant issues relating to retrofitting equipment into existing homes. These issues must be overcome if an equipment management system is to be successful in the future. Further work into these issues is essential.
3. Further collection of data from the Multi Home Trial. Two households who participated in this trial will be supported to provide on-going data. This will be used by both the commercial partners and the universities to provide a longer term insight into the technical system and household use.
4. Equipment will remain in the test house for ongoing research. This should see the integration of the EM and SA trials to produce a fully working integrated system. This will also provide a demonstrator system which can be used for further development.
5. A cheap reliable gateway for the commercial environment needs further development.
6. There are many diverse standards, electronic communication means, devices and systems that co-exist in a typical home environment. An overarching architecture capable of embracing all existing standards is essential in order to achieve interoperability between domestic equipment. Open standards and common data models are vital to the success of implementing equipment management systems in connected homes. Electronic equipment descriptions, open accessible interfaces and communication capabilities are fundamental facets for future "Smart" equipment.

7. The development of an independent test body for interconnected appliances and other products could also offer valuable development assistance to SMEs. The viability of equipment information management system will be tested using the gas safety data from the Multi Home Trial.
8. Certification could be based on a limited number of application tests for 'standard' functionality of the device in some reference implementations on the main broadband and LAN networks. The broadband or LAN protocol would be handled by existing pre-tested network drivers. This would result in a more affordable Mark of Conformity and so would not inhibit implementation due to prohibitive test costs. Further work is needed to develop a document outlining a set of recommended network interfaces, prototype OSGi bundle device interfaces, standard remote server interface descriptions plus a test framework detailing conformance test areas against which suppliers can self certify.
9. The trial does clearly indicate a number of areas where additional efforts are required to define how OSGi based systems should be implemented and these should form the basis of an open architecture and hence would also form the basis of the Mark of Conformity. The particular areas for attention are as follows:
 - a. Defining how the remote network connection be maintained between the server(s) and the gateway. In the TAHI EM MHT it was found that static IP addressing was not feasible and that VPN provided a working solution for the trial. VPN is not practical for large-scale implementation and so an alternative requires identification and proving.
 - b. Defining how remote server application will inspect and control the services within the gateway. This is in fact implemented in the Extrada glue bundle but this (or something similar) should be made generically part of a 'MoC' OSGi implementation.
 - c. Defining how a default local user interface be provided. This (as with the above point) is implemented in the Extrada glue bundle but this (or something similar) should be made generically part of a 'MoC' OSGi implementation.
 - d. Defining a common process for determining application status (e.g. communications with devices OK, etc) to ensure that all applications provide sufficient diagnostic information to enable effective remote management. It must be concluded that the MoC be fairly lightweight as the networked home business will be very cost challenged for some time. It can be seen that the MoC could recommend some standard approaches such as those detailed in section 10.
10. A means of practically implementing these in a customer's home network (network protocols, generic router setups, etc) is then needed. As the level of technical support required to maintain and run the system in the Multi Home Trial was unrepresentative of a commercial solution, further research into the customer value of the system is needed.

11. The need for energy usage display mobility requires further research.
12. The collection of detailed life cycle data provides manufacturers with considerable information about the use and performance of their appliances. From this, a number of services could be delivered, for example, bespoke warranty based on usage known from connected information gathering.
13. Equipment manufacturers should extend their responsibility and have data available at all stages of the equipment life cycle. This calls for an integrated information system open to access by other parties, such as those involved in supplying components, maintenance and recycling of the equipment. In general, users are looking for more efficient, convenience, trouble free and prolonged operation of equipment. Manufacturers should incorporate end of life strategy and “design for sustainability” within their equipment design, in addition to design factors such as use of common basic building blocks, design for disassembly, design for recycling, design for environment and design for maintenance. New methods, tools and business models will be required to facilitate sustainable product development. Adoption of standard on equipment life cycle information formats and protocols will help ensure uniformity across industrial sectors for system implementation and to achieve Mark of Conformance.
14. The means of implementing a reliable connection between remote server and gateways or devices in the customer’s home for the variety of infrastructures likely to be encountered (e.g. dial up, cable, ADSL, etc) needs further work. Likewise, the means of achieving interoperability (device/application discovery, management of the device/application lifecycle, remote discovery, application interaction) using the variety of platforms available (OSGi, uPnP, etc) is essential.
15. The use of a VPN for gateway-server communications is not really feasible for commercial rollout as the requirement on server resources is prohibitive so this issue remains as one that would require a satisfactory solution for any significant implementation of this type of technology. The prototyping system will be used long after the trial finishes since it is not dependant on vendor supplied hardware or white/brown goods. This will allow further research to be undertaken and ensure the best of breed ideas emerging from the single and multiple home trials to be further evaluated. Advantica’s work on the infrastructure shows that the cost of implementation and support of broadband systems piggybacking on customers existing infrastructure can be substantial. This is difficult to estimate but perhaps at least half a day effort for installation may be reasonable for the majority of sites with perhaps a day per annum for maintenance. In addition, the issues on developing a suitable trained workforce to achieve this should be taken into account. Acceptance that such a workforce would need several weeks of training and additional office support / help lines should also be considered.

16. Best of Breed Demonstrator Loughborough University are reviewing the results from the EM, SA and other CIHE trials and will develop a further demonstrator showing best of breed. This will lead to additional user evaluation trials where the more useful aspects of the connected home can be evaluated. It is hoped that this work will remove some of the uncertainty that exists in some of the technologies such as speech recognition. A number of the companies participating in the trials have expressed an interest in continuing their support of the enabling research for this activity. Further emphasis will be placed on integration with real devices in the home. This will also include the incorporation of additional sensing devices around the home. Data have already been collected for various sensing devices placed in a laboratory equivalent of a kitchen/hall way. The aim is to look at techniques to extract meaningful data from this and then possibly integrate this into a future trial. This will allow an investigation into the deeper integration issues of simple and complex devices around the home. The best of breed demonstrator will lead to the development of an animated functional specification for a future home system. This has the advantage of highlighting the best and most appropriate features of the future smart home.

The extensive database of documentation of the research undertaken on the trial will provide a foundation for future work.

5 OUTLINE EXPLOITATION PROSPECTS

Critically, the eventual commercial roll out of a Centrica-focused suite of products was ruled out by Centrica's change in direction but the trial became more evenly balanced through more active supply chain collaboration, and consequently had the freedom to innovate. The retrofit boiler energy management prototype and the white goods monitors are two products that would not have been created under the original plan.

Discussions have been held between trial members and utilities, local authorities and housing associations with a view to exploiting all or part of the EM product suite. TAMI members have been targeted to become involved in commercial development of the system.

Two of the field trial sites will be continuing in operation for a period of 6 months in order to provide energy data and a further test bed for the equipment.

6 REFERENCES

Trial documents referred to in this report are held in the virtual office.

External reports referred to in this document include:

The Arthur D Little Global Broadband Report. Update 2005, p26.

Tweed, C. and Quigley, G. (2000). The design and technological feasibility of home systems for the elderly. Research report, School of architecture, Queens University, Belfast.