# An Exploration of Home-care Technology to Enhance the Dialogue of Care between Older People and Carers

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## *Declaration by the candidate*

I declare that I am the author of this thesis; that, unless otherwise stated in the text, all references cited have been consulted by me; that, except for those parts of the work which are declared in this thesis to be based upon joint research, the work which this thesis records is mine; and that it has not been previously presented or accepted for a higher degree.

Nubia Marina Stewart

## *Declaration by the supervisor*

I declare that Nubia Marina Stewart has satisfied all the terms and conditions of the regulations made under Ordinances 12 and 39; and has completed the required 9 terms of research to qualify in submitting this thesis in application for the degree of Doctor of Philosophy.

Dr. Nicolas Hine

## *Abstract*


## *An Exploration of Home-care Technology to Enhance the Dialogue of Care between Older People and Carers*

Most older people, including many of the very frail, want to live in their own home for as long as possible as they age. In recent years, home-care technology has begun to have a more significant role to assist older people who want to live independently in their homes. In a review of home-care technology, a number of applications that can contribute towards the maintenance of independence and autonomy of older people were found. For instance social alarms, automated home environments, telecare and electronic assistive devices.

The ageing of the population, combined with the possibilities that technology presents, is leading to consideration of technological applications for older people. The challenges are the prevention of acute situations in older people's lives, the introduction of new forms of domestic well-being care, and the adaptation of appropriate technology to suit the needs of older people.

The purpose of this study was to analyse lifestyle data gathered in older people's homes and focus on the contribution of this data to the "dialogue of care" between older people and carers. Exploring the lifestyle data collected from sensors installed in older people's homes and validating this data with field notes to ensure that the data collected was accurate, complete, and reliable was the first mandatory step. Then, analysing the level of activity 'busyness' in their dwelling using a number of computing techniques revealed phenomena in the life of a person that reflected changes in well-being. The focus on "busyness" within the dwelling of older people was believed to be less intrusive and required less computing, than attempting to recognise specific activities. Rather than attempting to compute the meaning of a change in lifestyle

resulting in a change of “busyness”, the changes were discussed within a “dialogue of care”.

Collaborating with various stakeholders (older people, informal and professional carers, technologists and researchers) and using an inclusive design process to gather requirements from which a Domestic Well-being Indicator System (DWIS), could be designed and built. Various alternative visualisations of the home data were then evaluated for each stakeholder involved in the “dialogue of care” in order to test the usefulness of the system to provide data to both the older person and their carer within a conversation to find what things are affecting the person and their quality of life.

As a result of this study, home-care technology could be valuable when integrated and reliable data is presented to various stakeholders through personalised, visually and friendly user interface and could provide the following benefits:

- Carers and older people could have a focussed conversation based on the data presented by the system, discuss changes in the data and make an interpretation. Therefore, presenting lifestyle, health and contextual data through a personalised user interface could enhance the “dialogue of care” between older people and carers.
- Older people can be more aware of their own well-being.
- Carers can provide better health and social services to older people by using a Domestic Well-being Indicator System.
- Carers can use their time more effectively and efficiently, focussing on the patients and clients whose situation is changing in ways that require attention.

The thesis concludes by answering the research questions, highlighting the contribution to this domain and presenting further research themes that need to be investigated.

# 1 AN AGEING POPULATION

## 1.1 Introduction

The rapid increase in the number of older people within society and the lack of both human and economic resources to support the needs of this target population have required the examination of new approaches to care and to help carers to provide better health and social services.

The purpose of this research study is to analyse the data collected from sensors using a new data analysis approach called 'busyness'. Busyness is based on identifying changes at the level of activity of key areas of well-being such as mobility, sleeping, eating and drinking and personal hygiene. The objective of this approach is to present busyness data in conjunction with health and contextual data through a personalised user interface so the older person and the carer can have a conversation 'dialogue of care' towards finding the reason for change. By providing relevant data about the older person, the carer could make an interpretation of the level of well-being and could take a sensible action. This data could also be provided to the older person so he/she can be aware of his/her own level of well-being and be proactive towards improving their quality of life.

## 1.2 Ageing population and trends

The number of older people in society has experienced a dramatic rise. In 2008, it was estimated that there were about 13.5 million people in the UK over 60 years of age, of whom 11.8 million were over State Pension Age (SPA). 8.8 million were aged between 60-74; 3.4 million people were aged between 75 and 84, and 1.3 million were aged over 85. The population projection from 2008 until 2033 in the United Kingdom will be as shown in Table 1-1 (Wright, 2008).

| Ages | 2008 | 2013 | 2018 | 2023 | 2028 | 2033 |
|---|---|---|---|---|---|---|
| 60-74 | 8.8 | 9.4 | 10.0 | 10.5 | 11.4 | 11.9 |
| 75-84 | 3.4 | 3.7 | 4.0 | 4.8 | 5.2 | 5.3 |
| 85 and over | 1.3 | 1.5 | 1.8 | 2.2 | 2.6 | 3.3 |
| Total older population | 13.5 | 14.6 | 15.8 | 17.5 | 19.2 | 20.5 |

**Table 1-1: Projected population by age, United Kingdom, 2008 to 2033**

The Canadian population in 1995 was 30 million. Of those, 5.1% were aged between 75 and 84 years old and 1.2% were over 85. It is projected that by 2041 those over 75 will constitute 14.2% of the population and those over 85 will be 4.5% (Iliffe, Robertson, Yoshikawa, and Reichel, 1999)

The population of Americans over 65 will increase from 35 million in 2000 to 40 million in 2010 (a 15% increase) and then to 55 million in 2020 (a 36% increase for that decade). The population over 85 is projected to increase from 4.2 million in 2000 to 6.1 million in 2010 (a 40% increase) and then to 7.3 million in 2020 (a 44% increase for that decade) (Aging, 2007).

The European Region had 15% of its population 65 years old or older and nearly 7% 75 or over in 2000, the world's highest percentages. By 2030, these figures are expected to increase to 24% and 12% respectively (World Health Organisation, 2004b).

For Japan, the percentage of older people aged over 65 was 14.1% in 1994. By 2025 the proportion of people aged 65 and older will be 24.8%. In 1960, the life expectancy in Japan was 65.3 years for men and 70.2 years for women. However, by 1984, the life expectancy had reached 74.2 years for men and 79.8 years for women; the longest life expectancy of any country in the world (Levy, 1999).

From these population projections, it is clear that in the UK, America, Canada, Europe and Japan, the older population might increase and the working population might decrease. This means that there will be more people on pensionable age in society but only a very few people who might be paying taxes.

## *1.3 Characteristics of older adults*

The ageing process is often characterised by loss of sensory and physical abilities, changes in memory and cognitive abilities, changes in psychological, emotional and social aspects (Morrison, 2008). These contribute to an increased risk of accidents in older people's homes; hence, there is a greater demand on formal health and social services as well as informal carers such as family, friends, and neighbours (Roper, Logan, and Tierney, 2000).

For the purpose of this thesis, issues related to health including physical, sensory and mental functioning and social aspects such as relationships and social activity will be studied.

### 1.3.1 Health aspects

The major killers of older people include cardiovascular diseases (such as coronary heart disease), hypertension, stroke, diabetes, cancer, chronic obstructive pulmonary disease, musculoskeletal conditions (such as arthritis and osteoporosis), mental health conditions (mostly dementia and depression), blindness and visual impairment (World Health Organisation, 1998). Consequently, older people are likely to have a much greater need for health care services (DOH, 2001).

Older people may lose physical, sensory and mental abilities that can make it difficult to perform activities of daily living (ADL). Therefore, older people lose independence and autonomy to live on their own.

- **Physical disability:** Older people are likely to suffer from osteoporosis, falling down, and physical limitations. A survey of over 10,000 people aged over 65 years found that 11% of men and 19% of women had a physical disability (38% of these being aged over 85 years), 21% required continuous care and 62% required some form of daily care (Brayne, 2001). The ageing process has intrinsic consequences such as limited mobility, aches and pains, loss of independence to carry out activities of daily living like bathing, eating and drinking (Mountain, 2004).

  Falls in home accidents are a likely situation among older people which have a significant implication for individuals and the cost of health services associated with the treatment and rehabilitation. Based on research statistics up to 1990 reported by Fisk (2003), one third of people aged 65 years and over have fallen at least once a year. Falls are greater for women than for men and are one of the main causes of death among people aged over the age of 77 years in England and Wales.

- **Sensory impairment:** Older people are more likely to lose visual and hearing abilities. Some aspects associated with reduced vision include cataracts, macular degeneration, glaucoma, and diabetic retinopathy. Mountain (2004) stated that 80% of people over the age of 60 have visual impairment. People who have poor vision have a decreased quality of life due to limitations with regard activities of daily living (ADL) and loss of mobility.

  Hearing problems are also common among older people. Between 30 and 60% of older people have hearing impairment. The consequences for the individual are communication problems, loss of self-esteem, cognitive impairment and increased vulnerability. Approximately 22% of people have both visual and hearing impairment which can lead to loss of safety and independence (Mountain, 2004).

- **Mental aspects:** Older people may experience changes in memory and cognitive abilities. Diseases such as depression, dementia, Parkinson's disease and delirium are related to memory and cognitive changes. These changes can vary from small changes so people can cope with their activities of daily living to drastic changes so people will depend on someone else (Johansson, 2008).

  Mental health services should be an integral part of long-term care. These services include the provision of a comprehensive mental health services for men and women as they age, ranging from mental health promotion to treatment services for mental illnesses, rehabilitation and re-integration into the community as required (World Health Organisation, 2001a).

### 1.3.2 Social aspects

Older people are more likely to lose family members and friends and to be more vulnerable to loneliness, social isolation and social exclusion. Social isolation and loneliness in old age are linked to a decline in both physical and mental well being. In most societies, men are less likely than women to have supportive social networks. However, in some cultures, older women who are widowed are systematically excluded from mainstream society or even rejected by their community.

Social networks, support and participation are associated with health and quality of life (A. Bowling and Gabriel, 2004). Social support reduces distress during times of stress, and the lack of social support during times of need can lead to very stressful situations, particularly for people with high needs for social support but insufficient opportunities to have it, e.g. older people, the recently widowed. Social isolation is a risk faced by both genders and has been associated with poorer and reduced quality of life among older populations.

Because it is not enough to look at health or even social care needs, the following section will introduce broader concepts: quality of life and well-being.

## 1.4 Quality of life and well-being for older people

Quality of life is defined as ‘an individual’s perceptions of their position in life, in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns’ (A. D. Wood, Stankovic, Virone, Selavo, He, Cao, Doan, Wu, Fang, and Stoleru, 2008). It includes the individuals’ physical and mental health, level of independence, quality of social relationships and social integration, as well as the personal, religious and spiritual beliefs (World Health Organisation, 2002). As people age, their quality of life is largely determined by their ability to maintain autonomy and independence.

According to a survey undertaken in Britain of the quality of life of a random sample of 999 people aged 65 and over, participants expressed the following as being key factors of good quality of life for older people (A. Bowling, Gabriel, Banister, and Sutton, 2002):

- Having good social relationships with family, friends and neighbours so they won’t be isolated;
- Participating in social and voluntary activities, and individual interests so that they will feel part of society;
- Having good health and functional ability since they can carry out activities of daily living (ADLs) such as eating and drinking and personal hygiene, and instrumental activities of daily living (IADLs) such as shopping and mobility;
- Living in a good home and neighbourhood as they will feel happy and safe living in the community;
- Having a positive outlook and psychological well-being so that they won’t have mental and cognitive problems;

- Having an adequate income since they can afford to pay their expenses and save some disposable income;
- Maintaining independence and control over life so that they can make decisions and be autonomous.

Well-being can be defined in terms of “an individual’s physical, mental, social, and environmental status with each aspect interacting with the other and each having differing levels of importance and impact according to each individual. A change in the different aspects of well-being of an individual may be reflected in an alteration in behaviour or the performance of a task or activity” (Sixsmith, Hine, Neild, Clarke, Brown, and Garner, 2007).

Sixsmith defined a well-being model of a person taking into account the following aspects: person, context, activities and experience. The person factor refers to their physical, psychological and mental condition. The context refers to their housing conditions, the social network, neighbourhood and social support (carers, family and services provided). The activities refer to their life style, social interaction, personal goals and self-esteem and activities of daily living (ADL). The experience refers to their subjective interpretation of situations and activities such as life satisfaction, happiness and morale. The outcome of this model is the well-being in terms of the person’s mental/psychological, physical and social aspects.

Having identified that older people have complex care needs, and this population is increasing dramatically which implies that there will be less tax payers to pay taxes and few people in society available and wanting to be carers, it is necessary to have strategies for keeping older people well such as the active ageing policy framework.

## *1.5 Active ageing*

According to the World Health Organisations (WHO), active ageing is define as ‘the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age' (World Health Organisation, 2002). Health is the physical, social and mental well-being; participation is the ability of older people to continue participating in social, economic, cultural, spiritual and civic affairs; and security refers to social, financial and physical security as well as protection, dignity and family support.

Active ageing and successful ageing are overlapping terms. Successful ageing refers to optimal physical, psychological and social possibilities for living (Rowe and Kahn, 1998). From a biomedical perspective, successful ageing is defined as the 'longer life expectancy, less physical, mental deterioration and disabilities'. Psychosocial perspectives emphasises life satisfaction, social participation, functioning and psychological and social well-being (Ann Bowling and Dieppe, 2005), adaptation, productivity, self-mastery and control (Baltes and Baltes, 1990).

According to a survey carried out in the UK  at random with 337 older people aged 65 and over, participants defined active ageing as 'having maintaining physical, health and functioning, leisure and social activity, mental functioning and activity and social relationships and contacts' (A. Bowling, 2008).

The study reported that there was an overlap between older people's perceptions and theoretical models of active ageing in terms of optimum physical health and functioning, having leisure activities and social contacts, well-being and having adequacy financial status. However, in the theoretical models there was an additional focus on productivity, empowerment, dignity, human rights and neighbourhood (A. Bowling, 2008).

Active ageing policies have established as main goals: Maintaining autonomy and independence as a person grows older and extending healthy life expectancy and quality of life of older people.

Healthy life expectancy refers to how long people can expect to live without disabilities. It is measured by the abilities of an older person to carrying out activities of daily living (ADLs) and instrumental activities of daily living (IADLs). ADLs include, for example, bathing, eating, using the toilet and walking across the room. IADLs include activities such as shopping, housework and meal preparation.

## *1.6 Policies framework on active ageing*

The Policy framework on Active Ageing proposes the goals based on three pillars as shown in table 1-2.

According to the World Health Organisation (WHO), policies on active ageing should include the following aspects: hHealth and social service, personal factors, social environment, culture, gender, behavioural, physical environment, and economics. For the purpose of this study, the first three aspects will be discussed (World Health Organisation, 2002).

| **Goals** | **Pillar** |
|---|---|
| Prevent and reduce the risk of excess disabilities, chronic disease and premature mortality | Health |
| Reduce risk factors associated with major diseases and increase factors that protect health | |
| Develop accessible and high quality of health and social services that address the needs and rights of the older population | |
| Provide training and education to carers. | |
| Provide education and learning opportunities | Participation |
| Recognise and enable active participation of older people in society according to their individual needs, preferences and capacities | |
| Encourage people to participate fully in family community life | |
| Ensure the protection, safety and dignity of older people by addressing the social, financial and physical security rights and needs of people | Security |
| Reduce inequities in the security rights and needs of older women | |

**Table 1-2: Goals of the policy framework on active ageing**

### 1.6.1 Health and social service

To promote active ageing, health systems should be focused on health promotion, disease prevention and should avoid age discrimination in the provision of primary and long-term care services and service providers need to treat people with dignity and respect.

Health and social services to older people should be delivered in an expert and integrated manner to achieve optimal results. This is a challenge to meet since older people form a heterogeneous population with many complex problems. Policy makers have changed their attitudes towards the older population through the delivery of policy documents that involve older people and carers in designing these services and intending to provide them with high quality services.

Older people consider care as a right rather than a privilege and they do not want to feel that their lives are being run by other people; they want services to suit their needs. They want services that give them a sense of dignity, confidence and control (Leadbeater and Lownsbrough, 2005).

The following are the main aspects of health and social services according to the framework on Active Ageing:

- **Health promotion and disease prevention:** Health promotion is the process of enabling older people to take control and to improve their health. Disease prevention includes the prevention and management of conditions that are common with older people such as silent diseases and injures. Prevention also includes the avoidance of tobacco, early detection of chronic diseases and the appropriate clinical management of diseases.

- **Long-term care:** Long-term care service is undertaken by formal and professional carers to ensure that frail older people can maintain high quality of life (World

Health Organisation, 2002). The formal support includes community services, institutional care and mental health services.

- **Curative services:** Despite best efforts in health promotion and disease prevention, people are at increasing risk of developing diseases as they age. Thus, access to curative services becomes indispensable. Most curative services must be offered by the primary health care sector. This sector should well equipped to make referrals to the secondary and tertiary levels of care where most acute and emergency care is also provided.

The present acute care models of health service delivery are inadequate to address the health needs of rapidly ageing populations (World Health  Organisation, 2001). For instance, there is evidence of low quality of these services in the UK; the Health Advisory Service confirmed the deficit of staff trained in the care of people, lack of attention to nutritional needs and low staff morale (Mountain 2004).

### 1.6.2 Personal factors

Personal factors include biological, genetic and psychological aspects. The first one refers to the ageing process which is a set of biological processes including the loss of functioning, sensory and physical abilities. Genetic factors are important to determine the longevity as well the likelihood of diseases in older adults.

Psychological factors refer to the intelligence and cognitive capacity that are related with active ageing and longevity. Cognitive abilities can decline by lack of practice, illnesses, behavioural, psychological and social factors. Other psychological factors are self-efficacy and adaptation.

### 1.6.3 Social environment

Social support, opportunities for education, and protection from violence and abuse are key factors in the social environment that ensure health, participation and security as people become elder.

- **Social support**: Supportive connections and intimate relations are a vital source of emotional strength while inadequate support is associated with increase in mortality, morbidity and psychological distress and a general decrease in health and well-being. Loneliness and social isolation are linked to loss of physical and mental well-being (Gironda and Lubben, 2002).

  Decision-makers, nongovernmental organisations, private industry and health and social service professionals can help foster social networks for ageing people by supporting traditional societies and community groups run by older people: voluntarism and family members.

- **Violence and abuse:** Frail older people are vulnerable to crimes such as theft and assault. They are also vulnerable to physical, sexual, psychological and financial abuse, as well as social exclusion, medical rights and deprivation.

  Confronting and reducing elder abuse requires a multisectoral, multidisciplinary approach involving justice officials, health and social service workers, labour leaders, spiritual leaders, faith institutions and older people themselves. Sustained efforts to increase public awareness of the problem and to shift values that perpetuate gender inequities and ageist attitudes are also required.

- **Education and literacy:** Low level of education and illiteracy are associated with disability, death and unemployment. In order to keep older people engage in activities they need training and lifelong learning opportunities in the community. To compensate the reduction of sensory and cognitive abilities it is necessary to use assistive devices and to make some adjustment in technology to make them appropriate for older people. For instance, the use of large font size letters in electronic devices.

## *1.7 Regulations and policies in the UK*

The National Service Framework for Older People (NSFOP) emphasises the importance of integrated services, the delivery of person-centred care, user involvement, encouragement of self-management of long-term conditions, health promotion, the avoidance of age discrimination and maintenance of independence living and well-being. Table 1-3 shows the standards of the NSFOP (Milburn, 2001).

| Standard | Objective | Theme |
|---|---|---|
| Anti-discrimination and promoting equity | Provide a universal service for all based on clinical needs ensuring fair access and preserving dignity | Respecting the individual |
| Providing a person-centred care | Treat older people as individuals and enable them to make choices about their own care | |
| Providing intermediate care | Provide a comprehensive range of services | Providing a care service between primary and specialist service |
| Delivering appropriate specialist care in hospital | Improve quality of service and minimise errors. Staff competences and evidence based practice Train and motivate staff | Providing evidence-based specialist care |
| Improving stroke services | | |
| Improving fall services | | |
| Improving mental services | | |
| Promoting an active healthy life in older age | Promote health and well-being and reduce health inequalities | Promoting an active healthy life. |

**Table 1-3: Standards and themes of the NSFOP (Milburn, 2001)**

Experts on research for the ageing population ran 16 studies to validate the achievement of these standards (DOH, 2008). The following were the main findings:

- Even though the framework states that older people should have access to services and activities to promote their health and well-being, there is evidence of age discrimination and racism. They are recognised by lower rates of access to services compared with other groups and lower provision of services important to older people. Mountain confirmed that older people are both disempowered and devalued by some health services (Mountain, 2004). In addition, there is evidence that older people from minority ethnic groups suffer from discrimination in accessing health and social services (McDonald, 2004; Kerr, Gordon, McDonald, and Stalker, 2005).

- The principle of providing person-centred care has introduced resources such as the single assessment process to identify individual needs, intermediate care, better prognostic tools and better education for staff. However, the introduction of these services has been very slow because of the inadequate provision, the lack of information and the ageist attitudes towards older people.

- Frail older people or those with complex needs should receive integrated and long-term care services. There is evidence of tension between the integrated services and the continued separation of health and social services provided in the community (district nurses and social workers). For instance, the lack of collaboration between these partnerships to assist older people, especially those suffered from dementia, is reflected in the low quality of services (Askham, 2008).

- Even though the framework states that health and social staff should be motivated and continually trained to maintain their morale to ensure the delivery of high quality of services to older people, the Health Advisory Service confirmed the deficit of staff trained in the care of people and low staff morale (Mountain, 2004)

- The framework for older people includes a guideline about the participation of older people in the society, however, in some cases older people are not allowed to make decisions regarding their own health or they are not included in the definition of services to them (Askham, 2008).

- The primary care service is not a holistic and integrated service as it was proposed by the World Health Organisation. It is focused on the provision of general practitioner services and community-based treatment. Health service is focused on some physical health problems rather than on prevention and community involvement (World Health Organisation, 2002).

  Despite the active ageing framework, it is clear that health and social services need to be improved in order to satisfy the needs of this target population. Health and social care services in the United Kingdom covers the following aspects: lLong-term care, intensive support care, daily care, and community care services.

### 1.7.1 Long-term care

The long term care schemes provide long-term support for people becoming more frail to enable them to stay at home, rather than moving to residential home care. The service is delivered by a multidisciplinary team that provides personal, intensive and flexible care and that supports older people, carers or partners (ScottishExecutive, 2006).

Long-standing concerns about the quality of care provided in nursing and residential care have resulted on the introduction of a policy called “Better care; Higher Standards” (DoH, 1999). Subsequent policy guidance was provided to health and local authorities. The Care Standard Act (2000) was an important step for social care provision. It states the standards in social care and the responsibility for regular social work training and education.

Recently, the Government decided that nursing care provided in residential settings for older people should be provided free, but the social care should be charged. This policy was implemented in England and Wales, but the Scottish Parliament decided not to charge for social care.

### 1.7.2 Intensive support care

The intensive support care offers two types of service: hHospital discharge and rapid response teams. This kind of care service is short-term and intensive, available within 24 hours and it has time limit of 14 days. The service is provided by a multi-disciplinary team consisting of a social worker or care manager, dedicated home carer, home care organiser, district nurse, physiotherapist, occupational therapist, and an occupational therapy technician.

The quality of intensive support care for older people has frequently fallen short of what should be expected. The Health Advisory Service confirmed the deficit of staff trained in the care of people, lack of attention to nutritional needs and low staff morale (Mountain, 2004).

The Patient Advice and Liaison Services (PALS), introduced in 2002, are responsible for bringing the issues raised by service users and carers to the attention of a specific organisation. They are also responsible for helping staff to become more responsive through appropriate training to the need of users and carers. PALS are particularly focused on certain populations who may find it difficult to be heard. For instance, physically frail older people.

### 1.7.3 Daily care

Both health and social services have traditionally provided day services for older people and informal carers. These services include rehabilitation, respite for carers, social and recreational activities, among others. There is a lack of clarity regarding the role of day hospitals and day centres. The Audit Commission stated that day hospital provision for older people with mental health problems should exist for assessment and short-term treatment. Day centres should concentrate upon longer-term-care (Commission, 2002b).

Based on a systematic review of the role of day services, experts concluded that day hospital services are effective for older people who need rehabilitation; however, day centres are not effective because of the lack of rehabilitation facilities in those centres (Mountain 2004).

### 1.7.4 Community care services

In the UK, the Care in the Community Service was introduced in 1993 with the objective of delivering health and social care services at home wherever feasible and practical. It was underpinned by two White Papers: Working for patients (DoH, 1989b), concerned with reorganisation of health care delivery, and the Griffiths Report on Community Care (DoH, 1989c). This report had an impact upon the delivery of community services, particularly for older people, given that they are the largest consumers of health and social care services.

The Care Programme Approach (CPA), introduced in 1991, includes a mandatory and monitoring process targeted at people with mental problems, including older people. This involves the assessment of health and social care needs of the older person, the design of a care plan to meet those needs, designating a key worker for each person and regular reviews of the plan.

In response to assessment of need, local authorities may provide some social care services. For example: home care, meals on wheels and community equipment. The local authority also provides practical services such as shopping, domestic and household maintenance among others. In the early 1990s, the provision of personal care services was included. These services aim at helping older people to be independent at home and at preventing further deterioration, at ensuring they live in a healthy and safely environment, and at reducing potential exclusion. Social care services traditionally provided by the local authority are now provided by private contractors. This has led to some difficulties such as the interpretation of regulations by home care staff working for private organisations.

## *1.8 Differences between policies framework*

The policy framework on active ageing includes a wider range of services than the health and social services policy framework in the UK for older people. For instance, both the National Service Framework for Older People NSFOP (Milburn, 2001) and the policy framework on active ageing (World Health Organisation, 2002) include discriminatory abuse in their guidelines where the elderly person is discriminated against, abused or neglected on the basis of race, age, gender or disability. However, the latter includes a specific guideline for older women to protect them from sexual, physical and psychological abuses.

The participation of older people and their family in the community is included in the guideline of the policy framework on active ageing. This guideline only applies in societies where relatives live close to the older person such as in Asian and Latin American countries. Family members in the UK usually live far away from each other, making more difficult the inclusion of families in the community of the older person.

## *1.9 The process of care*

Care is a process structured by dialogue, in which an older person and a carer have a conversation concerning the well-being of the older person. The carer might ask to the older person questions like “How are you doing? How are you feeling today? Do you have any pain? If so, tell me the symptoms”.

In addition to this typical conversation, the carer can intuitively recognise some changes in behaviour such as the older person is becoming aggressive and irritable; changes in patterns such as changes in sleeping and eating patterns and changes in normal routines that provide some clues to determine the older person’s well-being.

Therefore, a face to face relationship between the older person and the carer is vital to know the real status of the older person (Gonzalez, 2009).

However, this direct dialogue might have some limitations when the older person is not able to express their feelings, symptoms and concerns due to cognitive or sensory impairments. Hence, technology could play a useful role to help carers to monitor some key aspects of the older person’s well-being such as mobility, eating and drinking, personal hygiene, sleeping and social interaction, that might provide better data about the older person. By gathering care related data in the home, and adding that to the care conversation or the “dialogue of care”, it is hoped that care can be improved

## *1.10 Impact of home-care technology*

Many technology driven smart home systems have been designed with little concern about older people’s quality of life. These projects are mainly interested in the automation of devices to deliver services and provide comfort and entertainment at home such as heating, air conditioning, lighting, appliances and equipment manipulated by remote control (Cook, Das, K. Gopalratnam, and Roy, 2004). Some researchers have being working on making technology scalable, easy to install and affordable for normal people (S. Helal, Mann, W., El-Zabadani, H., King, J., Kaddoura, Y., Jansen, E., 2005). Furthermore, there are a large number of projects that have developed technology and smart algorithms with excellent results within artificial environments. However, there is no evidence of testing this technology within real older people’s home (Noguchi, Mori, and Sato, 2002; Isoda, Kurakake, and Nakano, 2004).

Dickinson and Gregor stated that the impact of technology on the quality of life and well-being of older adults is generally tied to the training and other social and interactive aspects not to the technology alone (Dickinson and Gregor, 2006). Billipp reported that computers alone had no relationship with either depression or self-esteem, but participants that have a weekly training with nurses showed increased self-esteem and decreased depression (Billipp, 2001).

Researchers have undertaken some studies to understand the requirements, preferences and abilities of the older people using different techniques such as brainstorming and questionnaires (Prazak, 2007), living theatre (Morgan, Martin, Hine, McGee-Lennon, Arnott, Clark, and Wolters, 2008) and ethnography (Abowd, Mynatt, and Rodden, 2002). Furthermore, human factors researchers are leading projects towards developing design specification and guidelines to design for the older population. They are focused on designing and training for technologies that are usable, effective and safe to use with the elderly (Newell, Dickinson, Smith, and Gregor, 2006; Eisma, Dickinson, Goodman, Syme, Tiwari, and Newell, 2004).

Some researchers have investigated whether older people would consider technology as a tool to enhance their quality of life, independence and autonomy. In addition, it is important to examine the attitudes of carers towards using technology to help them to provide better health and social services.

Many research projects have developed technology to improve the quality of life, independence, autonomy and well-being of older people. All these projects have achieved significant results from the social, psychological, communication and health care perspectives (Rogers and Mynatt, 2003). For instance, technology could reduce the anxiety for family members and older adults (Tamura, Togawa, Ogawa, and Yoda, 1997), enhance the perception of being safe and secure, reduce the fear of falling and request help, detect deterioration of well-being and potential crises; support cognitive and memory deficits, detect abnormal patterns of well-being (Evans Nina, Orpwood R., Adlam T., Chadd J., and Self D., 2007) and control their own health status.

Some researchers have been exploring technology to enhance the communication between older people and their relatives towards reducing feelings of isolation and loneliness (Consolvo, Harrison, Smith, Chen, Everitt, Froehlich, and Landay, 2007). Moreover, communication and awareness between older adults and their family members can improve older adult's safety and independence (Rogers and Mynatt, 2003).

Other researchers have been working on the development of assistive devices to detect vulnerable situations such as falls, changes in vital signs and the raising of emergency alarms or contacting the appropriate stakeholder (Porteus and Brownsell, 2000).

Some research initiatives have been working on supporting, detecting and preventing further acute situations through the monitoring of activities of daily living (ADL) and anticipation of changes using technology to support people with specific needs like dementia (M. J. Rantz, Marek, Aud, Tyrer, Skubic, Demiris, and Hussam, 2005). In addition, some researchers have been working on embedded sensors and context-awareness to track people's location and have been providing assistance through multimodal interfaces or robots to support cognitive deficits (E.D. Mynatt, Essa, and Rogers, 2002a).

Home-care technology has the potential to inform family members and carers about daily activities, health status and potential problems as well as information about patterns of activities related to the older person's well-being over a period of time. Moreover, technology could enhance the carers' role by providing relevant information about the older person so carers can provide better care and make decisions to improve the quality of life of older people (Glascock and Kutzik, 2006).

However, some studies have demonstrated potential benefits including feeling more confident and less alone (Danowski and Sacks, 1980), feeling comfortable with computers (S. J. Czaja, Guerrier, Nair, and Landauer, 1993), increased cognitive abilities and independence carrying out activities of daily living and reduced depression (McConatha, McConatha, and Dermigny, 1994), decreased loneliness (White, McConnell, Clipp, Bynum, Teague, Navas, Craven, and Halbrecht, 1999), increased ability, willingness to leave home and increased desire to meet others (N. Bradley and Poppen, 2003) and increased social interaction (Osman, Poulson, and Nicolle, 2005).

Taking into account the studies of the impact of technology on older adults provide some support for the potential value to provide care; however, this area needs further exploration to provide more evidence of the benefits using technology.

There is a great interest in identifying effective technology to assist carers due to the older population increase. A European project designed an experiment to evaluate the impact of technology on quality of life of 1802 frail older and disabled people and their carers (Magnusson, Hanson, and Nolan, 2002 a; Magnusson, Hanson, Brito, Berthold, Chambers, and Daly, 2002 b). Participants reported that the systems were easy to use and they felt improved competence in providing care and increased connectedness and support.

The effect of a special computer network of carers of people with Alzheimer disease was noticeable for carers (family and friends), who had greater information gain and more frequent emotional support (Goodman and Pynoos, 1990). Results confirmed that technology made a significant improvement in carer's confidence and decision making (Brennan, Moore, and Smyth, 1995). It also reduced level of carers strain (Bass, McClendon, Brennan, and McCarthy, 1998).

In general, these studies indicate that the perceptions of carers are very positive toward technology, reporting them to be easy to use and providing mechanisms for increased information support and other potential benefits. However, because of the small number of studies, the results are suggestive but not conclusive.

Few studies have explored the ethical issues including the intrusiveness of smart technologies, privacy of the information and surveillance (Consolvo, Roessler, Shelton, LaMarca, Schilit, and Bly, 2004b; Magnusson and Hanson, 2003).

As a conclusion, technology in combination with human interaction through training and face to face interaction might increase older people and carers' quality of life.

## *1.11 Conclusions*

This chapter looked at the rapid growth of the ageing population, some characteristics of older adults and some consequences of the ageing process. The ageing process is often associated with the loss of mental and physical abilities, which contributes to an increased risk of accidents in their homes among the older adults. That is one reason why the need for assistance from both the health and social services and the support from family, friends and neighbours is called for.

There are some significant challenges to improve the independence and quality of life for older people: changing the attitudes of health and social workers towards older people especially in minority ethnic groups, reducing the social and health inequalities and providing integrated health and social services, training of staff to both provide better quality of services to the older people and increase staff morale, providing holistic and integrated care and social services.

Technology might give potential benefits to provide care to older adults, however further studies are required in order to provide more evidence about the impact of technology on the quality of life and well-being of older people and their carers.

The next chapter explores some leading home-care technologies throughout the world and examines various approaches to analyse data collected from sensors. In addition, it discusses the ethical, practical and computational issues regarding the use of this technology, discusses the main contribution of home-care technology towards the independence, autonomy, quality of life and well-being of older people. Finally, it summarises the main achievements of various research studies in terms of health, social and psychological, methodological, ethical issues, and technological perspectives.

# 2 HOME-CARE TECHNOLOGY

## 2.1 Home-care technology

Home-care technology concerns the use of technology to support independent living, improve the quality of life and the autonomy of older and disabled people living in their own home. It involves the use of information, communications, measurements, and monitoring technologies to evaluate health and environmental status. It also delivers services to people in their home (B. G. Celler, Lovell, and Basilakis, 2003).

In a review of home-care technology a number of applications that can contribute towards the maintenance of independence, quality of life and autonomy of older people were found. For instance, telecare, telehealth, telehealthcare, social alarms, electronic assistive devices, smart homes, smart and assistive environments, context awareness, ubiquitous sensing, lifestyle modelling, activity and health monitoring, and sensor networks. Some of these terms are often used interchangeably. As Suzanne Martin reported, there is a lack of standards or consensus on terminology, classification or taxonomy of technology among those terms (Martin, Kelly, Kernohan, McCreight, and Nugent, 2008).

In attempting to classify those technologies in a systematic way, the author of this thesis adopted the classification presented by Suzanne Martin, who had made an important contribution in exploring the effectiveness of smart home technologies as an intervention for people with physical disability and cognitive impairment living at home.

The scope of this part of the thesis literature review is the older population, who are living independent in their home, and to consider the effect of technology in helping multiple stakeholders to enhance care provided to older people by their carers.

The author used the following terms to search relevant information in various electronic databases, relevant journals, conference proceedings and web sites:

Telecare, telehealth, home-care technology, community alarm, prevention, health and social care, older people, activity monitoring, level of activity, smart homes, pervasive or ubiquitous computing, lifestyle modeling, demonstrators, field trial, and names of key authors.

These databases were consulted: The Cochrane Library, Scopus citation, Medline, the Science Citation Index and the WHO library. In addition, some papers were requested directly to their authors.

Research studies were included if they meet the following criteria:

- They examined home-care health and social services.
- They included some of these technologies as a core component: Telecare, social alarms, electronic assistive devices, and automated home environments.
- They included information about individual and effects of using technology. For instance, the product (service or device) satisfaction, participant's (older people, family members and carers) attitudes and feelings, the improvements of quality of life and the enhancing of the care's role.
- Included older people: independent, frail, with any impairment (physical, cognitive or sensory).
- Included pilots, field trials and demonstrators of any size run in labs, older people's home and residential homes.

The following sub-sections define some key terms related to home-care technology and provide evidence of how technology have been used to improve the quality of life, independence and autonomy of older people.

### 2.1.1 Definition of supporting technology

The following is the definition of some technologies used in the care of older people in their home.

- **Social alarms:** This term is also known as emergency response system (ERS) or personal response system (PRS) or community alarms. It can be defined as a device (with or without intelligence) installed within the home of older people. This device can be activated using a carephone or dispersed alarms that are connected to community care services. Thus, the aim of social alarms is to monitor and provide a response to calls. There are some products available in the market provided by Tunstall Telecom (United Kingdom) and Lifeline Systems (USA) (Malcolm J. Fisk, 2003) .

- **Automated home environments:** Automated home environments are the combination of pervasive computing and smart home technologies. Pervasive or ubiquitous computing is defined as 'a network of computers that are mobile and invisible (embedded in the environment) to people' (Thibodeau, 2003). Smart home is a home or working environment, which includes the technology to allow for devices and systems to be controlled automatically (Rogers and Mynatt, 2003).

  An automated home environment uses ubiquitous computing applications that augment the activities of the people living in the home by providing interactive information to the inhabitants, supporting their activities, detecting the behaviour of the dweller and adjusting the services according to the abilities of the inhabitant. An automated home environment has 'multimodal' interfaces, which means developing systems that can recognise voice and gestures. Therefore, it is possible to identify a person, location and activity only by his /her presence and the natural interaction with the environment (Abowd *et al.*, 2002).

These environments use smart algorithms able to: Recognise people's activities; to detect abnormalities in people's behaviour and the environmental conditions; to recognise people's movements and their interaction with objects, and to provide context-awareness services to the inhabitant (Kidd, Orr, Abowd, Atkeson, Essa, MacIntyre, Mynatt, Starner, and Newstetter, 1999). The goal of this technology is to improve the quality of life, independence autonomy of frail older people or people with disabilities.

There are many researchers around the world currently working in automated home environments. These studies include all areas of technology such as hardware, software, network protocols, human computer interaction (HCI) and security.

- **Telecare**: Telecare can be defined as a 'service bringing health and social care directly to a user in their own home, supported by Information and Communication Technology (ICT)' (Hine, Judson, Ashraf, Arnott, Sixsmith, Brown, and Garner, 2005b). This might include rapid responses to emergencies in people's home, treatment and medical advice, and physiological and activity monitoring.

  A telecare system must be responsive, supportive and preventive (D. A. Bradley, Williams, Brownsell, and Levy, 2002b):

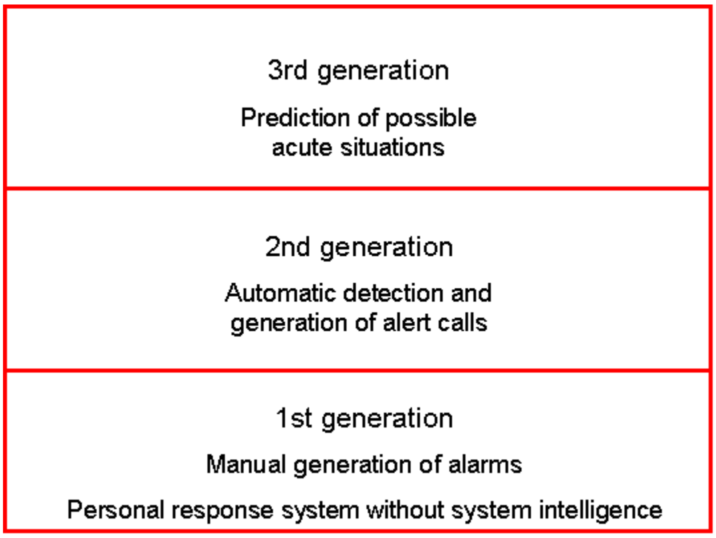



**Figure 2-1: Three generations of telecare**

Figure 2-1 shows three generations of telecare. The first generation requires a client to manually raise an alarm for help in an emergency (Doughty, Cameron, and Garner, 1996). The second one incorporates a degree of intelligence that enables the system to alert a carer without the client's intervention. This is a useful feature in the event that the client is not able to raise alarms by himself. A set of sensors to continuously monitor the client, an automatic interpretation of the current situation and automatic alarm raising when possible problems are observed. And the third generation of telecare is able to predict events and acts proactively to avoid chronic situations becoming acute. Based on the lifestyle monitoring and real-time analysis of activity, it will facilitate an interactive communication between the older person and the carer, with the aim of observing physical, mental and social issues related to the individual well-being (Brown, Hine, Sixsmith, and Garner, 2004).

Telecare may be an economical means of supplying care services particularly to older people (Brownsell, Bradley, and Porteus, 2003), and it also helps people to avoid hospitalisation (TheAuditComission, 2004) which is a contribution towards decreasing medical costs. Tang and Venables reported that telecare could be a method of reducing health care expenditure, as well as contributing towards autonomous living (Tang and Venables, 2000).

- **Electronic assistive devices**: It can be defined as devices or equipment that enhance, increase, or maintain the physical and/or mental capabilities of older people and people with disabilities (Miskelly, 2001). Electronic assistive items may range from fall detectors, sensors to detect movement, robots, and occupancy and alarm conditions.

  There are a great variety of sensors available for use at home such as Passive Infrared Sensors (PIRs), pressure mats, door sensors, fire alarms, flood detectors, fall detectors, and body sensors, but most of them worked independently (Miskelly, 2001). Therefore, in 1993 the Institute of Electrical and Electronics Engineers IEEE and the National Institute of Standards and Technology (NIST) began to work on a standard for Smart Sensor Networks. The result was IEEE 1451, the Standard for Smart Sensor Networks (Lewis, 2005). The following is the description of the most common commercial sensors:

- Passive Infrared Sensors (PIRs): Detect movement by responding at any heat variation. They can be useful to detect presence in a room. There is a possibility of false alarms due to heat sources or wind blowing curtains.
- Radio Frequency Identification (RFID) tags: These wireless sensors consist of two basic parts: A transmitter/receiver and a RFID tag. The transmitter/receiver is connected through a control box to a computer so that events can be captured. Each RFID tag has a unique ID that can be tracked.
- Pressure mats: These sensors are electro-mechanical devices which detect the occupancy of bed or chair. A change in pressure identifies if the furniture is in use.
- Magnetic switches: These sensors are usually attached in doorframes, cupboard, fridge to detect movement and activity (door open/close).
- Fire alarms: these sensors measure the temperature and rate of change of temperature. They are suitable for areas where a smoke detector is not convenient because of environmental conditions (smoke, dust). They react to visible and invisible threats of fire, and therefore, they can detect the early presence of fire. They can generate an alarm to a fire brigade centre too.
- Flood sensors: These sensors measure the water level of the bath and the sink. They send a signal to a database when the level is over reached.
- Fall detectors: These detectors are designed to be worn around the waist or the upper chest. Most of these detectors have two devices: An accelerometer that detects an impact greater than a certain threshold and the tilt meter that determines the person’s orientation (horizontal or vertical). If horizontal, the

detector generates an alarm after 15 seconds. During this period, it bleeps and the alarm can be cancelled (Miskelly, 2001).

- Body sensors: Detects vital body functions such as blood pressure, blood sugar, and pulse, (Soede, Vlaskamp, and Willems, 2008).

When the sensors are coupled with actuators and a suitable computing platform, it is possible to construct a system that is responsive to the output from the sensors. Using such technologies to construct an Electronic Assistive Technology system that can help improve physical or mental functioning, overcome a disorder or impairment, help prevent the worsening of a condition, strengthen a physical or mental weakness, and help improve a person's capacity to learn.

### 2.1.2 Application of home-care technology

Many studies have been undertaken around the world that focuses on telecare technologies, which might help elderly people to live independently and to improve their quality of life. For example, in 1979 the EMMA (Environment Monitor Movement Alarm) system was once the predecessor of lifestyle modelling systems. It incorporated sensors that monitored movement such as getting out of bed and dwelling temperature (Clark, 1979). Then, in 1993 the Glasgow City Council used Passive Infrared Sensors (PIRs) to link social alarm systems to both monitor for activity and provide detection of intruders at home (Fisk, 2003).The security of the dwelling was an additional characteristic of its predecessor system.

Table 2-1 summaries the main point of some project carried out around the world towards helping to improve the quality of life, independence, and autonomy of the elderly.

| Project name or affiliation | Participants | Type of study | Technology, data analysis technique, algorithms | Main points |
|---|---|---|---|---|
| EMMA (Environmental Monitor Movement Alarm) (Clark 1979) | Older people | Non-specified | Activity and environmental monitoring | Predecessor of lifestyle modelling systems. |
| Glasgow City Council 1993 | Older people | Non-specified | Social alarm system | PIR to link social alarm systems to both monitor for activity and provide detection of intruders at home |
| University of New South Wales (Celler *et al*. 1995) | 10 older people | Two field trials ran in older people's home for five months | Remote activity monitoring and interaction with home environment | Demonstration of the feasibility of using a remote monitoring system to determine the functional health status of older people |
| PROSAFE Project (Chan *et al*.1995), | Simulated data | Feasibility study | Activity monitoring using smart multisensor system. Neural networks algorithms to predict presence and absence of subjects | Feasibility of wireless infrared sensors to detect movement and activity |
| Kawasaki University of Medical Welfare, (Ohta 2002) | 8 older people | Field trial ran in older adult's home | Remote health monitoring system. Spatial-temporal analysis | New data analysis approach that estimates the health conditions of the residents by comparing the duration of stays in specific rooms with previously recorded data. The system reduced anxiety for both the older person living alone and their family members. |
| CarerNet project. Technology in Healthcare. Wales and Abertay Universities (Williams *et al.* 1998) | Potential participants: frail older people | Feasibility study | Activity and environmental monitoring (second generation of telecare) | The proposal of a model based on three categories: environmental factor, human and technological factors. |
| Durham project (Mills 1999) | Older people | Prototype system ran in sheltered homes | Activity monitoring using sensors and video cameras. | Identification of changes in mobility, sleeping and bathing patterns. As well as social isolation through recording video from users. Intrusiveness and privacy aspects were not considered. |

| **Project name or affiliation** | **Participants** | **Type of study** | **Technology, data analysis technique, algorithms** | **Main points** |
|---|---|---|---|---|
| The Aware home . (Kidd et al., 1999; Abowd *et al.* 2002; Mynatt *et al.* 2004) | 44 older adults | Usability evaluation of assistive devices | Activity monitoring using ubiquitous sensing to provide context awareness, , and support memory deficit | Main concerns of older people: overreliance on technology, intrusiveness and independence and personalisation of services. |
| Home Telecare System (HTS) (Celler *et al.* 1999). | 22 people suffered from chronic obstructive pulmonary | A trial ran with for six months | Activity monitoring. Home telecare system. | A care-oriented approach where a telecare system was used to provide active care services to patients with complex and chronic diseases using the telecare system. |
| CarerNet project. Technology in Healthcare. Wales and Abertay Universities (Williams *et al.* 2000) | Older person with health problems | Field trial ran to test a prototype | Activity monitoring and alarm system (second generation of telecare) | The proposal of a Carer model for older people using telecare. |
| BT/Anchor Trust (Porteus and Brownsell 2000) | 22 older people, 8 had some health difficulties and 9 had minor health problems | Field trial ran in older adult's home | Activity monitoring and alarm system (second generation of telecare) | Great acceptability of the system among older people and carers, reduced fear of falling, enhanced older people's perception of being safe and secure in their home and enhanced the carers role` |
| Automated Behavioural Monitoring System (Glascock and Kutzik 2000) | 1 older person | 12-day pilot study ran in the older adult's home | Activity monitoring and alert system. | Results were not validated. The impact of technology on carers and older people was not assessed. |
| PROSAFE Project (Chan *et al.* 2002; Chan *et al.* 2003) | 17 older people suffering from Alzheimer's disease | Field trial ran in older adult's home for short term | Activity monitoring using smart multisensor system. Statistical analysis | Agreement between the system and observations taken by carers |
| Ageing in Place. Georgia Institute of Technology (Mynatt *et al.* 2002; Rowan and Mynatt 2005) | A healthy older adult living alone | Field trial ran in the older person's home over a period of one year | Activity monitoring | Digital Family Portrait: A novel, metaphorical user interface. An effective way to communicate the older person's well-being to family members. |

| **Project name or affiliation** | **Participants** | **Type of study** | **Technology, data analysis technique, algorithms** | **Main points** |
|---|---|---|---|---|
| House_n. MIT (Intille 2002; Intille *et al.* 2004) | 20 non-elderly volunteers | Demonstrator tested in a Living lab for two weeks | Activity recognition and prediction using sensors to provide context awareness. Decision trees and Bayesian network algorithms reported accuracy in activity recognition and prediction. | Training of context awareness algorithms using an artificial environment. Introduction of the "Just-in-time " concept : presentation of information at the right place and time. |
| Sensing room. University of Tokyo (Noguchi *et al.* 2002) | Non-specified | Demonstrator ran in a living lab. | Activity monitoring using sensors to provide context awareness | Technology driven project. The system detected a person position and the status of objects. |
| Mavhome. Texas University at Arlington (Das *et al.* 2002) (Cook and Das 2004; Cook 2006) | Synthetic data and data collected from students | Demonstrator ran in a smart house | Automated home environment that monitors and recognise activities and provides context awareness services | Intelligent environment able to identify patterns, detect anomalies, predict changes in health status, provide reminders and automatic assistance. Technology tested in artificial environment |
| Health integrated smart home information system HIS2 (Virone *et al.* 2002; Virone *et al.* 2003) | N/A | Demonstrator ran with simulated data | Monitoring of physiological and circadian activity | Algorithms were validated using simulated data |
| The independent Lifestyle Assistance (ILSA) (Haigh *et al.* 2006). | 11 older adults | Field trial ran in older adult's home | Monitoring of mobility and medication management. Machine learning algorithms were used to learn people's routines. | The validation of attitudes and needs of older people. The importance of technology to support older people and reduce costs. Further analysis is needed to find the potential shortcoming of touch screen technology. |
| Matilda house. University of Florida (Helal 2003). | Non-specified | Feasibility study ran in a lab. | Tracking the occupant's location, providing task reminders and controlling appliances and security of the house. | Smart phones and sensors were connected using the Open Services Gateway Initiative (OSGi).The study introduced bias because people have to wear devices to track their location |

| Project name or affiliation | Participants | Type of study | Technology, data analysis technique, algorithms | Main points |
|---|---|---|---|---|
| CareNet display. Intel Research Seattle (Consolvo *et al.* 2004; Consoivo *et al.* 2007) | older people | Four trials were ran in older peoples' home for three weeks. | Short-term activity monitoring (daily) presented through an interactive ambient display | Analysis of the impact of technology on the quality of life of older people . Privacy and reliability of data collected were considered. Evidence that data might help to have a dialogue of care. |
| Experimental House. NTT DoCoMo Multimedia Laboratory (Isoda *et al.* 2004). | Non-specified | Demonstrator ran in a living lab. | Activity monitoring based on location and time dimensions. Behaviour modelling was learned using decision trees. | The system was tested with satisfactory results; however, it was not tested in older people's home |
| The Millennium Home project (Perry 2004). | Non-specified | Demonstrator ran in a living lab. | Activity monitoring and multimodal interactive system (third generation of telecare) | The creation of a sophisticated telecare system. Useful methodology to design an interactive multimodal system. |
| The care in the community centre. BT and some UK universities. (Brown *et al.* 2004; Nauck and Majeed 2004; Hine *et al.* 2005; Sixsmith *et al.* 2007), | Five older people | Field trial ran in older adult's home | Activity monitoring that provides awareness to carers (third generation of telecare). Data visualisation tools (OLAP), Classification of events using fuzzy rules. | A well-being model and a demonstrator of a well-being monitoring system to assess the older person's quality of life and well-being |
| Sensorized Elderly Care Home project. (Hori *et al.* 2004; Hori *et al.* 2006 a; Hori *et al.* 2006 b) | An older person | Field trial ran in a real home for a month and a half | Activity monitoring using a wheelchair locator and an ultrasonic radar subsystem | The system was effective not only for reducing accidents of the elderly people but also for reducing workloads on carers. Impact of technology on older people and carers was missing. |
| PROSAFE Project (Chan *et al.* 2005) | 4 older people with cognitive impairments | Field trial ran in older adult's home | Activity monitoring using smart multisensor system. People's trajectories analysis | Impact of technology to assist carers to provide support to people with cognitive deficits towards ensuring their security, safety and autonomy |
| The Ageing in Place project. University of Missouri, (Rantz *et al.* 2005) | 15 Older people | Preliminary pilot | Monitoring of physiological and vital signs using wireless sensors | Collection of main concerns of older people. Technology has the potential to identify functional decline in older people |

| Project name or affiliation | Participants | Type of study | Technology, data analysis technique, algorithms | Main points |
|---|---|---|---|---|
| GatorTech House. University of Florida (Helal 2005) | One older person | Field trial was ran in a living lab | Automated home environment that monitors and recognise activities and provides context awareness services. | Researchers were focused on observing the older adult's behaviour rather than evaluating the impact on the independence and quality of life of the older person. |
| Domus project. University of Sherbrooke home (Vergnes *et al.* 2005) | 12 people with mild intellectual disability | Demonstrator | Activity recognition and prediction. Probabilistic model and plan recognition | Demonstration of assistive service to assist people suffered from dementia. I If the demonstrator was tested with people who had sensory impairments, the system would have some potential problems |
| MARC project. University of Virginia (Barger 2005; Alwan *et al.* 2005) | One middle age person | Field trial ran in a living lab for 18 months | Activity monitoring, recognition of patterns and notification of alerts. Clusters, mixture models and rule-based approach. | Validation of algorithms using self-reporting techniques might result annoying for the participants. |
| PlaceLab (Intille *et al.* 2006) | Middle age adults | 3 pilots ran in a living lab with middle age adults. | Activity recognition and prediction using sensors and multimodal devices to provide context awareness. | High acceptability of the system. Experiments run in artificial environment for a short term. |
| MARC project. University of Virginia (Alwan, Dalal, Mack, Kell, Turner, Leachtenauer and Felder 2006a; Alwan, Leachtenauer, Dalal, Mack, Kell, Turner and Felder 2006b) | 22 older people, 7 of them with memory impairment | Field trial ran in older people's home | Activity monitoring, recognition of patterns and notification of alerts. | The results suggested that monitoring technologies could provide care coordination tools that are accepted by residents and may have a positive impact on thei quality of life |
| Automated Behavioural Monitoring System (ABMS) (Glascock and Kutzik 2006) | 17 frail older people | 12-month pilot study ran in the older adult’s home | Activity monitoring and alert system. | Provision of behavioural information to carers. A technical solution with great reliability. The ABMS system helped to provide better care and greater peace of mind. |

| Project name or affiliation | Participants | Type of study | Technology, data analysis technique, algorithms | Main points |
|---|---|---|---|---|
| ALARM-NET. (Wood *et al.* 2006; Virone *et al.* 2008) | 22 older people, 7 participants needed memory care assistance | A pilot study ran for 3 months to one year | Monitoring of physiological and environmental conditions. | The system was effective to detect deviations and alert carer; however, the study did not analyse the impact of technology on the life of older adults and carers. |
| The Liverpool City Council (LCC) in cooperation with Liverpool Direct Ltd (LDL) and the BT Telecare Group (Barnes *et al*. 2006). | 21 frail older people | Field trial ran for a period of two years | Activity monitoring and alert system. Adaptive threshold algorithms and visualisation of daily behavioural profiles | The integration of telecare within social services and the identification of potential benefits using technology. |
| PlaceLab (Logan *et al.* 2007) | A married couple | A pilot ran in a living lab | Activity recognition and prediction using sensors to provide context-aware and empower people with information. | Lack of data from some sensors, multiple occupancy and incomplete annotation. Results from field trial are awaiting for publication. |
| The ExtraCare Smart House. Dementia Services Development Centre in Bristol, and the Bath Institute of Medical Engineering (BIME) (Evans *et al.* 2007). | 1 participant suffered from dementia | Field trial ran in a living lab | Activity monitoring | Technology was useful to detect unusual patterns of behaviour and helped to improve the older person's quality of life. There was a potential bias in the experiment because the older person was moved to a new place making him felt disoriented |
| Columbia University (Holmes *et al.* 2007) | 100 older people (50 of them used the system) | Field trial ran in sheltered accommodation | Activity monitoring using sensors to recognise sleeping and toileting patterns | Significant improvement in affective disorder using the system was demonstrated. |
| The Ageing in Place project. University of Missouri (Rantz *et al.* 2008). | 33 Older people | Field trial ran in sheltered accommodation over a period of two years | Monitoring of physiological and vital signs using an integrated sensor network | The system was able to detect changes in the resident's condition that were not detected by conventional health care assessment |
| GatorTech House. University of Florida (Helal *et al.* 2008) | 20 older people | Field trial was ran in the Gathor house and the CASAS flat | Automated home environment that monitors and recognise activities and provides context awareness services. | The construction of an innovated living environment that provided smart functions to their residence and carers. The impact of this technology on the quality of life of people was missing. |

**Table 2-1: Home care technology projects**

Celler *et al*., at the University of New South Wales in Australia, conducted a telemonitoring health smart home to measure mobility, sleep patterns, and interaction with the environment .This research team was interested in finding the association between health status functions and changes to determine the level of well-being (B.G. Celler, Earnshaw, Ilsar, Betbeder-Matibet, Harris, Clark, Hesketh, and Lovell, 1995). Two field trials were run with 10 older people living at their home for five months.

This project is very significant because it was the pioneer in demonstrating the technical feasibility of using a remote monitoring to determine the functional health status of the elderly.

In 1999, Celler *et al*. developed a Home Telecare System (HTS) to measure the individual health status and reported it to the primary cares. The objective of the project was to assess the person in advance and provide preventive interventions (B. G. Celler, Lovell, and Chan, 1999). A trial was carried out for six months with 22 people suffered from chronic obstructive pulmonary.

Researchers measured the usability, functionality and effectiveness of the Home Telecare System (HTS) with both older people and carers. The results of these measures were very satisfactory (Lovell, Celler, Basilakis, Magrabi, Huynh, and Mathie, 2002; Garsden, Basilakis, Celler, Huynh, and Lovell, 2004). This project differs from its predecessor because it has a care-oriented approach where a telecare system was used to provide active care services to patients with complex and chronic diseases using the telecare system.

The PROSAFE project built a smart multisensory system based on advanced telecommunication and information technology, aimed to support autonomous living and to raise an alarm in case of emergency. The system consisted of wireless infrared sensors to detect movement and activity. The first study used neural networks to predict the presence and absence of a subject using simulated data (Marie Chan, Hariton, Ringeard, and Campo, 1995). The research team then used this approach in a later system to measure the night activities of 17 elderly people suffering from Alzheimer's disease for a short term. According to the results, a good agreement was found between the system and the observations made by the nursing staff (M. Chan, Campo, and Esteve, 2002). The motor activity data (in bed, getting up, getting out, visiting the toilets) was analysed from a statistical perspective to assess changes in occurrence, time and duration (M. Chan, Campo, and EsteÃÄve, 2003).

Later on, the researchers used unsupervised algorithms to process elderly trajectories with simulated data (M. Chan, Campo, and Esteve, 2004a). A trial was run with four older people that required cognitive assistance. The results demonstrated that technology can assist carers to provide support to people with cognitive deficits towards ensuring their security, safety and autonomy (M. Chan, Campo, and Estève, 2005)

At the School of Medicine of Kawasaki University of Medical Welfare, Okayama (Japan), Ohta and his team developed a remote health monitoring system for elderly people living alone. This project differs from their predecessor because it was not focused on monitoring Activities of Daily Living. Instead of this, data from sensor was used to estimate the health conditions of the residents by comparing the duration of stays in specific rooms with previously recorded data (Ohta, Tanaka, Fujiwara, Ishijima, and Nakamoto, 1997).

The system collected data from infrared sensors, After that, the data was transmitted through Internet to a web server. Afterwards, this data could be consulted by family members, who could make a decision about the older person's health. The data from sensors was analysed using statistical methods. When an unusual pattern was found, the monitoring system informed the family members by telephone or e-mail. The system was tested with eight persons (Ohta, Nakamoto, Shinagawa, and Tanikawa, 2002).

This project was really valuable because technology was considered as a tool to help family members to be aware of their elders. It also provided relevant information so people could make a decision. Thus, the health monitoring system improved the quality of life of the participants because the system helped to reduce the older person and their family members anxiety.

Another important aspect of this project was the reduction of bias in people's behaviour because participants did not wear or carry any devices in their body or clothing. Thus, helping to collect more reliable and realistic data related to older people's behaviour was needed.

The CarerNet model was another second-generation telecare system designed in the UK. It consisted of various elements such as emergency alarm, access to community health information and ambulatory monitoring. The goals of this project were to provide a cheap telecare solution for frail older people, improve the quality of life of physical and mentally impaired people, provide care services to users discharged  from hospital and increase the efficiency of care services using technology (Williams, Doughty, and Bradley, 1998).

The CarerNet model was used to build a prototype called MIDAS (Modular Intelligent Domiciliary Alarm System) to monitor older people. The system included various devices: motion and bed occupancy sensors, bed light and alarm, fall detector and front-door security. A trial was run; however, the results of this research are still awaiting publication (Williams, Doughty, and Bradley, 2000).

Doughty stated that 'the quality of the care experienced by the client has a significant effect on the overall safety of the client remaining at home' (D. A. Bradley, Williams, Brownsell, and Levy, 2002a). This team proposed some variable to collect quantity data that might help to interpret the quality of services provided to the older person automatically by using an intelligent telecare system. Nevertheless, by the time of writing this thesis, there were not results about this hypothesis.

The Durham project was a prototype lifestyle monitoring system installed in sheltered homes. The aim of the system was to detect emergencies, monitor environmental factors, recognise patterns of activities, detect deviation from a norm and monitor long-term changes (Mills, 1999). Various sensors and devices were able to detect falls, high or low temperatures and to record visitors. In addition, they used video to record the participants lifestyle. This project was very effective because the system helped the carers to identify changes in mobility, sleeping and bathing patterns. Carers also identified through recording video that some users were socially isolated. There are important issues of intrusiveness and privacy due to the use of video; however, these aspects were not discussed by the author of this project.

In the USA, the Aware Home Project carried out by researchers at Georgia Institute of Technology, developed an intelligent environment (Kidd *et al.*, 1999). The aim of this project was to examine the usability and engineering challenges in designing devices for ageing in place and assessing the acceptability of this technology by users (older adults and their families). The Aware Home research focussed on: context awareness and ubiquitous sensing (Abowd *et al.*, 2002), monitoring and assisting activities of daily living and supporting memory deficit  (E. D. Mynatt, Melenhorst, Fisk, and Rogers, 2004; Siio, Rowan, Mima, and Mynatt, 2003).

Forty four participants aged 65 to 75 were interviewed to evaluate five devices. The outcome from the evaluation was the fact that older people were concerned with overreliance on technology, intrusiveness and independence and personalisation of services.

The authors concluded that technology can both increase and limit a person’s feeling of independence (E. D. Mynatt *et al.*, 2004). On one hand, technology can assist people with physical, sensory or cognitive impairments to carry out some tasks. On the other hand, technology can limit the mobility of people by the automation of simple tasks such as switch on/off lights, open or close windows. Using technology to improve the quality of life of people should be focused on helping them to carry out tasks when needed rather than avoiding people to perform certain tasks.

Another important output was the tension between privacy and independence. Older people want to have privacy of the personal information to maintain their independence. Older adults might accept technology with privacy implications if they increase their independence (E. D. Mynatt *et al.*, 2004). Older adults can perceive technology as intrusive or not depending on the activity they are carrying out. For instance, the use of cameras can be accepted for an older person with cognitive impairments to assist the older person preparing a meal.

The significance of the Aware Home Research consisted in the investigation of needs and attitudes of older people and family member using the latest technology. Knowing the real needs of people might help researchers to design appropriate technology to help older adults to maintain their independence.

There are some challenges in designing technology for older people: The personalisation of services and the creation of flexible technology driven by people. The customisation of services should be done based on the specific needs of the older person. In addition, technology should be flexible, easy to use and configurable. For instance, a person must decide what data can be monitored, when and who have access to this data.

One of the first organisations in the UK to investigate telecare technologies were the Anchor Trust together with British Telecom. The purpose of this project was to allow older people to live at their home for a longer time rather than moving them to a sheltered house and to allow people an earlier discharge from hospital. A second generation telecare system was developed consisted of a set of sensors that monitored the user's activities of daily living and an alarm that sounded when a significant change in behaviour was detected. The system was tried with 22 people. The age of the participants ranged between 60 and 85 years. Eight participants had some health difficulties and nine had minor health problems (Porteus and Brownsell, 2000).

The success of the trial reported great acceptability of the system among older people and carers, reduced fear of falling, enhanced older people's perception of being safe and secure in their home and enhanced the carers role. The last three aspects are really important factors of quality of life for an older person. There is evidence that people are more autonomous and independent when the fear of falling is reduced. Living in a safe environment might increase the older person's confidence because if anything goes wrong, older people can have someone to help him/her. Enhancing the cares role might have a direct impact in older people's quality of life. For instance, if the carer has reliable information about changes in the older person's health and social needs, the carer can make a decision towards helping to improve the quality of life of the older person.

The limitation of  this system was that it was not able to respond immediately to urgent circumstances but its potential role was to provide the capability to identify changes in activity level and to predict deterioration or improvement in physiological conditions (Porteus and Brownsell, 2000).

Glascock and Kutzik undertook a research study with the purpose of providing care for the frail elderly and people with chronic diseases. The preliminary study collected data from four behavioural domains: Medication adherence, movement inside the house, bathroom usage, and meal preparation (Glascock and Kutzik, 2000). This system was tested during a 12-day period the home of a 71-year-old non-impaired male who lived alone. However, these results were not validated and the impact of monitoring on carers or older people was not assessed.

A further development was a monitoring system named Automated Behavioural Monitoring System (ABMS) that consisted of two components: A set of motion sensors and a base station and a website that provided behavioural information to carers (Glascock and Kutzik, 2004). In 2006, the researchers piloted a study for 12 months with 17 frail older people and carers (Glascock and Kutzik, 2006).

As a whole, the project was very significant because researchers were interested in providing an integral solution that used technology as a tool to provide better care and greater peace of mind for both the older person and the carer. In addition, this project was very effective from the technical point of view since the ABMS system was 98% reliableand the machine validity was at a 95% level. In addition, the system had high acceptability by both the volunteers and their carers.

The Support for the Ageing in Place project at Georgia Institute of Technology aimed to provide support, awareness of long-term-health, activity and social well-being without being intrusive. This project consisted of three parts. First, a Digital Family Portrait (DFP) was designed as an interface to keep an open channel of communication between elder parents and adult children. The system shows the activity level of the resident through the use of butterfly icons that changed their size according to the level of activity (E.D. Mynatt, Rowan, Jacobs, and Craighill, 2002b). The DFP system was tested in a field trial over a period of one year between an ageing parent living alone in her own home and her son (Rowan and Mynatt, 2005). Second, an augmented system was implemented to support memory and planning deficits of older adults (E.D. Mynatt *et al.*, 2002a). Third, the system was able to detect and identify potential crises and contact the appropriate service when needed (Kidd *et al.*, 1999).

The significance of the project consisted in the design of a novel user interface to show the activity level of a healthy older person to their family. The user interface design was very effective in presenting the level of activity of a person because the data collected from sensors was presented through an intuitive and self-explanatory user interface.  The use of a metaphorical user interface was very effective to show the level of activity of an older person that represents health, relationships, activities and events that are highly correlated to the health and social well-being of the older people.

The House_n project carried out by researchers at the Massachusetts Institute of Technology (MIT) worked on tracking people, context awareness, activity recognition and prediction. The goal of this project was to create health care strategies including monitoring, compensation and prevention, to motivate changes in people's behaviour like consuming healthy food and increasing exercise routines.

Data collected from sensors, audio, video, appliances usages was fed into a probabilistic model that let the researchers track people's movement around the living lab and determine the type of activity that the person was doing (Intille, 2002). Various machine learning algorithms such as decision trees and naïve Bayesian networks were developed to recognise and predict activities (Intille, Rondoni, Kukla, Anacona, and Bao, 2003; Intille, Tapia, Rondoni, Beaudin, Kukla, Agarwal, Bao, and Larson, 2003; Intille, Bao, Tapia, and Rondoni, 2004). The results of the algorithms were better with decision tress between 80-95% of accuracy than naive Bayesian between 25%-89% (Tapia, Intille, and Larson, 2004). These algorithms then were trained with data collected from 20 non-elderly volunteers within a living lab during a period of two weeks. Intille and his team used several user-reporting techniques to validate the accuracy of the algorithms.

This project is different from the Aware Home because Intille and his team were interested in discover the best supervised learning dataset rather than in understanding the needs of people before the implementation of any technology.

Another challenge of this study was the development of technologies and the design of strategies that used context-awareness to empower people with information by presenting it at the right time and place. This information could motivate behavioural changes in healthy eating, physical activity, personal and work safety, and learning (Intille, 2002). The project introduced the concept of “just-in-time” technology to present information at point of decision to motivate behaviour change (Intille, 2004).

Later on, the MIT team built a living lab called “The PlaceLab”, which was equipped with multi-modal sensors, cameras, speakers, and a large number of sensors. In addition, the participants wore sensors to detect motion and their heart rate. The use of many distributed sensors might help to improve redundancy to obtain a high level of activity and context detection tasks. However, building this technology can be very expensive due to the large number of sensors and equipment (Intille, Larson, Beaudin, Nawyn, Tapia, and Kaushik, 2005).

Another issue is the perception of intrusiveness when a large number of sensors and cameras is installed to collect people’s behaviour. Thus, keeping the balance between cost and benefits is something that researchers should take into account to build a more realistic solution affordable for a normal older person.

The MIT team run three pilots with non-elderly voluntary participants, aged between 35 and 60 years for a period of ten days (Intille, Larson, Tapia, Beaudin, Kaushik, Nawyn, and Rockinson, 2006). Participants expressed high acceptability and felt comfortable living in the PlaceLab. Nonetheless, there was evidence that some people wanted to have their personal objects such as mugs and pillow. This showed that it was better to collect data in people’s homes rather than in living laboratories in order to collect more realistic data from participants.

These kinds of studies might not provide relevant knowledge to understand older people’s behaviour because the experiments were conducted with young people (between 30-60). Newel *et al*. stated that older people’s behaviour differs from young adults because their physical, sensory and mental abilities are dissimilar (Newell *et al.*, 2006).

Ten days is a short period of time to claim that people became accustomed to the living environment. In fact, Evans and her team ran a trial for one year with an older person suffering from vascular dementia and reported that the participant felt disoriented because of moving into an unfamiliar environment (Evans Nina *et al.*, 2007). Intille said that ’although techniques such as ethnography could be used to learn more about the older person’s activities, those methods do not provide multi-modal datasets synchronized with specific examples’. Other researchers have proved that learning the habits of residents in advance using ethnography could help to increase the accuracy of the machine learning algorithms. The use of ethnography in pervasive computing has enabled IT designers and developers to understand the real needs of the end user and provide more realistic solutions taking into account the human factors such as social interaction, and attitudes (Abowd *et al.*, 2002). Gaining a richer understanding of a particular setting and the everyday practices is the primary purpose of ethnographic studies. It relies on observations taken by a person who is in the field gathering information about the subject and the environment using questionnaires, listening, watching and interacting with people.

Intille and his team then conducted a trial with a married couple who were asked to move into an instrumented home for 10 weeks. Activities that took place in the same location reported high accuracy; however, those activities performed at different places reported low accuracy. The results of this trial highlighted some problems of the study such as lack of data from some sensors, multiple occupancy and incomplete annotation.

The House_n project was a good example of activity recognition and prediction using a large number of sensors and developing various smart machine learning algorithms. Although the results from the algorithms reported relatively high accuracy in recognising and predicting activities on artificial environments, the authors of this project have not published results testing this technology in a real home environment or field trial.

At the University of Tokyo, Noguchi and his team built a “Sensing Room” that collected quantitative data on human daily actions, then learnt from and analysed the data. The objective of this project was to provide context-awareness to the occupant. The states of the floor, bed, table, appliances and switches were collected using sensors. The combination of this data defined the room state. An algorithm named “summarisation” was also developed to segment the sensory data when a drastic change was detected (Noguchi *et al.*, 2002). Although this was a technology driven project, the success of the system consisted in the ability to detect the person position and the status of objects using a different approach which is less intrusive than the self-reporting techniques employed by Intille and his team.

‘The Managing an Intelligent Versatile Home’ (MavHome) project implemented by a group of researchers at the University of Texas at Arlington, aimed to provide home health monitoring and assistance to the inhabitant (Das, Cook, Bhattacharya, Heierman Iii, and Lin, 2002). The Mavhome team developed an intelligent agent that was able to learn from movement history and predict mobility patterns and device usages of the inhabitants (Cook, Youngblood, Heierman, Gopalratnam, Rao, and Khawaja, 2003; Cook *et al.*, 2003).

In addition to the characteristics of previous context awareness system mentioned above, this research team was focused on: The identification of patterns; detection of anomalies in data; prediction of changes in health status; the provision of reminders and automation of assistance to the occupant (Cook and Das, 2004; Cook, 2006).

The Mavhome is a technology driven project because the main purpose was to test sophisticated algorithms based on synthetic data or data collected from students. This data might not be representative to understand older people's behaviour; however it might be useful to test algorithms. Results would be different if those algorithms were tested in a real home environment.

In France, a Health Integrated Smart Home Information System (HIS2) was developed to ensure the security and quality of life for patients who needed home cared medical monitoring. The system collected the individual's activity, weight, vital signs and circadian activity. The team developed some algorithms that detected abnormal behaviour based on deviations (Virone, Noury, and Demongeot, 2002; Virone, Istrate, Vacher, Noury, Serignat, and Demongeot, 2003).

This approach was completely different from the studies mentioned before because it was based on measuring the circadian activity and some physiological aspects. But, the validity the algorithms were tested using simulated data, which constitutes the main weakness of this study.

Afterwards, Virone and his team developed another monitoring system called ALARM-NET. It was a wireless sensor network designed to monitor people's physiological and environmental condition. A circadian activity rhythms (CARS) learned patterns of behaviour and automatically setup the system according to these conditions (A. Wood, Virone, Doan, Cao, Selavo, Wu, Fang, and Stankovic, 2006).

Data access, privacy and security were important requirements considered in the design. Furthermore, to reduce the vulnerability of wireless communications, the team used a lightweight protocol to encrypt the data transmitted (A. D. Wood *et al.*, 2008). A pilot study was carried out with 22 older people, 7 participants needed memory care assistance. Data was collected for periods of 3 months to one year. The results showed the effectiveness of the system to detect deviations and to alert carers (Virone, Alwan, Dalal, Kell, Turner, Stankovic, and Felder, 2008).

This study did not assess the impact of the system on the older people and carers' quality of life. Having information about changes in the health status of the older person and providing a rapid care intervention might help to improve the quality of life of older people.

The Independent Lifestyle Assistant (ILSA) project, developed by Honeywell Laboratories, was a passive monitoring prototype system to support the independence of elders living in their home (Haigh, Phelps, and Geib, 2002). The system was tested with 11 older people aged between 55 and 96 years old. Researchers were interested in monitoring mobility (activity level, home occupancy, falls detection) and medication management (medication taken and reminders). Two user interfaces were chosen to interact with the older person and the carers: Telephone and a web-based touch screen. Haigh *et al*. reported that automatic telephone calls were evaluated as intrusive, rude and annoying. (Haigh, Kiff, and Ho, 2006).

The ILSA project was significant because its findings provided some human factors analysis to design technology to assist independent living, disproved the assumption that older people fear to use technology and validated the importance of artificial intelligence and machines learning techniques to support older people and reduce costs by anticipated changes in peoples' needs. This project is a good example of gathering requirements with people rather than assuming what could be useful for older people.

Touch screen technology would have a great impact on the quality of life of older people; however, a further analysis from the ILSA project might be the investigation of web-based touch screen with older people suffering from any sensory impairment or dexterity.

In Seattle, the Computer Supported Coordinated Care (CSCC) project, aimed to improve the quality of care and life for older people and carers by providing data about the older person such as health, mental, and emotional aspects that might give an overall person's well-being. The project also took into account important issues such as the privacy and reliability of the data collected and provided to carers (Consolvo *et al.*, 2004b).

As part of the project the team developed a CareNet display, an interactive ambient display that provided awareness about the older person's daily life. The CareNet display differed from the Digital Family Portrait (DFP) in various aspects: It provided daily data to local carers instead of 28-day period provided by the DFP to extended family; the CareNet display showed more detail data that the DFP. Providing detailed information to formal and informal carers might be helpful in specific situation. Ffor instance, older people with special needs.

However, privacy issues might appear when detail information is presented among various stakeholders. An example of a private issue is related to what the older person is doing, and why and when he or she is doing it.

The researchers also considered other important aspects such as allowing the user to control what data to share and deciding who could see what type of data. Allowing users to control the system is an essential characteristic of an automated home environment; however, it is important to consider the user's cognitive abilities and skills.

Four field trials were carried out in older people's home over a period of three weeks. The results reported that older people were afraid that sensors would provide personal data and others wanted to have detailed qualitative data about the activities or events. Personalisation of the level of data presented is an important issue when designing a user interface. Allowing users to drill down from general to specific data detail would satisfy this data presentation requirements.

One interesting aspect of this trial consisted in analysing the impact of the CareNet display on elders and their care network members in terms of improving the quality of life of the older person and cares. There was evidence of how detailed information about an older person can help to detect the need of more care and; therefore, improve his/her quality of life. For instance, a diabetic older person with mild dementia was eating the same thing every day. Her family member noticed this pattern from the data showed and requested a carer to help the older person to buy her groceries. Carers also improved their quality of life because the CareNet display helped to reduce their level of stress by providing a more relaxed interaction with the older person.

Another interesting finding was the usefulness of having data about the older person to have a meaningful conversation between the older person and her carers as well as providing better care (Consolvo, Roessler, and Shelton, 2004a). This is in fact, the evidence that having data about the older person can help to enhance the dialogue of care between the older person and the carer.

The Matilda Smart House project was an assistive environment to support the elderly (S. Helal, 2003). A house was instrumented into a lab with smart phones, and sensors connected using the Open Services Gateway Initiative (OSGi). This team was focused on tracking the occupant's location, providing task reminders and controlling appliances and security of the house. One limitation of the Matilda House was that people had to wear a device to detect their location, which constitutes a limitation to understand people behaviour. In addition, wearing a device does not provide useful data since they might forget to carry a device or people might feel observed and controlled.

Later on, this team developed a second generation smart house named “The Gator Tech”. The goal of this project was to assist older persons in maximizing independence and maintaining a high quality of life. In addition to the Matilda Smart House, this approach uses self-sensing services to enable remote monitoring and allow carers to assist older people living in their house (S. Helal, Mann, W., El-Zabadani, H., King, J., Kaddoura, Y., Jansen, E., 2005). A field trial was run with an older person living during one day. The trial was focused on observing an older person living into a smart environment (Davenport, Elzabadani, Johnson, Helal, and Mann, 2007). However, the results did not provide evidence of how the system impacts the independence and quality of life of the older person.

Helal and his research team worked in collaboration with researches at the Washington University. The aim of the project was to monitor the health status and provide assistance to diabetic people. The smart health monitoring system was tested with 20 adult participants (non-diabetic). Hidden Markov models were used to recognise activities. Chewing video analysis was used to determine the quantity and type of food taken by a person. The Gator Tech Smart Home and the CASAS smart apartment were used to demonstrate the system (A. Helal, Schmalz, and Cook, 2008). The accuracy of Markov model validation using three-fold cross was 98%.

The success of the project consisted in the construction of an innovated living environment that provided useful smart functions to their residence and awareness to their carers. However, the analysis of the evaluation should have included: what was the impact of using smart technology on the life of older people?

There are some researchers working on user activity assistance applications such as the NTT DoCoMo multimedia laboratory, which developed a system for modelling and recognising activities based on data collected from sensors embedded and Radio Frequency Identification (RFID) tagged objects installed within a living laboratory. Activities of Daily Living (ADLs) were described by the sequences of the states of the users interacting with objects. This approach adds the time dimension to recognise activities that take place at a specific location. The behaviour of users was learned using decision trees algorithms. The research team tested this algorithm in an experimental house with satisfactory results; however, by the time of writing this thesis, there were not publication about field trials using this technology (Isoda *et al.*, 2004).

This is an example of a technology oriented project because it didn't provide information of how the researchers decided to installed a set of sensors without a previous gathering requirement task.

A third generation of telecare was the Millennium Home project. This research was based on the Anchor Trust / BT telecare initiative. It was carried out by a research team at the University of Brunel. The goal of this project was to support the elderly in their home. The Millennium Home was implemented within a laboratory environment and consisted of two modules:  A lifestyle monitoring system (LMS), and an interactive multimodal system. The LMS had a set of sensors, magnetic switches and a reminder for medication. And the interactive multimodal system that included speech, video, voice recognition, and input devices. The system was able to escalate an alarm and select the suitable output device. For example, if there was no response from the user the system raised an alarm to request external help (Dowdall and Perry, 2001). In addition, the Millennium Home provided the user with a quick and easy mechanism to cancel false alarms and a more rapid response to a real emergency (Perry, 2004).

The significance of the Millennium project was the methodology employed to design an interactive multimodal system to monitoring activity and supporting older people living in their home. However, this novel approach was not tested within a real home environment.

The Care in the Community Centre, a collaborative project between BT and some UK universities, developed a third generation of telecare system that anticipated problems and provided awareness to carers to allow them to provide better care interventions, towards improving both the quality of care services and the quality of life of the older person (Brown *et al.*, 2004; Sixsmith *et al.*, 2007).

This research consisted of four projects: The Domain Specific Modelling (DSM) project employed on-line analytical processing (OLAP) technology to show data collected from a sensor network at different levels of detail (Hine, Judson, Ashraf, Arnott, Sixsmith, Brown, and Garner, 2005a). The SensorNet project focused on installing the right set of sensors for each participant. The Intelligent Data Analysis (IDA) project used fuzzy rules that classified significant episodes and trend analysis to capture comprehensive information about a person's daily activities (Nauck and Majeed, 2004) based on long-term well-being data of vulnerable persons living at home. Based on a set of fuzzy rules of normal activity patterns, data can be tested for variations over time from the normal trend (Majeed and Brown, 2006). The output of these three projects were fed into a Demonstrator Project, a well-being monitoring system, initially installed in the homes of two people receiving social care in (Sixsmith *et al.*, 2007).

The well-being monitoring system was demonstrated during a pilot study with five older people living in their homes. By the time of writing this research, the findings of this study were not yet available.

The success of this project was the proposal of a well-being model and the demonstration of a well-being monitoring system to assess various factors that contribute toward the older person’s well-being and quality of life living in their home.

Nishida and his team in collaboration with a nursing home in Tokio worked on a project called “Sensorized Elderly Care Home” that introduced a nursing care support system. The system employed ultrasonic 3D tag technology to monitoring activities. The aim of the project was to provide relevant data to carers so they could understand, monitor and make decisions. The system consisted of a wheelchair locator and an ultrasonic radar subsystem. The system was tested with one older person for a month and a half (Hori, Nishida, Aizawa, Murakami, and Mizoguchi, 2004) (Hori, Nishida, and Murakami, 2006 a; Hori, Nishida, and Murakami, 2006 b).

This project was significant because researchers proved that the system was effective not only in reducing accidents of the elderly people, but also in reducing workloads on carers. Furthermore, with the data provided about the older person carer could analyse the older person’s activities patterns and make an assertive decision about the older person’s care. This kind of proactive system might be useful to prevent acute situations in older people’s lives and reduce cost in providing health and social services to this target population. However, the results of this project would be more significant to the scientific community if researchers analysed the impact of technology on older adults and carer’s quality of life.

Automated decision-making and control techniques are available in smart homes. The Adaptive Home project used a neural network and a reinforcement learner to determine ideal settings for lights and fans in the home (Mozer, 2004). Like the Mavhome project, this approach has been implemented and tested with volunteers in an artificial environment. One benefit of this project was the use of smart home technology for energy efficiency; however, the results did not report findings about the effect of using smart technology on the quality of life of older people.

The Ageing in Place project, at the University of Missouri, aimed to improve the quality of life of older adults in their place “age in place” (M. J. Rantz *et al.*, 2005). This project consisted of two initiatives: Senior Care and Tiger Place. Senior Care was designed to provide community-based support and health services to senior residents of the Tiger Place and private and public senior residents as well. The TigerPlace consisted of 33 flats installed with a network of wireless sensors that measured proximity and motion, weight and various vital signs.

This collaborative project investigated the care needs of older people by consulting older people from the Senior Care and nurses. A preliminary pilot carried out with 15 older people revealed that older people are willing to use technology in their homes if it is reliable. Furthermore, Fisk found that elderly people are reluctant to use technologies that are unfamiliar or useless for them; however, they are attracted to products that improve their quality of life and their independence (Malcolm J. Fisk, 2003). The following user requirements were collected as the main concerns for older people: Falls, mobility, social isolation, security and reminders.

Further work included the development of a system to detect functional deterioration and raise a call for an intervention in case something goes and the installation of this system  at the TigerPlace. Researchers aimed to measure the benefits of technology of the residents. For instance, data collected for a period of two years from motion and bed sensors demonstrated some correlation between the sensor data and health events, such as falls, emergency room visits, and hospitalisations. Researchers presented evidence that the system was able to detect changes in the resident’s condition that were not detected by conventional health care assessment (M. Rantz, Skubic, Miller, and Krampe, 2008). Therefore, technology might help carers to detect or anticipate health changes.

The DOMUS project at the University of Sherbrooke in Canada, aimed to provide an adapted and customised environment to promote a person’s autonomy, reduce hazards and risks and help relatives and carers to keep in touch at a distance with the elderly (Vergnes, Giroux, and Chamberland-Tremblay, 2005; J. Bauchet, Vergnes, Giroux, and Pigot, 2006).The researchers developed two prototypes for assisting cognitively impaired people at home. The first one, the pervasive cognitive assistance PCA, was monitoring activities of daily living ADLs related to the morning routine (J. Bauchet *et al.*, 2006). The second one, Archipel, was focusing on the meal preparation activity (Giroux, Bauchet, Pigot, Lussier-Desrochers, and Lachappelle, 2008). The PCA prototype used various types of sensors and computing techniques (probabilistic model, plan recognition system based on lattice theory and action description logic) to recognise activities (J. Bauchet, Mayres, A., 2005; Bouchard, Bouzouane, and Giroux, 2006).

This project was initially conducted in a laboratory with healthy people (non- cognitive impaired users). Then, the researchers conducted an experiment with 12 people with mild intellectual disability in the smart flat of DOMUS. The comparison of the performance between preparing a meal with and without Archipel was measured. Researchers reported that Archipel was able to reduce the human assistance by 50%.

A potential problem that would emerge using video to help people to remember how to carry an activity might be if the person has any hearing and visual impairments. In that case, researchers should try another type of multimodal communication or assistive device to help those users to continue doing the activity.

One of the key aspects of quality of life for older people is maintaining their independence and autonomy to carry out basic activities of daily life (eating, medication, sleeping, appointment and personal care). The project was an excellent example of using technology to promote the autonomy of people with specific needs (mild dementia) by reducing human assistance. However, reducing direct care might have a negative social effect on the life of the older person because for some elderly having carers visits is counted as their social interaction rather than an annoying event.

The University of Virginia's MARC project was interested in developing technology to support the independence and healthy lifestyle of older people living in their home. The research team developed an In-home Monitoring System (IMS) that used basic sensors to monitor the activity of a person in a living laboratory. Several data analysis techniques, including clustering, mixture models (Barger, Brown, and Alwan, 2005) and rule-based approach (Alwan, Leachtenauer, Dalal, Kell, Turner, Mack, and Felder, 2005) were used to develop a probabilistic model of behavioural patterns and infer specific activities from sensory data.

Preliminary evaluations of the algorithms were run within a living lab with a middle age, healthy person for 18 months. The user was asked to register every single activity using a personal device assistance (PDA) (Alwan *et al.*, 2005). Asking people to record their activities could be useful to validate these algorithms; however, this approach could be useless because people often forgot to record their activities. As well, it might irritate people and may introduce bias to the data collected because people might behave in a different way.

The latest version of the IMS was tested with 22 residents, 7 of them with memory impairment over a period of three months. Several evaluation methods were used to evaluate the IMS system. Changes between before and after using the system were significant for the residents. For instance, the increase of sense of security and the increase of social interaction with professional carers. The goal of this project was to assess the acceptance and the psychosocial impact of technology on older people and carers (Alwan, Dalal, Mack, Kell, Turner, Leachtenauer, and Felder, 2006a; Alwan, Leachtenauer, Dalal, Mack, Kell, Turner, and Felder, 2006b).

This is a good example of controlled experiment driven by people's needs. At the beginning, a team of researcher investigated the potential needs of older people and carers. After that, the team ran a field trial to evaluate the acceptance of the system and the impact of technology on the quality of life of older people and carers.

In cooperation with Liverpool Direct Ltd (LDL) and the British Telecom Telecare Group, the Liverpool City Council (LCC) ran a telecare pilot with 21 frail older people for two years. The profile of the participants was 80 years old, with mobility problems and high dependency on social services. The objective of this pilot was to provide proactive monitoring and to highlight situations related to the person's well-being. This telecare system consisted of sensor (PIRs motion detector and state change sensors), a scalable alert system and adaptive thresholds algorithms(Barnes, Webster, Mizutani, Ng, Buckland, and Reeves, 2006).

Daily behavioural profiles of the older person were e-mailed to carers through graphs. In conjunction with the carer's knowledge, these visualisations could provide proactive detection of medical issues. Having the daily profiles provided evidence for making a risk assessment, allowing the community teams to monitor changes in older people's patterns of behaviour, which could help to predict required changes to treatment plan or care packages (Buckland, Frost, and Reeves, 2006).

The significance of this project was the integration of telecare within social services that might provide some potential benefits such as the prevention of acute problems; the anticipation of higher social care or hospital services; the avoidance of moving to sheltered accommodation; the provision of peace of mind to the older people and their family; and the incremented confidence of the older people because someone was keeping an eye on them.

The ExtraCare Smart House was a collaboration between Dementia Voice, the Dementia Services Development Centre in Bristol, and the Bath Institute of Medical

Engineering (BIME), which worked towards helping people suffering from dementia. People with dementia and their carers were involved in the design and development of a smart home. Sensors were installed to monitor the occupant's activity to provide comfort, safety and security to the resident. The data gathered from sensors wwas analysed to find abnormal behaviour such us night-time restlessness. In addition, if something abnormal was detected, an alarm was sent to the warden call system (Evans Nina *et al.*, 2007).

The system was tested for one year with one male old person suffering from vascular dementia within a living lab. The sensor data revealed that the tenant only slept for about three hours and his movements were disoriented. His disoriented movement was influenced by moving into an unfamiliar environment and the general deterioration in his cognitive abilities. As a result, the research team customised some automatic functions such as automatic lights and voice prompts to guide the older person to go to the toilet and return to bed. After these changes, the tenant improved his sleeping patterns from three hours to six and his orientation moving around the flat.

There was a potential bias in the experiment because the older person felt disoriented due to moving to a new place or his cognitive deterioration. In order to have a real reason of this effect, the experiment should be run in the older person's home.

This project was an example of how technology should be used to support older people's quality of life. Recognising the needs of the residents was the first mandatory step; then, analysing the data collected from sensors to understand patters of the person. Finally, making some modification of the initial design was necessary to improve the elderly quality of life.

At the University of Columbia, Holmes and this team implemented a system called Vigil for dementia residents of a special care unit (SCU) in a large nursing home. The Vigil monitoring system had a bed exit sensor positioned under each resident's bed sheet, and bathroom and bedroom exit monitors. The experiment was run with 100 participants, half of them used the system and half were provided direct care. Results showed that there was no significant reduction in falls and injuries, but there was a significant improvement in affective disorder in the group that used the system as contrasted with the comparison group (Holmes, Teresi, Ramirez, Ellis, Eimicke, Kong, Orzechowska, and Silver, 2007). However, there was no evidence whether the increase in affect was cause by using the system or the increased staff time while training the system. In order to reduce the bias of the results, a second field trial should be run in older people homes to examine the effects of the system.

## *2.2 Exploring changes related to people's behaviour*

### 2.2.1 Other perspectives

In order to understand the significance of the studies undertaken around the world to help older people to remain at their home- keeping their independence, autonomy and quality of life-, the researcher classified these studies into four categories:

- **Activity monitoring**: It is based on monitoring the Activities of Daily Living (ADLs) using some algorithms. This recognises specific activities, such as mobility, sleeping and bathing, and detects changes in those activities (Tapia *et al.*, 2004; A. Helal *et al.*, 2008). In some cases, these algorithms predict changes based on historical data and make automatic interpretations (Das *et al.*, 2002; Virone and Sixsmith, 2008). In other cases, those algorithms provide awareness to carers (Hine *et al.*, 2005a).

Activity monitoring can be valuable to provide significant data about the older person's well-being. As Sixsmith said, there are some activities such as sleeping, eating, social interaction that reflect the older person's well-being. In addition, there is evidence that the provision of relevant data about the older person's activities can contribute to have a meaningful conversation between the older person and the carer. The problem with monitoring specific activities, however is that it is difficult to be sure the data from a set of sensors is actually referring to a specific activity, and in classifying a specific activity as symptomatic of a loss or gain in well being. People may successfully complete activities of daily living, but this may take all their time and energy so that they are unable to do the activities they really want to do. Therefore, the sensor data might suggest that older people are well because activities are completed when in fact; they are frustrated and unfulfilled because they are unable to do the things they would prefer to do.

- **Modeling the inhabitant behaviour**. Consists in building a model of a person to customise the environment such as automation of appliances, security and energy efficiency. This model can be used to detect anomalies and changes in the inhabitant patterns (Youngblood, Cook, and Holder, 2005; Majeed and Brown, 2006; Isoda *et al.*, 2004).
- **Monitoring physiological, vital signs and environmental conditions**. This approach collects data from sensors automatically and then employs an agent to determine the status of the person (M. J. Rantz *et al.*, 2005; B. G. Celler *et al.*, 2003; Ohta *et al.*, 1997; Nishida, Hori, Suehiro, and Hirai, 2000; A. Wood *et al.*, 2006).
- **Spatial-temporal analysis**. Consists in describing activities by sequences of the state of the user interacting with objects in terms of location and time (Isoda *et al.*, 2004).

In the approaches mentioned above, there is an assumption that the cause or consequence of the sensor firings is understood and predictable. Just because an appliance has been used or an activity enacted, it may not mean that the consequence is as predicted. For example, an older person may use a kettle periodically, but forget to use the hot water to make a hot drink.

In addition, there are some practical and ethical challenges associated with these studies. The ethical challenges include the avoidance of intrusiveness, privacy and confidentiality of the data collected. Further investigation is needed since for some older people the intrusiveness of technology can be accepted if the benefits enhance the older person's quality of life and well-being. The ethical issues will be discussed further in section 2.3

The practical challenges are related to the reduction of cost in the installation of sensors. Industries that are interested in developing technologies to provide care to the older population have started to address this problem. That means that this kind of technology might become increasingly affordable in the near future.

Some technical challenges include the implementation of smart algorithms to recognise activities of daily and predict human behaviour, understand the data and provide accurate information about the older person. Some of these challenges have been successfully committed in controlled laboratories; however, this computing techniques need to be evaluated in real-home environments where older people are used to living.

### 2.2.2 Busyness

This research thesis is interested in investigating whether the level of activity 'busyness' of a person at a specific period of time and location might be enough to communicate changes related to the older person's well-being. Because of the difficulty in knowing what the activation of sensors means in terms of well being, and because of the potential intrusiveness and loss of privacy associated with detailed analysis of what exactly a person is doing in their own home. Busyness will be defined as a measure of overall movement and activity within a dwelling, and of interactions with objects at different places and periods of time.

Measuring the level of activity, presence in locations and interaction with objects in a private dwelling, without attempting to infer specific activities, might provide information to characterise an individual's lifestyle. The nature of the busyness, the count of movements or interactions, could help to describe a person's behaviour. This, in conjunction with contextual and health data could give indications of well-being.

Busyness is a way of focusing on general care needs without being intrusive, without collecting a large amount of data and with less computational cost. Busyness might be less intrusive than other approaches undertaken in this area because it is not focused on identifying, measuring of inferring specific activities. Busyness data might be enough to know changes related to the older person well-being towards improving his/her independence and autonomy. Therefore, keeping balance between intrusiveness and independence is something that researchers should take into account to build an acceptable solution from an ethical point of view.

Busyness might be a cheaper computational solution as a data analysis approach to determine changes on key areas of well-being of a person (mobility, eating and drinking, personal hygiene and sleeping). It also does not require a large amount of sensors and cameras to collect data about the older person. Busyness needs a plan to determine what kinds of sensors are relevant to collect key data according to the user's needs. Then, this busyness data could be analysed using on-line analytical processing (OLAP) tools and some data mining techniques to extract useful information.

Many sophisticated algorithms have been used to recognise activities and predict behaviour of people; however, most of those studies have been undertaken in artificial environment (lab settings or short term studies). Thus, it is not proven that these algorithms are sufficiently robust to work in real home environment. Busyness is focused on highlighting changes in general activity levels without employing complex algorithms to detect specific activities.

## 2.3 *Ethical perspectives*

Ethical concerns arise with regard to the implementation of technology due to the risk of intrusiveness, surveillance, data privacy, loss of confidentiality, and fear of replacing people with technology.

Intrusiveness is often connected with technology that monitors a person's movement at home. All monitoring systems are intrusive and the perception of the level of intrusion is determined by the user (Doughty *et al.*, 1996). Aspects such as the previous experience using technology; the opinion or attitudes of others about technology; the way in which the technology service or product is advertised or marketed; the design, size of the equipment; the autonomy of the user to have control over the technology; the duration and frequency of interaction between the user and the technology; and the added values offered by the technology determine the level of intrusion (M. J. Fisk, 1997).

Some researchers suggested that passive detectors such as Passive Infrared Sensors (PIRs), pressure mats, fire and flood detectors are rarely cited intrusive technology. The sense of intrusion can be offset if users see the technology as beneficial, useful, aesthetical and controllable (Brownsell *et al.*, 2003). In addition, Porteus and Brownsell said that PIRs were not intrusive because they did not provide information about what a person was doing. They only detected movement. However, a few participants from the Anchor Trust trial expressed the potential loss of privacy and the feeling of being observed. Fisk stated that if the benefits of using technology can be shown then the perception of intrusion can be reduced (Malcolm J. Fisk, 2003).

Surveillance is another important concern among elderly people. Magnusson and Hanson stated that a group of frail older people and their carers felt worried about being observed by other people with the use of videophones (Magnusson and Hanson, 2003). However, some researchers found that lifestyle monitoring systems were well-accepted among elderly people who might need emergency assistance

(Brownsell *et al.*, 2003). Fisk added that the service provider should have the consent of the older person to collect personal information related to physical activities, health record, and social interaction (Malcolm J. Fisk, 2003).

Another important issue related to ethical aspects is the data privacy and confidentiality. The Data Protection Act 1998 gives individuals the right to know what information is given about them. It provides a framework to ensure that personal information is handled properly (Information Commissioner Office, 1998). Confidentiality refers to the one who has access to the information and who controls its access. Magnusson and Hanson stated that the individual should have control to the information about him or herself and only the user should determine who could have access of this information (Magnusson and Hanson, 2003). In addition, the user should be able to set the parameters to collect the information and switch off or remove any equipment (Malcolm J. Fisk, 1998).

Fear of replacing people with technology is a concern among carers because of the possibility of reducing costs by reducing care levels (Porteus and Brownsell, 2000). The fact is that the older population is increasing and there is a lack of human resources to meet their needs. Technology could be seen as helping carers to do a better job using their time more effectively and efficiently.

## *2.4 Discussion and conclusions*

Various research studies that include telecare, social alarms, electronic assistive devices, automated home environments and ubiquitous homes have been undertaken around the world to improve the quality of life, independence and autonomy of older people. Some of these initiatives aimed to enhance the social contact with family and neighbours, to support cognitive deficits and provide safety at home. Other research projects have focused on detecting changes related to the older person’s well-being by anticipating and preventing acute situation. Meanwhile other initiatives tended to concentrate in home automation and to provide comfort to its occupants by installing automatic lighting and curtains.

From a methodological perspective, researchers have used many methods to understand the various stakeholders needs (older adults, informal and professional carers, family members, researchers and technologies) and attitudes with technology. Some research teams have produced innovative user interfaces either to present data or to interact with the end user such as augmented user interfaces (E.D. Mynatt *et al.*, 2002b; Giroux *et al.*, 2008), multimodal systems (Perry, 2004), robots (J. Bauchet, Mayres, A., 2005) (Bouchard *et al.*, 2006), and distributed assistance services (Haigh *et al.*, 2002), Others have used conventional user interfaces such as telephone, web-based application and touch screens (Ohta *et al.*, 2002).

From an ethical perspective, some studies have demonstrated that there is a fine line between what information can be shown to carers to provide support and keep the privacy of the older person data (E. D. Mynatt *et al.*, 2004). The reliability of the data collected; the control access to this data (Consolvo *et al.*, 2004b); surveillance (Magnusson and Hanson, 2003) and fear of replacing people with technology (Porteus and Brownsell, 2000) have been also discussed.

From a technological perspective, the application of many novel computing techniques have been explored to recognise activities; context-awareness (Abowd *et al.*, 2002); predict user behaviour (Das *et al.*, 2002); correlate phenomena (M. Chan *et al.*, 2003); monitoring long-term activity trends (Brown *et al.*, 2004); data visualisation; proactive monitoring (Barnes *et al.*, 2006) , track people’s movement (Intille, 2002) and measuring health status based on physiological data (Celler, *et al.,* 1995). It has also been highlighted technology that fits a specific requirement. For instance, Passive Infrared sensors (PIRs) are good at recognising activities that take place in the same place, whereas Radio Frequency Identification (RFID) tags can be used to track moving objects and people.

From a human-computer perspective, some evaluation studies have been conducted with older people and carers that showed acceptability and reliability of technology (Porteus and Brownsell, 2000; Glascock and Kutzik, 2006).

Busyness, as it was defined previously, looks at the volume of activity within the house at different places and periods of time. Recognising activities in an accurate way is a difficult task because human behaviour is unpredictable. Busyness might be a solution as a data analysis approach to determine changes on key areas of well-being of a person (mobility, eating and drinking, personal hygiene and sleeping).
Showing the busyness data of key areas of well-being (sleeping, eating and drinking, personal hygiene and mobility) has advantages in comparison with activity monitoring such as busyness is less intrusive, busyness requires less computation and data is interpreted by people through a dialogue of care.

Older population combined with the possibilities that technology presents, is leading to consideration of technological application to support health and social services for older people. The changes in the demographic population will affect the way these services are delivered to their customer, as well as,  the fact that most older people, including many of the very frail, want to live in their home (ScottishExecutive, 2000). Therefore, the use of technology might help carers to provide better health and social services to older people who want to live independently in their home.

In addition technology might help to improve older people and carers quality of life (Consolvo *et al.*, 2004b). For instance, by using technology carers can have relevant data about the older person and provide better care. As well carers can reduce their care load and plan in advance, the older person’s care plan.

As Sixsmith pointed out, there are some challenges to introduce technology to monitor the well-being of older people in real life. First, algorithms to recognise activities and predict human behaviour have been developed and tested in artificial environments that might not produce good results in older people's homes. Second, the introduction of this technology into industry and specifically involved the social services to use technology as a tool for preventive strategies of care. Third, the acceptability of the system involves issues such as people's attitudes toward technology and ethical aspects (privacy and information usage) (Sixsmith *et al.*, 2007).In addition, it is necessary to design appropriate, easy to use and friendly user interfaces; provide training; personalise technology according to the user's capabilities and skills; and make technology affordable for everyone.

## *2.5 Research questions*

The literature suggests that home-care technology might help to support the independence, quality of life and well-being of older and disabled people. It enables the carers to respond to a crisis and can help prevent problems arising in the first place by providing early indications of deterioration in an individual's well-being.

The principle of well-being monitoring is that human behaviour is habitual and any deviation can be detected from data analysis of longitudinal trends. By examining the deviation from the norm for an individual, a decision can then be made by carers about whether or not a change may be associated with improvement or deterioration in well-being.

Many researchers are already using different technologies to support older people living in their home. Most of these projects are focused on monitoring and recognising activities of daily living (ADL) such as taking a shower, bathing, toileting, etc; which might seem a bit intrusive from the ethical point of view.

This research is focused on observing and analysing changes in the level of activity 'busyness' rather than understanding what activity the person is doing. This approach may provide sufficient data to know the lifestyle and patterns of behaviour associated with well-being of the elderly without being intrusive. Presenting the lifestyle data in conjunction with health and contextual data about the older person through a personalised user interface might help to enhance the dialogue of care (communication) between the older person and the carer.

Given the previous exploration, this study aims to answer the following research questions:

**Question 1:**

Can data be collected and computed to extract phenomena in the data that might reflect changes in the well-being of an older person living independently?

In answering this question, lifestyle data is analysed using a number of computing tools to show the level of activity ‘busyness’ of an older person. In addition, health and contextual data is used to understand the meaning of the data. The results are presented in **Chapter Three**.

**Question 2:**

What is the best way to present the well-being data in a usable system reflecting the needs and interests of various stakeholders including the service user, informal and professional carers, technologists, researchers, and policy makers?

Based on an initial literature review, a domestic well-being indicator system (DWIS) was designed, built and it was then evaluated iteratively with users. This question is investigated in **Chapter Four**.

**Question 3:**

Can a well-being indicator system be used as a tool to enhance a conversation between the older person and the carer? If so

- Would a personalised user interface that provides lifestyle, health and contextual data be useful?

- Would data presented in the form of graphs and textual data help to communicate changes related to the well-being of an older person?
- Would the well-being data be useful to help the carers to detect a change in the life of the older person?

This is dealt with in **Chapter Five**, which focuses on evaluating the value of presenting lifestyle, health and contextual data in the dialogue of care between the older person and the carer. The results and findings are discussed in **Chapter Six**.

# 3 EXPLORING HOME BUSYNESS DATA

## 3.1 Introduction

The overall purpose of this chapter is to discuss the enhancement of home-care technology by revealing individual patterns in the life of a person, through analysing the level of activity ‘busyness’ in their dwelling, so that care can be better tailored to their needs and changing circumstances.

This chapter aims to answer the following question:

Can data be collected and computed to extract phenomena in the data that might reflect changes in the well-being of an older person living independently?

Technology might enable carers to improve the care and support, to respond a crisis and help prevent problems by providing early indications of deterioration in an individual’s well-being. One possible solution is to build a model of people’s lives that learns and reveals the individual’s pattern of ‘busyness’ (level of activity), then it uses this data to inform the dialogue of care between home residents and carers.

The measuring of activity, presence in locations and interaction with objects might provide information to assist understanding of patterns in people’s behaviour. If there are regular patterns in the life of a person, changes to such patterns could suggest a change that should be followed up through a dialogue between a carer and that person – the dialogue of care. However, without additional contextual data, it is not possible to know what the reason is for being busy, what it is, or why a person is behaving in a certain way.

Busyness data might provide changes in patterns such as sleeping and mobility; however, these changes do not tell exactly how these changes affect the quality of life of the older person, so contextual data can explain the meaning of these changes. Hence, a new approach to interpret sensor data is needed, the dialogue of care between the older person and their carers. This is the process of interpreting changes in patterns to understand how they affect the quality of life and well-being of the older person.

The incentive for this work is to provide domestic residents and carers, but particularly formal and informal carers, with data, so that they can have a discussion about changes in patterns, towards the provision of better care and improving the confidence of the older person to continue living independent at home.

As presented in chapter one, many research studies have been undertaken in laboratory environments where people are invited to live for a period of time. In contrast, this research used sensor data collected from real home environments. There is evidence that people behave differently when they live in an unfamiliar environment in comparison with when they live in their home (Evans Nina *et al.*, 2007). Nor do the data sets gathered from very controlled environments really reflect the data gathered in an environment where researchers have much more restricted access as is the case of an individual living in their own home. Therefore, the data collected from these trials could be useful to train and test algorithms, but it would probably not be so useful to understand the lifestyle of an older person.

In addition, this research study is different from the studies cited in chapter one because it is based in the concept of busyness (level of activity at different periods of time and location) within the dwelling where the older person is living alone. Another significant difference is the way the data is interpreting through the dialogue between an older person and a carer.

Analysing changes in busyness might provide some indications of how the older person is doing. The use of some data mining techniques and on-line analytical processing (OLAP) tools are potentially useful in this context because of the possibility of exploring and detecting changes in the level of activity of people that may reflect changes in well-being. An investigation is presented here into the use of some computing techniques to analyse lifestyle and health data from a trial project, run in a domestic context.

Despite the nature of the data, changes can be detected that may reflect changes in a person's well-being. Exploring changes in the level of activity 'busyness' of an older person might help to detect changes related to a person's behaviour. However, merely analysing lifestyle data collected from sensors is not enough to construct a real picture of a person's life. It is necessary to match lifestyle data with contextual data such as changes in medication, holidays, hospitalisation, anniversaries, and health data (blood pressure, blood sugar and pulse) in order to extract the meaning of the data and make an interpretation.

## *3.2 Data analysis techniques*

There are various data analysis techniques that might help one to understand the meaning of the data. The following techniques were explored:

- **Data storage:** Sensors could generate potentially enormous volumes of data. Therefore, data needed to be organised into databases, data warehouses, and OLAP cubes to explore this large amount of data in a meaningful way.
- **Data segmentation:** Older people normally have routines that happen at specific periods of time during a day. For example, in the morning a person may usually get up, go to the bathroom, brush his/her teeth and have a cup of tea. When lifestyle data is segmented by time zones, the level of activity can be examined by matching contextual data (events) with lifestyle data.
- **Data visualisation:** The data could be explored through graphs and other visual representation. A technique that might be useful for this is on-line analytical processing (OLAP) because it could provide richer data to various stakeholders

(cared for, informal and professional carers), and it could also visualise the data at different levels of granularity.

- **Phenomena discovery:** The data could have phenomena or patterns that might not have been explicitly revealed using OLAP. The application of some simple data mining techniques might help to extract patterns or reveal artefacts in the data.
- **Data contextualisation and exploration:** The lifestyle data shows only sensor firing not the human behaviour. The contextual data about the older person could help one to know what the data means and the cause of phenomena in the data. For example, hospitalisation, holidays, medication changes, and high blood sugar levels. Therefore, the lifestyle data could be analysed along with health and contextual data because this data could make it easier to understand the life of a person rather than relying only on the data collected from sensors.

### 3.2.1 Data storage

Large volumes of data could be generated by a lifestyle monitoring system. High performance retrieval of data and efficient data storage techniques are essential to organise, understand, analyse and make strategic decisions. Data can be organised into a variety of database structures such as relational databases, dimensional databases, and data warehouse.

A relational database is a collection of data items organized as tables from which data can be accessed on-line in many different ways without having to reorganize the database tables. Relational databases are based on entity-relationship (E/R) modelling. The basic elements of E/R modelling are entities, attributes and relationships. Entities are equivalent to tables, attributes to columns and relationships to rules of referential integrity in the relational database (Date, 2004).

The dimensional model is an alternative to entity-relationship (E/R) modelling. It appeared because of the many problems generated using the E/R model when companies had to work with huge volumes of data and very complex entity-relationship diagrams (Kimball, Reeves, Ross, and Thornthwaite, 1998).

The main components of a dimensional model are fact tables and dimension tables. The fact table is the primary table in each dimensional model that contains measures of the cube. Dimensional modelling has been applied to many different business areas, including retail, banking, insurance brokerage, customer analysis, telecommunications, oil company fuel sales, government spending, manufacturing shipments, and healthcare. However, there is no evidence of using dimensional databases to explore and analyse lifestyle data.

A data warehouse is a set of data in an enterprise that contains historical data, organised in a dimensional model. The data warehouse can be updated on a controlled load basis as data is corrected (Kimball *et al.*, 1998). One of the most important aspects of the data warehouse is the capability to track behaviour over time. For example, how frequently the resident visits the kitchen during the evening.

### 3.2.2 Data segmentation

Data segmentation is the process of splitting the data into an unknown number of segments that have similar features, so they are considered to be homogeneous. Automated data segmentation can be done by using unsupervised learning data mining algorithms to discover homogeneous groups in the data.

Data segmentation has been widely used in other research domains such as audio recording, video and computer vision (Zhang, Jay, and Kuo, 1999). However, there is no evidence of using automated data segmentation using telecare data.

Splitting the lifestyle data by zones (periods) of time might help to identify phenomena in the data that might not be identified when the data is presented by hours. Visual representations of the daily lifestyle data were plotted to observe and define the data segments by looking at the graphs. Although this was a time-consuming task, it was a very useful strategy.

### 3.2.3 Data visualisation

On-Line Analytical Processing (OLAP) is the activity of querying and presenting historical data from data warehouses for analysis-based decision support. OLAP engines were developed primarily to support fast and complex querying of dimensional structures. An OLAP cube allows the exploration and manipulation of large volumes of historical data (Seidman, 2001), provides facilities for summarisation and aggregation and stores and manages information at different levels of granularity. OLAP presents data from data warehouse systems without concern as to how or where the data is stored.

When OLAP technology appeared, it was a market-oriented system, and it was usually used for data analysis by business users including managers, executives, and analysts. OLAP technology has been widely explored in various business areas such as retail, marketing, and sales. However, OLAP has rarely been used to model, explore and analyse lifestyle data collected from sensors.

### 3.2.4 Phenomena discovery

Discovering unexpected and useful patterns and rules in large quantities of data could be done by using some simple data mining techniques. Data mining is based on the application of statistical methods, data classification, clustering, association and the combination of different techniques to generate interesting data for end-users (Witten and Frank, 2005).

There are some data mining techniques according to the type of task that the data miner is attempting to carry out as in table 3-1. The choice of a particular combination of data mining techniques depends on the nature of the task, the data available and the skills and preferences of the data miner (Berry and Linoff, 2004).

| Task / Technique | Classification | Estimation | Prediction | Affinity grouping or association rules | Clustering | Description and profiling |
|---|---|---|---|---|---|---|
| Decision trees | X | X | X | | | X |
| Nearest neighbour: memory based reasoning | X | X | | | | |
| Neural networks | X | X | X | | X | |
| Regression models | | X | X | | | |
| Association rules | | | X | X | | X |
| Automatic cluster detection | | | | | X | X |

**Table 3-1: Data mining techniques**

For further description of data mining techniques see appendix A.

Of this group decision trees, clustering and regression models were chosen because these techniques let the researcher classify and estimate the lifestyle data more easily.

### 3.2.5 Data contextualisation and exploration

Colleagues were involved in the EQUAL (Supporting independence: New products, new practices, new communities) project that aimed to evaluate the feasibility of using various sensors to record lifestyle patterns of older people, and to understand the role of technology in home-based care (Amaral, Hine, Arnott, and Barlow, 2008).

As part of the aforementioned, a pilot study of six flats at a residential care home was conducted for 9 months. Each dwelling was installed with a set of sensors: Passive infrared sensors (PIRs), pressure sensors, door contacts and electrical sensors to measure the activity of the resident based on known interests and habits, following discussion with each of the residents. Data recorded from these sensors, health data collected by carers and contextual events from the lives of the residents was also recorded during the study. This research took into account the data that came from the EQUAL project. The two case studies presented in this study were contextualised with events in participants' life. The contextual and sensor data were collected by researchers involved in the EQUAL project.

#### 3.2.5.1 Resident J: change of medication

The resident had some changes in medication that were accompanied by observed changes in busyness. The participant was suffering from non-insulin-dependent diabetes. For some time, the participant's blood sugar levels were consistently outside the desired range. As a result, her doctor made a decision to change the medication in week nine. Unfortunately, this change of medication did not bring expected positive results and the participant's blood sugar level remained high. Therefore, in week sixteen the doctor decided to change the medication for the second time.

#### 3.2.5.2 Resident E: hospitalisation

Participant E had a long history of heart problems, and she was hospitalised in the period from week nine (Friday) until week eleven (Friday) due to a very high blood pressure. After the hospitalisation period until week fifteen, the participant did not feel very well. She had a visit from hospital, had to ask for meal delivery, and received emotional support.

## *3.3 Applying data analysis to lifestyle data*

In order to explore different data analysis techniques, an appropriate data set was sought. The lifestyle data collected from two participants involved in the EQUAL project was analysed in conjunction with health and contextual data.

### 3.3.1 Data storage

Data from sensors (lifestyle data) was gathered continuously into a local database and consisted of the following attributes: Timestamp (when the sensor was firing), sensor ID and the state of the sensor (ON/OFF). In addition, health data such as blood pressure, blood sugar and pulse was collected by the formal carers and then, this data was included in the database. This data was then organised into a relational database that had the following structure (see figure 3-1):

- Lifestyle: Contains the lifestyle data collected from sensors (mobility, eating & drinking, sleeping, and personal hygiene).
- Wellbeing: Contains a list of well-being indicators.
- Health: Contains the health data (blood pressure, blood sugar and pulse).
- Client: Contains a list of residents (A, E, H, J)
- Location_sensor: Contains a list of rooms (bedroom, bathroom, hall, kitchen and living room).
- Spe_Location: Contains a list of objects to which the sensors were attached (bed, chair, fridge, lamp, etc).
- Sensor: Contains a list of sensors (PIR, pressure, door contact, and electrical sensors).

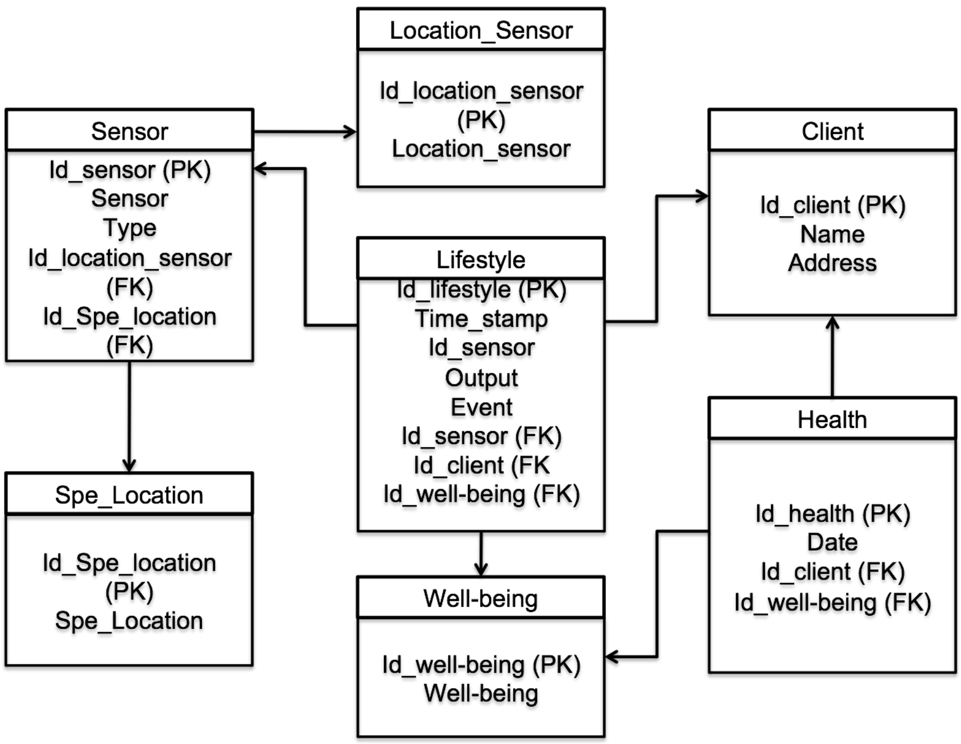



**Figure 3-1: Relational database model**

### 3.3.2 Data segmentation

After exploring the data from different flats for several months, the lifestyle data was segmented by time zones. Each time zone was labelled as sleeping, early morning, late morning, lunch, afternoon, evening and late evening as shown in table 3-2 and 3-3. This segmentation was different for each person because each person has his /her own routines.

| **Zone** | **Hour** |
|---|---|
| Sleeping | 00:00 – 7:00 a.m. |
| Early morning | 7:00 – 9 a.m. |
| Late morning | 9:00 – 12:00 p.m. |
| Lunch | 12:00 -4:30 p.m. |
| Afternoon | 4:30 – 7:00 p.m. |
| Evening | 7:00 – 10:30 p.m. |
| Late evening | 10:30 – 12:00 midnight |

**Table 3-2: Segmentation of time into zones for flat J**

| **Zone** | **Hour** |
|---|---|
| Sleeping | 00:00 – 5:00 a.m. |
| Early morning | 5:00 – 10:00 a.m. |
| Late morning | 10:00 – 12:00 p.m. |
| Lunch | 12:00 - 1:30 p.m. |
| Early afternoon | 1:30 – 3:00 p.m. |
| Late Afternoon | 2:30 – 7:15 p.m. |
| Evening | 7:15 – 11:00 p.m. |
| Late evening | 11 – 12:00 midnight |

**Table 3-3: Segmentation of time into zones for flat E**

Lifestyle data segmentation was done by other characteristics like areas of well-being such as mobility, eating and drinking, sleeping and personal hygiene because these views of the lifestyle data in conjunction with health and contextual data could be related to areas of people's well-being (see table 3-4).

| Area of people's well-being | Sensor |
| --- | --- |
| Mobility | All PIR (passive infrared sensors) |
| Eating and drinking | Sensors installed in appliances and furniture in the kitchen and living room e.g. microwave, kettle, fridge, and chair |
| Sleeping | Bed and chair pressure sensor |
| Personal hygiene | Sensors in the bathroom |

**Table 3-4: Segmentation of sensors into areas of well-being**

### 3.3.3 Data visualisation

OLAP technology was used as the data modelling technique to visualise the data and look for phenomena. It was employed to explore the level of activity within the dwelling for each occupant who lived alone (four out of six flats) because a data cube makes it possible to visualise the data at different levels of granularity (general or detail). Both lifestyle and health data were organised into a data warehouse to build a data cube (Hine *et al.*, 2005a). Multidimensional OLAP (MOLAP) architecture was used to build the data cubes. For further OLAP background see appendix A. The lifestyle data cube shown in figure 3-2 has a factless[1] fact table that counts the number of sensor firings at different locations and periods of time by client. It also has three dimensions as follows:

- **Time:** One record in this dimension is every time a sensor fires. The time dimension is a view of the table lifestyle that splits the attribute timestamp into useful time attributes such as year, month, week, weekday, hour, minute, day of year, zone, time zone (sleeping, early morning, later morning, lunch, afternoon, evening and late evening) and date (derivated attribute, example: Wednesday 18

[1] Factless fact tables are the preferred methods for recording events in a data warehouse where there is no natural numeric measurements associated with the event

February 2009). This dimension has various hierarchies. For example, the data can be aggregated by year, month, date, hour, and minute. It can also be aggregated by year, week and date.

- **Client:** One record in this dimension for each client (A, E, H, J).
- **Location:** One record in this dimension for each sensor. This dimension has its own location grain (bathroom, bedroom, kitchen, hall and living room) and specific location (chair, bed, door).

Using the data segmentation by time zones, the OLAP cube could visualise data at different levels of granularity (detail), and it could answer questions such as:

- What is the busyness in a specific room during a specific time zone given a period of time?
    - Show the busyness in the bathroom during the evening time period during the last week.
    - Show the busyness in the bedroom during the sleeping time period during the current month.
    - Show the busyness in the kitchen during the morning time period for the last ten weeks.
    - Show the busyness in the living room during the lunch time period for today.

Show the busyness in the hall during the afternoon time period for yesterday. Similarly, using the data segmentation by areas of well-being (mobility, eating and drinking, sleeping and personal hygiene), the OLAP cube could answer questions such as:

- What is the pattern of a specific area of well-being given a period of time?
    - Show the mobility pattern during the past three months.
    - Show the eating and drinking pattern for the last ten weeks.

- Show the personal hygiene pattern for yesterday.
- Show the sleeping pattern for today.

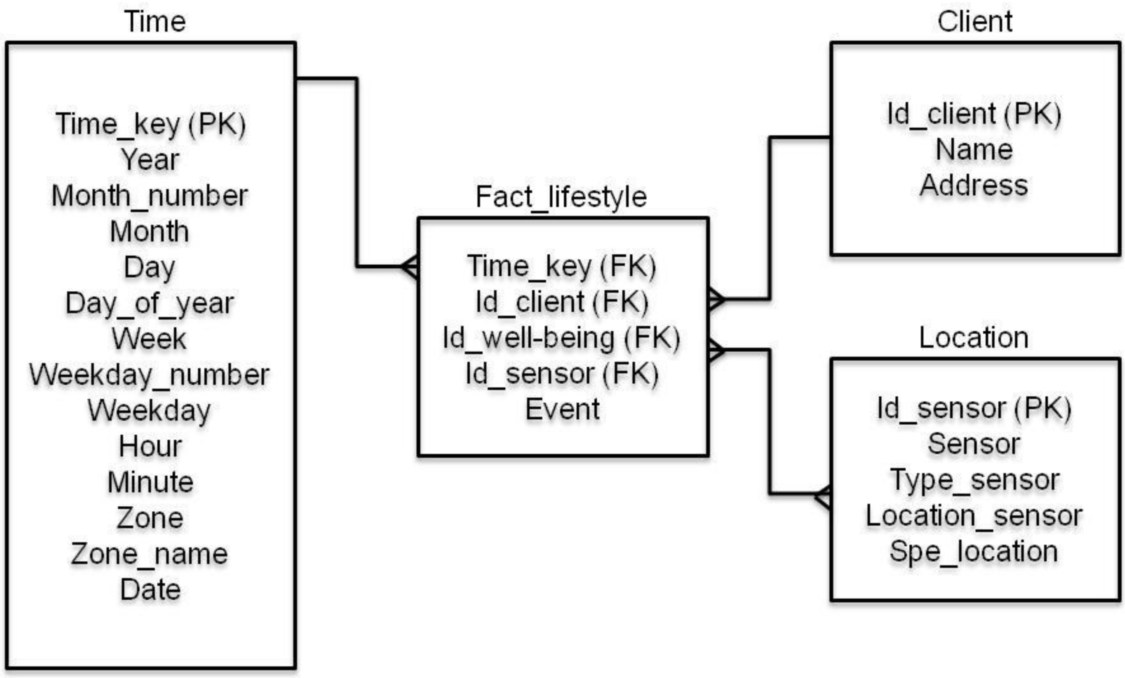



**Figure 3-2: Lifestyle data cube**

In addition, the data cube could answer more general questions or make comparisons like:

- Which rooms were the busiest?
- Which sensors were the most lightly used?
- Which clients were the most active during the sleeping time period?
- What is the trend pattern of a specific area of well-being?
- Compare the busyness in the kitchen by days from clients A, E and H.

The health data cube (figure 3-3) has a fact table that measures the average of blood sugar, blood pressure and pulse of the clients at different periods of time. This cube has three dimensions:

- **Client:** One record in this dimension for each client (A, E, H, J).

- **Well-being:** One record in this dimension for each health indicator (blood sugar, blood pressure and pulse).
- **Time:** One record in this dimension every time a health indicator was collected. The time dimension is a view of the table health that splits the attribute date into useful time attributes such as year, month, week, weekday, day of year and date.

This data cube could answer questions like:

- What is the pattern of a specific health indicator given a period of time?
  - Show the blood sugar / blood pressure / pulse pattern by months, weeks, and days from client A.

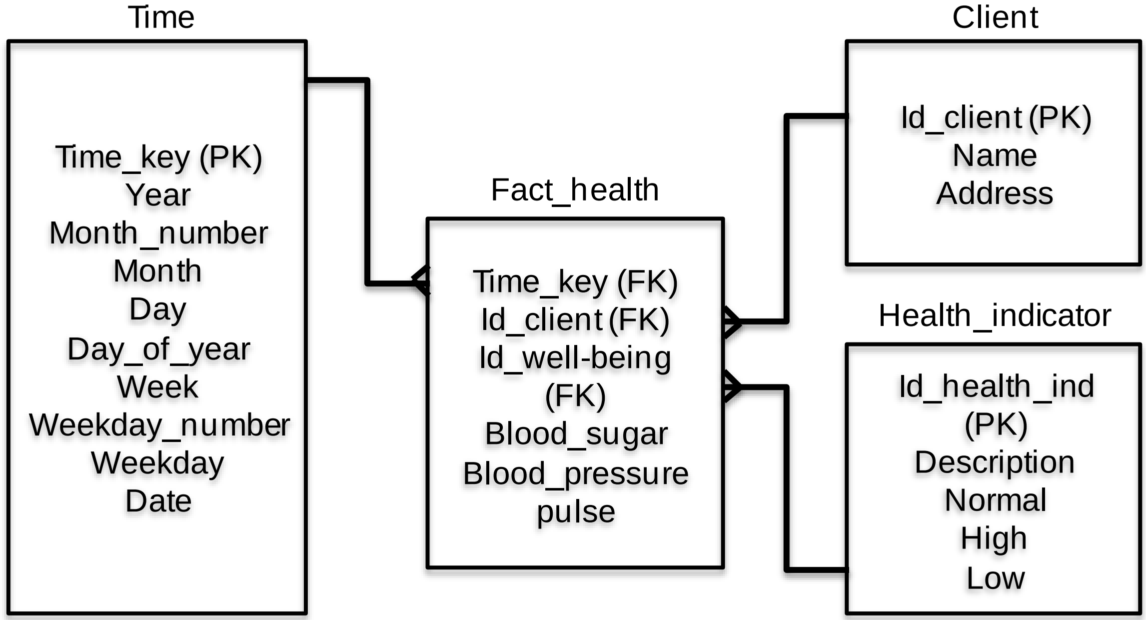



**Figure 3-3: Health data cube**

It might seem that the two cubes could be joined into a single one by having two fact tables: One for the lifestyle data and one for the health data. However, it was not possible because the grain of the data was not consistent. The lifestyle data was collected automatically every time any sensor fires while the health data was collected manually on a weekly basis. It can be sorted out by having two fact tables and two time dimensions. In that case, the data cube could show issues like:

- Show the mobility pattern when the blood sugar is high from client A.
- Show the busyness in the bathroom when the blood sugar is high from client E.

After analysing the data using OLAP techniques, the researcher found some interesting phenomena that could be further analysed with some data mining techniques.

### 3.3.4 Phenomena discovery

With OLAP techniques, it is not always possible to detect deviation by looking at the graphs; build a model based on important characteristics of the data; or discover associations or affinities between some attributes. For example, when the busyness data shows high activity of a person in the bedroom and moderate activity in the living room, in 85% of the cases the person is about to go to sleep. Therefore, it is necessary to use some data mining techniques to train the computer to reveal hidden phenomena.

Weka data mining tool (Waikato, 2006) and SPSS (SPSS-15, 2006) were employed to train and test various data sets to see if it was possible to compute change in real lifestyle data. Some supervised learning techniques such as decision trees, clusters, and regression analysis were used to extract phenomena in the data because it could reveal issues that could not have been easily visualised in OLAP. These techniques might help to inform the dialogue of care and to alert domestic residents and carers when changes break the regular pattern.

Supervised learning algorithms have been used by various researchers to learn the behaviour of people. For instance, The Massachusetts Institute of Technology used decision trees C 4.5 algorithm to recognize activities such as walking, running, climbing stairs, sitting, lying down, working of a computer, bicycling and vacuuming within a controlled environment. They reported that the accuracy of the classification algorithms  rates between 80% and 95% (Intille *et al.*, 2004). NTT DoCoMo multimedia laboratory also used decision trees algorithm to train a model with a data set collected from sensors and RFID tagged object installed into a Lab (Isoda *et al.*, 2004). The results reported by these studies were quite accurate and reliable; however, there were no results using these algorithms with data collected from older adults living in a natural environment.

The data mining process undertaken in this study consisted of the following steps:

- **Data selection:** Lifestyle data that showed a normal pattern of busyness was used in the classification algorithms. The data was split into training (66.66%) and testing (33.33%) data sets, using 8 weeks (17-24) and 4 weeks (5-8) respectively as suggested by Han and Kamber (Han and Kamber, 2001).

  Table 3-5 displays the location attributes: Bathroom, bed, hall, kitchen and living room (considered as inputs) and the attribute time_zone (output). An individual row is an instance of data. For example, the second row shows the sensor firings in the bathroom=2, bed=20, hall=3, kitchen=1 and living room=1. This level of activity corresponds to a single day in week 23.

| **Location** | | | | | **Time_zone** |
|---|---|---|---|---|---|
| **Bathroom** | **Bedroom** | **Hall** | **Kitchen** | **Living_room** | |
| 2 | 20 | 3 | 1 | 1 | Sleeping |
| 3 | 11 | 4 | 4 | 12 | Early_morning |
| 6 | 9 | 9 | 1 | 38 | Late_morning |
| 1 | 0 | 2 | 1 | 6 | Lunch |
| 2 | 7 | 3 | 6 | 33 | Afternoon |
| 1 | 6 | 2 | 4 | 47 | Evening |
| 1 | 9 | 2 | 0 | 0 | Late_evening |

**Table 3-5: Example of training data aggregated by day for Flat J**

- **Algorithm selection:** Weka (Waikato, 2006) software was employed to train and test the data model because it offers several algorithms to classify and predict data such as C4.5 (pruned and unpruned trees), CART (classification and regression trees) and NBtree (Naïve Bayesian trees) among others. A statistical software (SPSS-15, 2006) was also employed to train and test the data using decision trees

CHAID (CHI Squared Automatic Interaction Detection) and clusters (K-mean and two-step cluster).

After running the various decision trees algorithms (C 4.5, CART, NBtree and CHAID) with different sets of data, the pruned C4.5 decision tree algorithm was selected because it produced the most accurate rules (see appendix B for further detail).

- **Data training and testing:** Various data sets were trained and tested several times until the results produced an understandable and simple set of rules. In addition, the set of rules was selected by choosing the model with the highest accuracy percentage on the training and testing data, and with the lowest error rate.

### 3.3.5 Data contextualisation and exploration

Charts representing daily sensor firings segmented by time zones, from week 5 to week 24 inclusive, were visually explored (see figure 3-4). Health data was also explored using simple graphs (see figure 3-8 and 3-11). Moreover, contextual data describing the dates of various events in the participant's life, such as changes in medication and hospitalisation were analysed.

The lifestyle and health data was analysed using a polynomial trend line and was then employed to reveal the underlying trends of changes in busyness in the life of the person. Over time, the trend lines showed change, and how great the change had been (see figures 3-5 to 3-11).

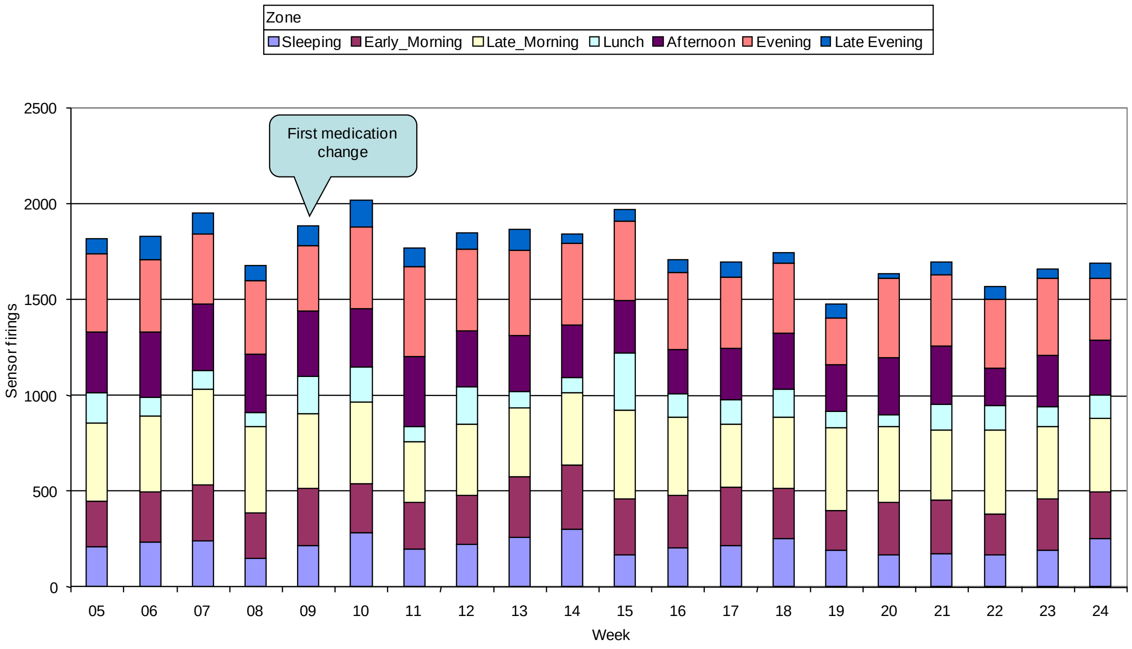



**Figure 3-4: Sample of lifestyle data by time zone during 20 weeks**

## *3.4 Results*

The results reported in this chapter were based on data from sensors installed in two of the six flats, whose residents live alone in sheltered accommodation. In addition, there was health data such as blood sugar, blood pressure and pulse collected by carers. The examples illustrated bellow showed the detection of change in the life of an older person.

### 3.4.1 OLAP results

Resident J

The lifestyle data presented in figures 3-5 to 3-7, showed some changes in busyness in the evening time periods, around the time when changes in medication were also happening (week 9 and 16).

There was a slight increase in firings on the lamp in the living room in the period between weeks 14 and 17 in relation to the preceding and following periods (see figure 3-5). It was known this lamp was used while doing crosswords and Sudoku in the evenings. This increase probably reflects a change in this entertainment activity. Next, there was a slight increase in ‘busyness’ in the kitchen between weeks 14 and 16 in comparison with the period before (weeks 10-13). After week 16, the trend line decreased as shown in figure 3-6. Additionally, there was a fluctuation in data during the observed period in the hall (week 9 -16). The hall is a transit space, reflecting movement from one part of the flat to another (see figure 3-7).

When the data from the bathroom PIR and bed pressure sensors were analysed, the data did not coincide with the phenomena discovered from the other sensors (lamp and kitchen ‘busyness’). Going back to the notes taken by researchers from the EQUAL project, it was found that those sensors were on maintenance on Monday of week 15. Figure 3-8 illustrated the sensor firing activity in the bathroom before the maintenance. It was clear that after the maintenance, the sensor activity decreased considerably. This highlighted a problem with sensor reliability. Fortunately, data from others sensor provided evidence to discover phenomena in the data related to the change of medication event.

The blood sugar levels also fluctuated. According to figure 3-9, the blood sugar level was high during week 6-8, 11 and 13. After the second change in medication, the blood sugar was more stable.

Resident E

The hospitalisation period of participant E, lasting from week 9 (Saturday) until week 11 (Thursday), was clearly visible on all graphs representing an output from the sensors installed in the flat. In fact, figures 3-10 and 3-11 showed a gap in the sensors’ data. There were some changes in busyness in the daily data collected from bed and chair sensor.

There was a decrease in the bed sensor readings after hospitalisation in comparison with the preceding period (see figure 3-10). In contrast to the bed sensor, the chair sensor indicated an increase in the total number of firings after hospitalisation suggesting that the participant tended to use her chair more often than before. The fact that the person received visitor from health and social services was also reflected in the increase in sensor firings between weeks 11 and 15 (see figure 3-11).

According to figure 3-12, the blood pressure level was high leading to the hospitalisation event (week 5 – 9). After the hospitalisation period, the blood pressure remained stable.

All these results revealed interesting fluctuations in the lifestyle data that may or may not be important; taken together; they showed changes in busyness in the household. The cause of any change is usually a matter of interpretation, but the evidence of change can be made available for discussion between the resident and the carer. Hence, helping to stimulate and inform the dialogue of care among them is of paramount importance.

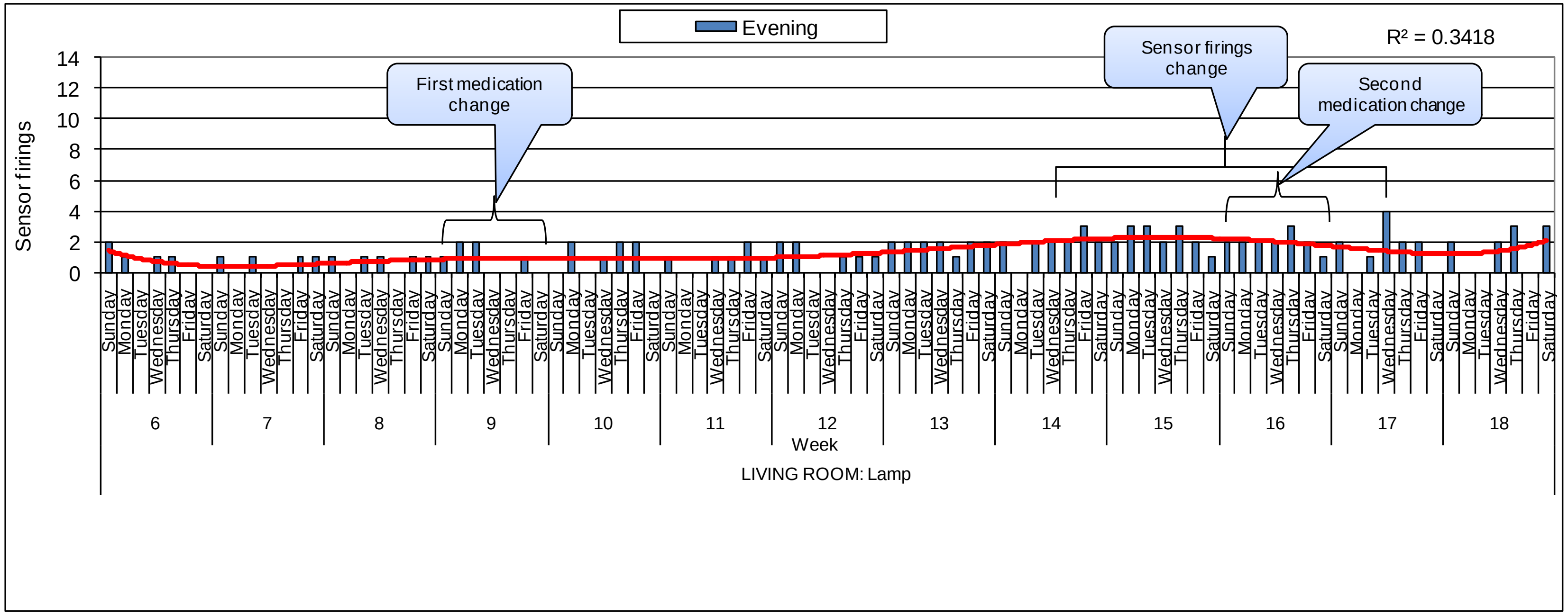



**Figure 3-5: Living room lamp (electric sensor) busyness during the evening time period resident J**

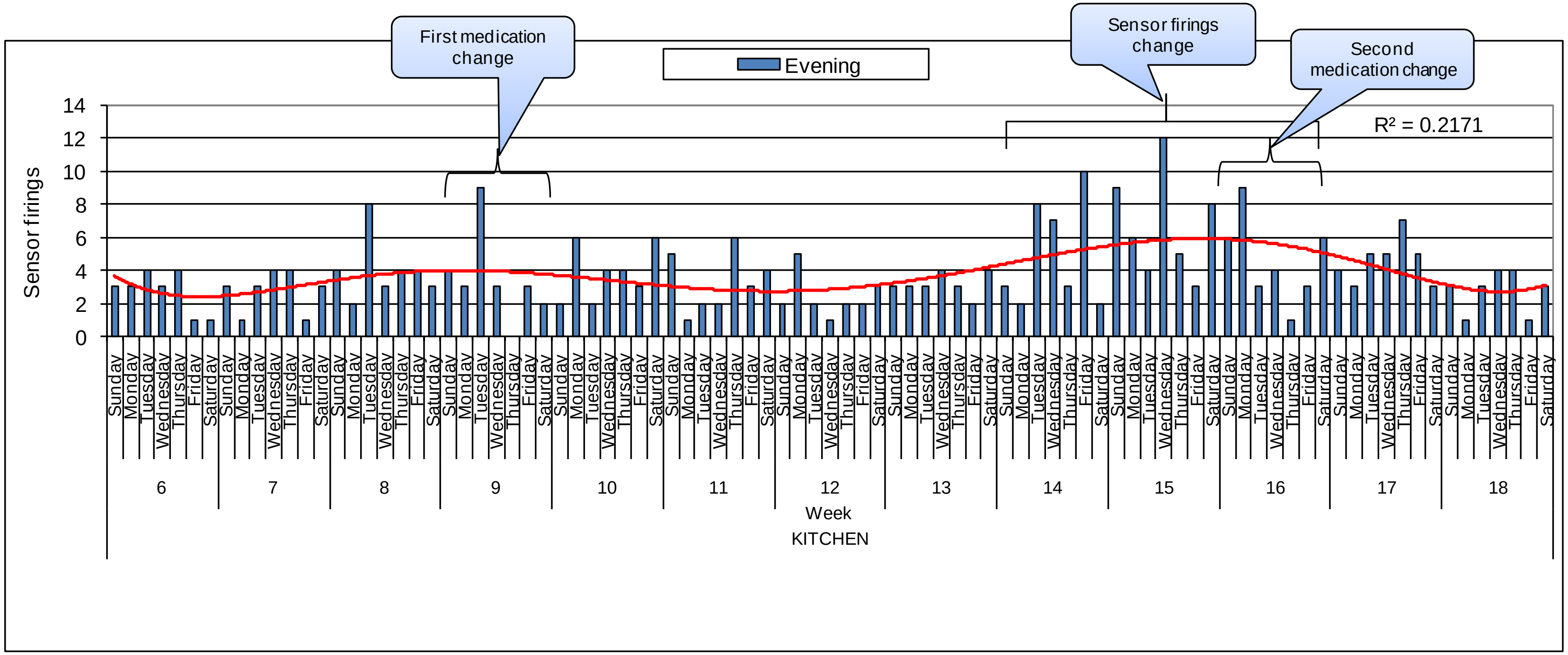



**Figure 3-6: Kitchen busyness during the evening time period resident J**

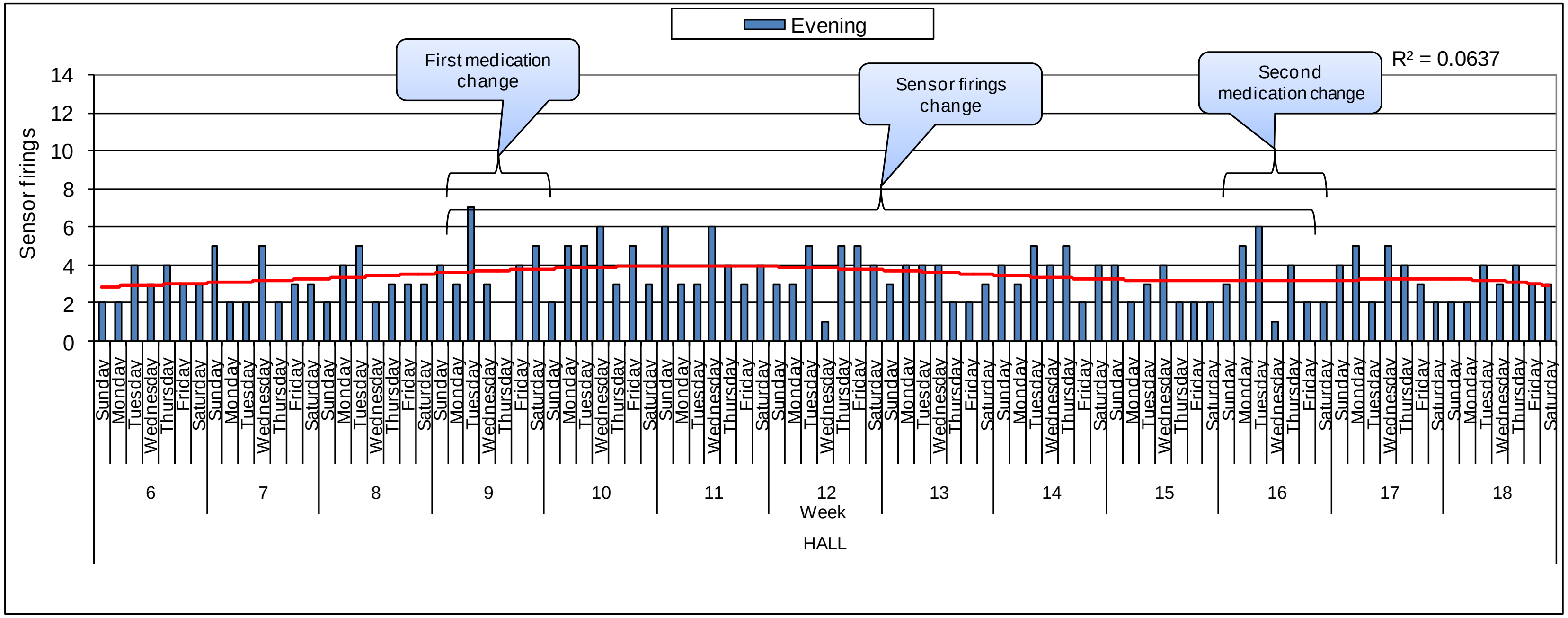



**Figure 3-7: Hall busyness during the evening time period resident J**

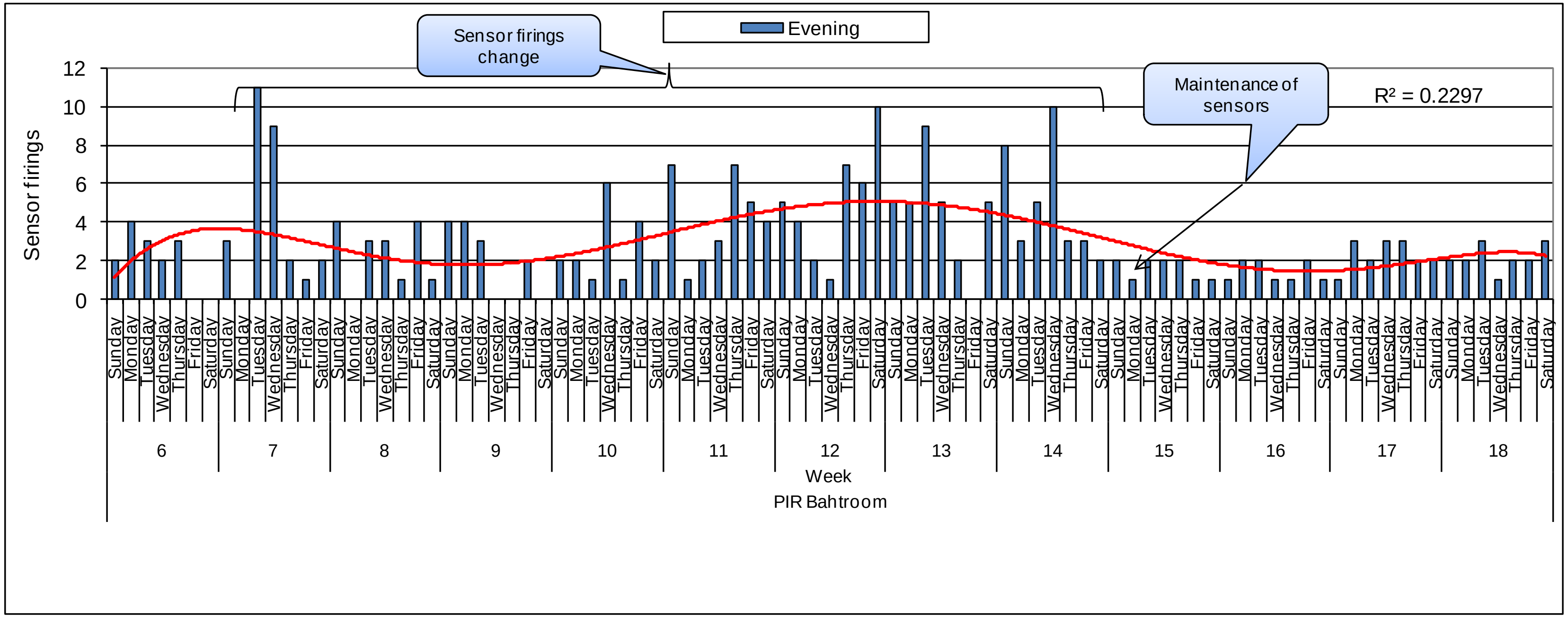



**Figure 3-8: Bathroom busyness during the evening time period resident J**

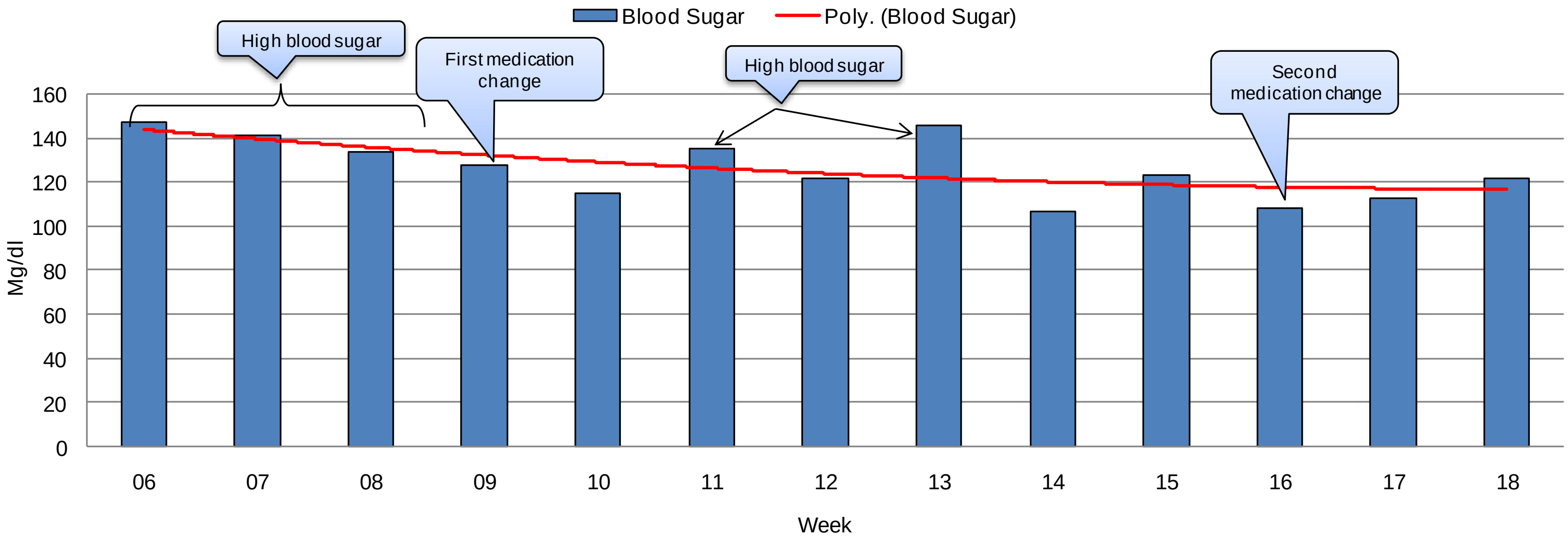



**Figure 3-9: Sample of blood sugar data during 13 weeks resident J**

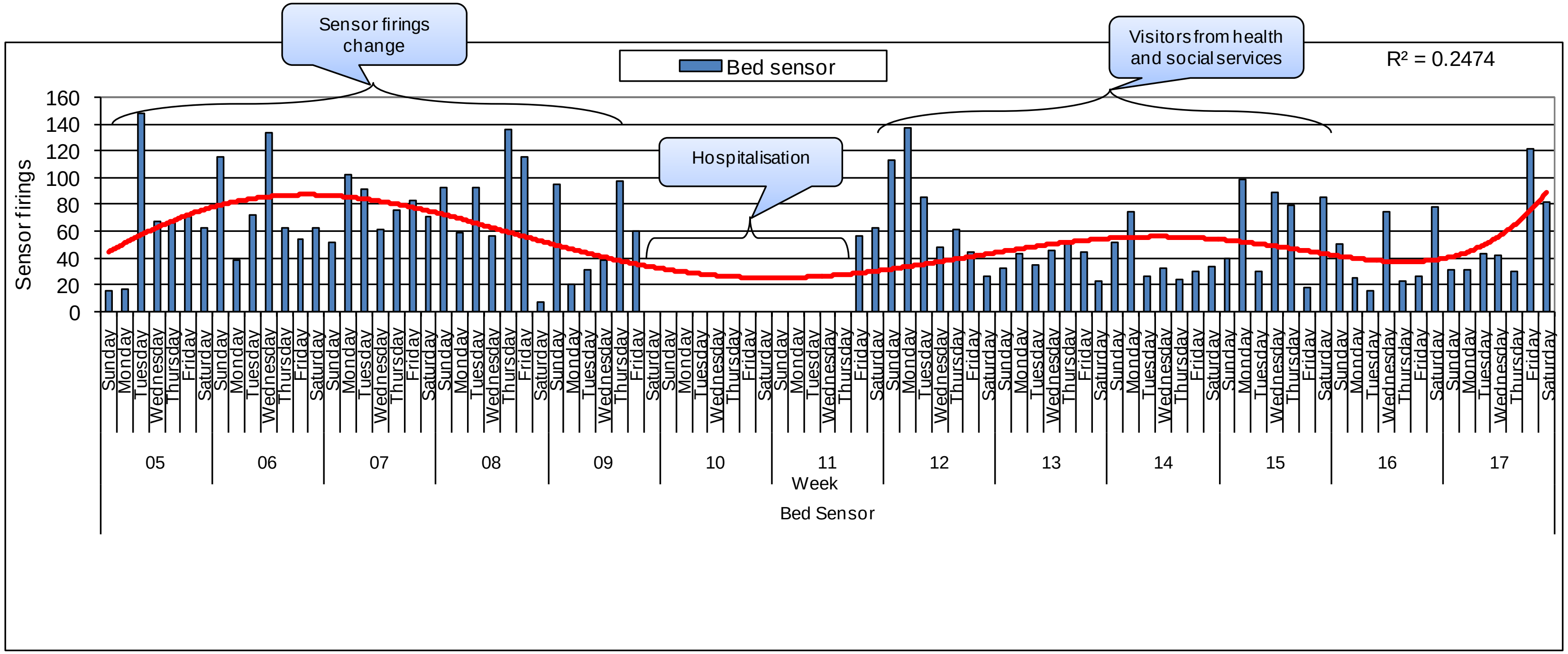



**Figure 3-10: Daily bed occupancy resident E**

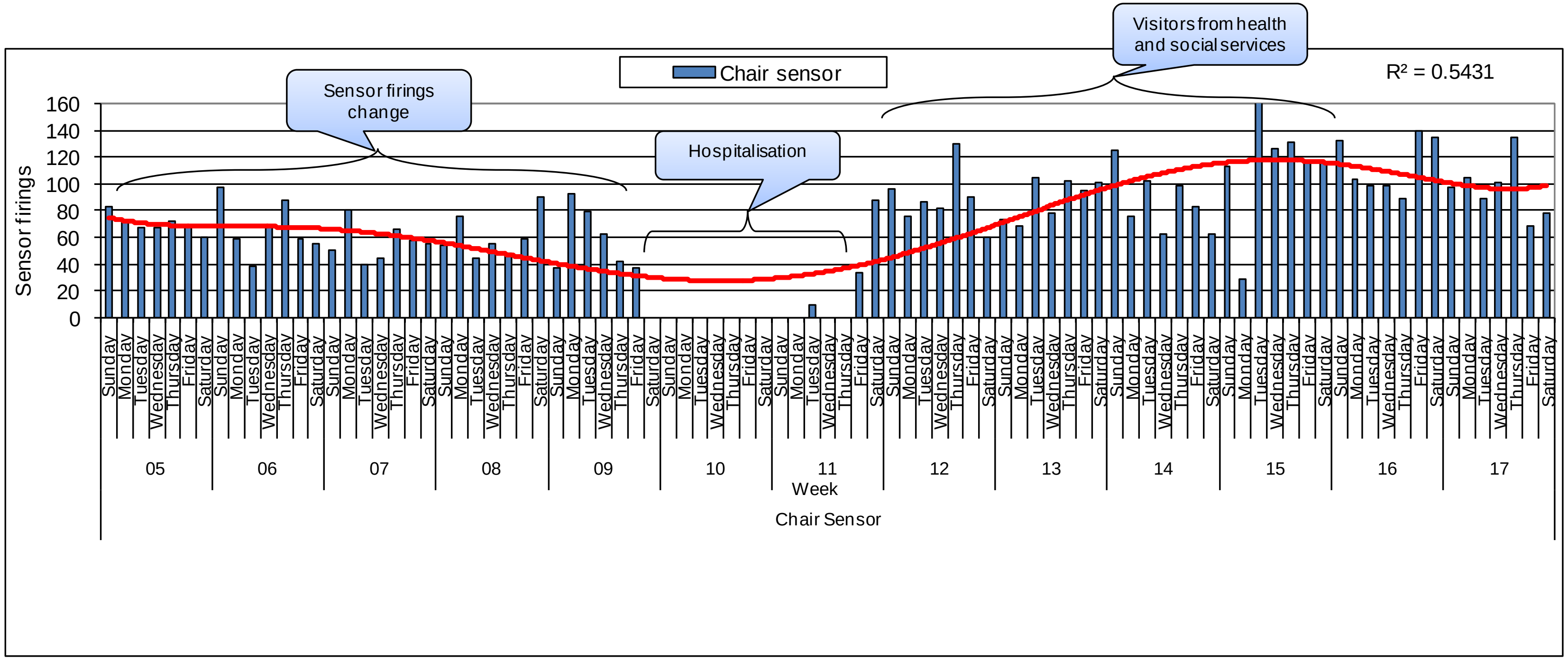



**Figure 3-11: Daily chair occupancy resident E**

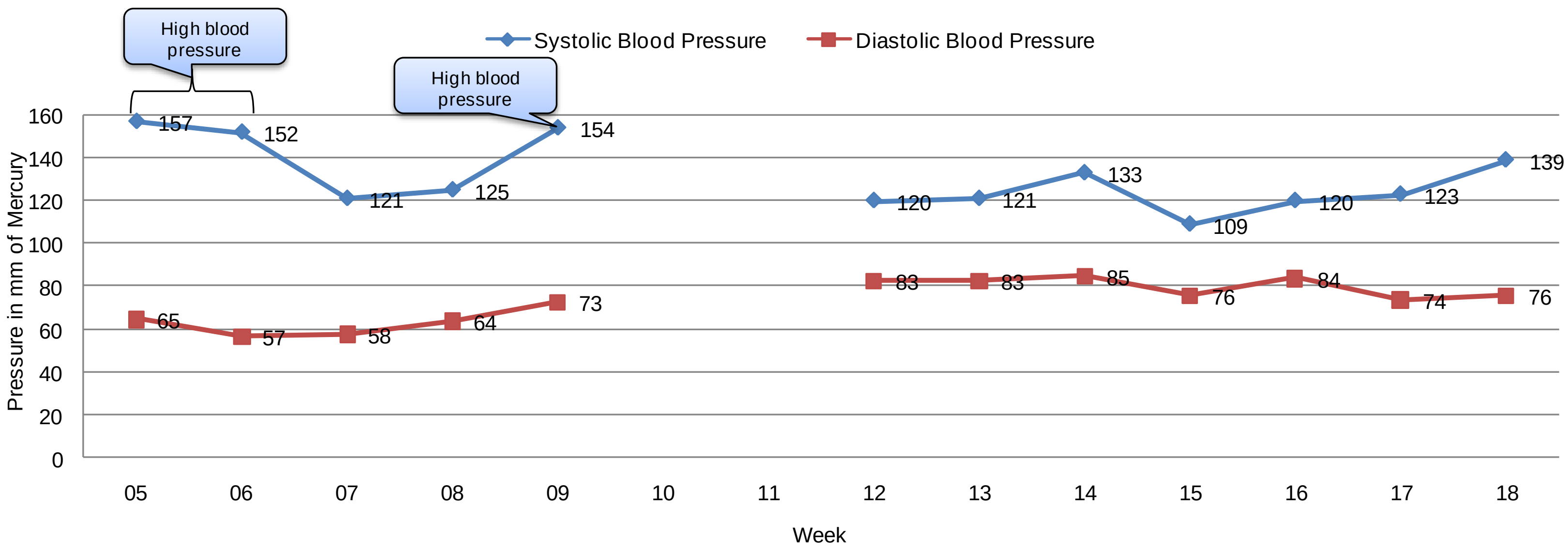



**Figure 3-12: Sample of blood pressure data resident E**

## 3.4.2 Data mining results

After using the decision tree algorithms to produce a set of rules from the lifestyle data, those representing unambiguous events were selected.

Resident J

The most important rules are shown in table 3-6:

| id | Rule (volume of sensor firings) | Output | Total instances | Correctly classified | Incorrectly Classified |
|---|---|---|---|---|---|
| 1 * | Living <=0 AND Bed[1-8] | Late Evening | 33 | 32 | 1 |
| 2 ** | Living[1-10] AND Bed <=4 AND Kitchen <=4 | Lunch | 37 | 33 | 4 |
| 3 * | Living <=10 AND Bed >12 | Sleeping | 48 | 45 | 3 |
| 4 | Living >10 AND Hall <=6 AND Bed <=1 AND Kitchen >1 | Afternoon | 42 | 38 | 4 |
| 5 | Living[11-22] AND Hall <=6 AND Bed[2-14] AND Kitchen >5 | Early Morning | 26 | 24 | 2 |
| 6 ** | Living >29 AND Hall <=6 AND Bath <=3 AND Bed >7 | Evening | 20 | 20 | 0 |
| 7 | Living >10 AND Hall >6 AND Bath >3 AND Kitchen <=6 | Late Morning | 37 | 34 | 3 |
| .. | ……………. | …. | … | .. | … |
| | Total number of instances | | 380 | 330 | 50 |

**Table 3-6: Most important rules generated using C 4.5 algorithm for resident J**

Rules 1 and 3 (*) confirmed that during the late evening and sleeping time period this participant was more likely to be in the bedroom than in the living room as would be expected. Sleeping at night is a normal pattern in people's lives associated with well-being. Other important rules were 2 and 6 (**), which showed the living room as the busiest place during the lunch and evening periods. Being in the living room at lunch and evening is associated with eating, having a rest or having social interaction.

Some of the measures used to evaluate the results of the classification algorithms were accuracy and error rate. The accuracy is defined by the number of instances correctly classified divided by the total number of instances (Han and Kamber, 2001).

The accuracy of the algorithm with training data was 86.84 % (330/380) and 72.58 % (135/186) with testing data. The error rate is defined as 100% - accuracy. The error rate of the algorithm with training data was 13.16% and 27.42% with testing data.

These results seem not very high in comparison to results presented by other researchers (Intille *et al.*, 2004). The difference could be explained by the fact that this study trained and tested the decision trees algorithms with real data collected from an older person's home.

Resident E

These rules came out as in table 3-7 after training the data sets.

| id | Rule (volume of sensor firings) | Output | Total instances | Correctly classified | Incorrectly classified |
|---|---|---|---|---|---|
| 1 | Kitchen <=0 AND Bed <=9 AND Hall <=0 | Late Evening | 37 | 29 | 6 |
| 2 | Kitchen <=18 AND Bed <=12 AND Hall>2 AND Living <=9 | Lunch | 45 | 26 | 19 |
| 3 | Kitchen <=18 AND Bed <=15 AND Hall[1-3] AND Living >0 Bath <=0 | Early Afternoon | 6 | 6 | 0 |
| 4 * | Kitchen <=18 AND Bed >20 AND Bath <=5 | Sleeping | 49 | 39 | 10 |
| 5 | Kitchen >18 AND Bed <=11 AND Bath >0 | Late Morning | 19 | 15 | 4 |
| 6 *** | Kitchen[19-48] AND Bed >12 AND Bath[4-7] AND Hall <=13 | Evening | 41 | 36 | 5 |
| 7 ** | Kitchen[19-56] AND Bed >56 AND Bath >7 | Early morning | 42 | 41 | 1 |
| …….. | | | .... | .... | ... |
| | Total number of instances | | 441 | 354 | 87 |

**Table 3-7: Most important rules generated using C 4.5 algorithm for resident E**

On the one hand, some rules showed accurate results. For example, rule 4 (*) showed that this person was more likely to be in the bedroom than in the bathroom during the sleeping time period. Another important rule was number 7 (**), which showed the kitchen and bedroom as the busiest places during the early morning period, followed by the bathroom. The transition among bedroom, kitchen and bathroom between 5 a.m. to 10 a.m. could be related with the morning routine.

On the other hand, some rules showed unlikely results. For example, rule 6 (***) showed that the resident was more likely to be in the kitchen than in the bedroom during the evening time period (7:15. – 11:00 p.m.). This rule would need to be discussed between the carer and the resident in order to find out the cause of this pattern of busyness.

As data from flat E fluctuated too much, the results from the algorithm didn't provide high accuracy. The accuracy of the algorithms with training data was 80.27 % and 61.61% with testing data. The error rate of the algorithm with training data was 19.73 % and 38.39 % with testing data.

## *3.5 Discussion*

OLAP technology offers great possibilities for exploring data at different levels of granularity (general or detail). This issue might help various stakeholders (formal and informal carers, and technologists) to look at periods when important changes might arise.

Decision trees algorithms were used to find some rules from two of the participants in the study. In some cases, the rules were very important but in others were not important enough. Further and better data is needed in order to build a more solid model of people's lives. Deviations from rules might be useful for detecting signs of forthcoming problems.

If the life of an older person can be shown to have patterns or rules, certain rules might confirm that. If those rules are broken, this can suggest the need for a discussion between the older person and carers to check if these changes are significant and if any action is required.

Heatley et al. (Heatley, Kalawsky, Neild, and P.A., 2006) reported that people have consistently accurate patterns of well-being (eating, sleeping, toileting and having a shower). However, it was found that the life of a person can be rather irregular. Therefore, the rules need to be relaxed, to be more fuzzy, operating within limits rather than thresholds.

Cluster algorithms were used to segment the lifestyle data. When the data was tested with the two- step cluster algorithm to find similarities in the lifestyle data, the results were nearly similar to the time zone segmentation approach done with OLAP. Afterwards, the results from the cluster algorithms were trained with a C4.5 decision trees algorithm. The accuracy of the decision tree algorithm increased from 86.84% to 87.63% with training data.

In attempting to build a model of a person, regression analysis was used to find any correlation between the lifestyle data collected from sensors and the health data. Blood sugar was taken as the dependent variable. Converse.y, mobility, eating & drinking, personal hygiene, and sleeping were the independent variables. The lifestyle and health data was aggregated by weeks. According to the results, the multiple correlation R value between the dependent and the independent variables was 0.4178 with an R square of 0.1746. When the correlation was analysed between the dependent variable and each independent variable, all the results of the R square value were even smaller except the blood sugar and sleeping correlation that was 0.432. Correlation values were not high. Consequently, this analysis was discarded.

These results are likely to be improved if the lifestyle and health data is aggregated by hours and if it is observed at specific periods where interesting phenomena happened. For example, analysing the blood sugar levels before and after the first medication change. This approach was not undertaken because the health data was collected on a weekly basis.

The cases shown in this chapter reveal the great value of having contextual and health data because carers can follow a situation that can lead into a deterioration or improvement of a person's wellbeing. The results show that lifestyle (busyness) data can be analysed using some computing techniques, and useful and expected phenomena can be detected. As the lifestyle data was explored, it became clear that it is difficult to know what the detected phenomena mean in terms of well-being. The data needs to be contextualised and interpreted by people.

There were some problems in analysing the data such as sensor failures, incomplete lifestyle, health and contextual data, and small amount of data that needed to be resolved. There were some technical problems with sensors from January 12-25 (week 2 – 4) and also with maintenance of sensors performed in later weeks. Fortunately, data from others sensor provided evidence to discover phenomena of interest so the maintained sensor data was discarded from the analysis.

In addition, when nobody was at home, sensors didn't send any signal to inform that there was no activity; thus, there were some periods of time with no data. In order to resolve this problem, some records were inserted into the database indicating no activity.

Contextual data was a key element to understand the meaning of lifestyle data. This data was collected for 5 months (from January to May 2005). Contextual data was not available from June to September 2005, which limited the value of the lifestyle data.

Multiple occupancy was not likely to be modelled with the data collected in the telecare project because it was not possible to determine who was at different places in the flat. Consequently, data collected from 4 out of the 6 flats (with a single occupant) was analysed.

## *3.6 Conclusions*

Some computing techniques can be used to reveal change and well-being related phenomena in real lifestyle data. In particular, OLAP and some simple data mining techniques offer interesting possibilities for exploring and detecting changes in the level of activity of people that may reflect changes in well-being. Changes in activity are visible and detectable from the lifestyle data gathered in domestic environments despite irregularities in the data collected. Changes in health data are also visible especially when a particular event happens. Nevertheless, contextual data is necessary to interpret the meaning of these changes through the dialogue of care.

Having data from multiple sources: Lifestyle, health and contextual data, could provide useful data to the carer to interpret changes in the older person’s well-being. For instance, in a given day, week or month, the carer could interpret the activity level of an older adult given specific health conditions. Therefore, collecting data carefully from multiple sources and stakeholders (informal and professional carer, the older adult) to interpret the data would provide more sensible and reliable information.

Lifestyle data collected from a ‘real’ home environment can be incomplete and unreliable. Understanding the meaning of the data could be a hard job because of the following reasons:

- **People’s lives get interrupted:** People behave in a different way when an unexpected event happens. For example illness, hospitalisation and funerals. Knowing the routines and habits of a person would help in the interpretation of the behaviour. Making interpretations about an older adult’s life without asking him/her or their carers is a risky approach that should be avoided. For that reason, data needs to be contextualised to make the right interpretation.
- **People’s lives get modulated:** Peoples’ lives can be modulated by, monthly or annual special events such as anniversaries, weddings, birthdays, and holidays.

Having a detailed diary of peoples' events or asking them to record the activity they are performing might help one understand the data collected automatically by sensors. The problem is whether or not they are keen on reporting those events. Studies using self-reporting tools (Barger *et al.*, 2005) showed that people sometimes forgot to report an event. Video could be a solution for the forgetfulness in reporting events; it is very intrusive though. Hence, better methods need to be used to know the special events in a person's life.

- **Sensor performance:** Sensors can collect wrong data if they are not properly configured and maintained. For instance, the Anchor Trust project reported that sensors could have conflicts such as the detection of movement at the same time by two or more PIRs (Porteus and Brownsell, 2000). Knowing the technical specification of the sensor and having well-trained engineers would reduce the gathering of incomplete and unreliable data. Not only is the correct installation of the sensors important but also the necessity of the consumable items monitoring such as batteries and the sensor themselves. Sensors and consumables need to be checked regularly to ensure reliable operation. Nonetheless, if the engineers visit the older person too often, it might not be pleasant for the resident. This is an important issue to consider checking the sensors regularly without disturbing the person's life.

Various researchers around the world have implemented sophisticated algorithms for the monitoring and modelling of specific activities, tracking peoples' movements, and making automatic interpretations based on the data collected. Conversely, there are many factors that introduce fluctuations in the data, making the data interpretation difficult in many cases.

This technology is useful, along with all the other technology being explored elsewhere. However, this data needs more work because the datasets are very different from traditional data such as e-commerce data, grocery stores, and data from financial or insurance companies. The quantity of data collected in homes is small in comparison with these other types of data. Continuing research needs also to investigate the optimal size of data sets for data mining of lifestyle information of the kind seen here.

Having investigated the use of technology in processing and presenting the data and making an interpretation from lifestyle data collected from older people, it was decided that a promising way forward was to investigate the use of this data in promoting and supporting the dialogue of care between stakeholders.

Designing and personalising user interfaces to present lifestyle, health and contextual data to various stakeholders offered the possibility of helping older people and carers to understand and discuss what was happening in the lives of the older people. This dialogue of care is important in assisting stakeholders to plan the interventions and care required. The research now proceeded to investigate and evaluate the value of using lifestyle, health and contextual data in the dialogue of care. Finally, this work is reported in the remaining chapters of the thesis.

# 4 DESIGNING AND DEVELOPING A DOMESTIC WELL-BEING INDICATOR SYSTEM (DWIS)

## 4.1 Introduction

The overall purpose of this chapter is to design a Domestic Well-being Indicator System (DWIS) using an inclusive design process that involves various stakeholders including the cared for, informal and professional carers, technologists, researchers and policy makers. The key point is to evaluate the usability, functionality, usefulness and acceptability of the user interfaces to present well-being data in a meaningful way.

This chapter aims to answer the following questions:

- What is the best way to present the well-being data in a usable system reflecting the needs and interests of various stakeholders including the service user, informal and professional carers, technologists, researchers, and policy makers?

The inclusive design process following the 'interaction design' model was used throughout the requirements gathering, design, development and evaluation of a domestic well-being indicator system DWIS. Various stakeholders: Cared for, informal and professional carers and technologists were included to collect the requirements through various elicitation techniques such as workshops, brainstorming and focus groups. Scenarios and paper-based prototypes were used to design a DWIS system with a small group of participants who attended a workshop.  An interactive version was built to provide an early model for the design team and to provide a system which could then be refined. A preliminary evaluation of the DWIS system was done with users not exclusively involved in the design team. Some evaluation sessions were conducted individually and some in groups. The feedback and discussion between users involved and not involved in the design team was compared. The individual and group evaluations were also compared.

## *4.2 Design background*

Technology might help to support communication needs, health care, social interaction and leisure. In particular, telecare technology might enable carers to respond to a crisis and help to prevent problems by providing early indications of deterioration in an individual's well-being. Examples include community alarm centres; a wide set of sensors to detect motion, occupancy, and environmental conditions; fall detectors; and various computing techniques to anticipate changes in patterns of well-being of the older person.

Researchers around the world have conducted various telecare projects that aimed to support the independence and autonomy of older people. Feasibility studies to test technology (Porteus and Brownsell, 2000); environmental and movement monitoring; community alarm systems; health conditions monitoring (Malcolm J. Fisk, 2003); housing-based alternatives provided with sensors (Bowes and McColgan, 2003); intelligent algorithms (Nauck and Majeed, 2004) and OLAP technologies to visualise activities of daily living (ADL) (Hine *et al.*, 2005b). Although technical contributions have been broadly reported, very few studies have reported the human aspects when designing and developing technology for older people.

Researchers involved in the human aspects have proposed methods, methodologies, guidelines and recommendations to design and develop technology that involves older people. The UTOPIA project (Eisma *et al.*, 2004) proposed a methodology to design and develop technology that fits older people's needs using different techniques to involve the older people in the elicitation process such as questionnaires, interviews, focus groups and workshops.

A successful example that followed this methodology was the Cybrarian project (Newell *et al.*, 2006), whose purpose was to build and evaluate an email system and a search and navigation system for older people. The system was built in collaboration between a group of researchers with good knowledge in designing for older people and a group of software developers with knowledge in human- computer interaction (HCI). Older people were trained before testing the system.

Researchers at the University of Toronto designed a mobile phone using participatory activities such as meetings between older people and designers, and paper-based prototypes (Massami, Baecker, and Wu, 2007). Various mobile models were evaluated by older people and then, the participants suggested software and hardware features that they would like to have in their own mobile. At the end, a real mobile device was tested by the same group of people involved in the design team. Design and user engagement recommendations were the output from the testing and the participatory activities.

The ENABLE project (Jones and Gilliard, 2004) involved formal and informal carers and older people with dementia to test two assistive technology devices. They also included the participants to develop and test a remote day planner prototype. They used different techniques to elicit the user requirements such as mock-ups, early prototypes and focus groups. A trial was run with people with dementia and their family carers to validate the appropriateness and usefulness of the products.

Taking into consideration the results and recommendations from the projects mentioned before (in order to design accessible and useful interfaces for older people and carers), it was necessary to understand the features of the target population, its needs, and constraints.

## *4.3 Older computer users are different from young ones*

According to Newell (Newell *et al.*, 2006), older people differ from a typical younger computer user in two essential aspects: The technical skills and abilities and the sensory, motor and cognitive characteristics that come with ageing.

### 4.3.1 Technical skills and abilities

Older people, who have no computer skills or bad previous experiences using a computer, have the following barriers when trying to carry out a task:

- **Technology is perceived as too complicated, difficult to understand and unfriendly:** Based on a user-requirement gathering session using live theatre the following issues came to light: Some older people were not keen on exploring technology because they thought it was too complicated; some people said that the instructions given were not easy to understand because of the vocabulary used; other people thought that some computer interfaces were not friendly (McGee-Lennon, Clark, Wolters, Martin, Morgan, Hine, Gil, Arnott, and Newell, 2008).
- **Fear of technology:** Older people feel fear of technology partly because they considered themselves too old to learn. They tend to blame themselves when making a mistake performing a task on the computer (Eisma *et al.*, 2004). Czaja and Lee said that older people like technology and are willing to use computers; however, initial training is required to ensure a successful experience. In addition, confidence and comfort are determined by previous experiences.
- **Learning skills and abilities:** Czaja and Lee (S. Czaja and Lee, 2008) reported that older people have different learning skills and abilities in comparison to young people because their cognitive skills decrease with age. They recommended providing help, support and training to tackle the learning problems that might appear.

### 4.3.2 Sensory, motor and cognitive changes with age

Fisk *et al.* (A.D. Fisk, Rogers, Charness, Czaja, and Sharit, 2004) gave a complete description of the ageing changes that occur in sensing and perceiving information, processing that information and physically responding to the information. The following are some concerns of the elderly:

- **Visual and hearing impairment:** Vision is one of the main concerns among older population. Due to visual impairment, looking at complex visual graphs or finding information could be very hard tasks for an older person. Fisk *et al.* (A.D. Fisk *et al.*, 2004), suggested minimising the number of tasks that involve these activities. Czaja and Lee (S. Czaja and Lee, 2008) reported that selecting a small target on the computer screen, perceiving small icons, reading e-mails and locating information on a complex screen or webpage were complicated actions to do for older people with vision difficulties.

  Likewise, people's auditory functions may decline due to the ageing process (Shieber, Fozard, Gondon-Salant, and Weiffenbach, 1991). For example, the ability to recognize high frequency tones and problems localizing sounds. Nevertheless, older adults may also have difficulties in understanding synthetic and multimedia systems, and in detecting alerting sounds like beeps.

- **Movement control:** Older adults take longer than younger adults to make similar movements, and the movement is less precise. Thus, older adults find it difficult to carry out tasks like pointing at an object with the mouse or doing a double click (S. Czaja and Lee, 2008). Some authors (Milne, Dickinson, Carmichael, Sloan, Eisma, and Gregor, 2005) and usability guidelines (Park, 1992) recommend avoiding the use of double click and vertical/horizontal scrolling.

- **Cognitive:** Processes that decline with age include problem solving, inference information and interpretation, working memory, and attention processes (S. Czaja and Lee, 2008).  Consequently, older adults require more time to process the information and more time to respond. Czaja and Lee (Sharp, Rogers, and Preece, 2007) demonstrated that older people are more likely to make errors, and their performance is poorer than younger users when conducting a test.

Having discussed the differences between older people and younger adults the researcher needed to find a way of designing a domestic well-being indicator system that presented useful data for all the stakeholders.

## *4.4 Inclusive design process*

In order to design and build the DWIS system, an inclusive design process following the interactive design model steps (Kurniawan and Zaphiris, 2005; WC3, 2008) was used throughout the requirement process: Gathering, design, development, and evaluation. In addition, some methodologies and recommendations proposed by many authors (Eisma *et al.*, 2004), and guidelines to design for older people (S. Czaja and Lee, 2008) were reviewed and consulted.

All previous studies helped the researcher to use the techniques described, to conduct the design, and to build processes following the steps illustrated in figure 4-1 and in table 4-1.

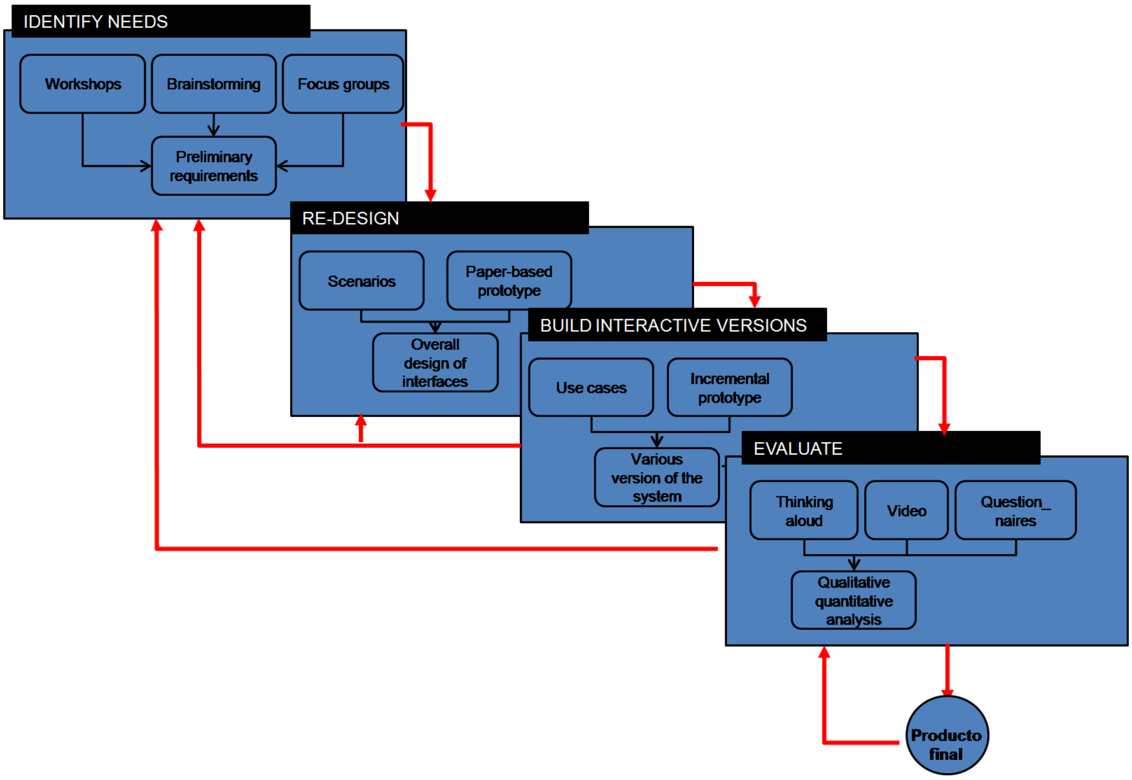



**Figure 4-1: Inclusive design process used in this study**

| Step | Technique | Stakeholder | Purpose | Result |
|---|---|---|---|---|
| Identifying needs | Workshop, brainstorming | Large mixed stakeholder (cared for, informal carers, professional carers, technologists and one policy maker) | Establish different stakeholder perspectives | Some high-level requirements |
| Identifying needs | Focus groups | Design team. Small mixed stakeholder (cared for, informal carers, professional carers and technologists and researcher) | Refine the initial requirements and establish the scope of the DWIS system | Preliminary functional, non-functional and design requirements |
| Re-designing a DWIS system | Scenarios | Design team. | Illustrate some situation that a potential user is likely to face | Further functional, non-functional and design requirements |
| Re-designing a DWIS system | Paper-based prototype | Design team and invited designer | Design a user interface one for older people, and another one for carers | Overall design of interfaces. |
| Building interactive versions | Use cases | Researcher | Observe the interaction between the end-user and the DWIS system | Use-cases |
| Building interactive versions | Incremental prototype model | Design team | Provide an early model of the DWIS system | Coded version of DWIS system |
| Evaluation | Thinking aloud | Small mixed stakeholder (group of two or three participants and individual performance) | Observe the dialogue between participants or verbal thinking while doing the exercise | Observation notes |
| Evaluation | Video | Small mixed stakeholder | Capture the interaction between the participants and the DWIS system | Notes from video |
| Evaluation | Questionnaire | Small mixed stakeholder | Measure the usability, functionality and acceptability of the DWIS system | Qualitative and quantitative analysis |

**Table 4-1: Techniques used during the interaction design process**

The following section explains in detail the stages of the inclusive design process described in figure 4-1.

## *4.5 Identifying preliminary needs and user requirements*

The first step of the inclusive design process was to identify the preliminary needs and user requirements. This step aimed to establish the stakeholder perspectives, identify the initial needs and establish the scope of DWIS.

In order to encourage a collaborative, team-oriented approach to requirement gatherings, a team of stakeholders and researchers worked together to identify the problem, propose elements of the solution, negotiate different approaches, and specify a preliminary set of solution requirements.

### 4.5.1 Elicitation techniques

During the identification of user needs, different elicitation methods were used to collect the requirements directly from the end users (A.D. Fisk *et al.*, 2004) such as workshops, brainstorming, and focus groups.

#### 4.5.1.1 Workshop

Twenty six participants attended the workshop. Eleven older people (nine cared for and two informal carers), six occupational therapists, two physiotherapists, three researchers, three technologists, and one policy maker attended a one-day workshop. The purpose of the event was to establish different stakeholder perspectives about home-care, expectation and the individual role.

#### 4.5.1.2 Brainstorming

During the workshop, the participants were divided into five groups: Two groups of elderly people and three mixed groups (physiotherapists, researchers and technologists). During four brainstorming sessions, people were asked to give their opinion on the following aspects:

- What kind of information would be useful to older adults and formal and informal carers?
- What are the preferences in data presentation of each stakeholder?
- Where would end-users prefer to have this information (computer, telephone, mobile, television)?

Older people and informal carers said that they would like to have a reminder for: Medication, appointments, and tasks, and be aware of environmental conditions such as temperature and safety. All the stakeholders: Cared for, informal and professional carers and technologists expressed that they would like to know the state of the occupant (mobility skills, personal hygiene, eating and drinking habits, sleeping patterns, health conditions, social interaction and psychological behaviour). Czaja and Lee (Pressman, 2005) reported that older people wanted to monitor their safety and security at home. For instance, monitoring home appliances and linking them to emergency services.

In order to find out the preferences in data presentation for each stakeholder, different ways of presenting data were shown to the group of participants: Icons, symbols, graphs, and text. There was a lengthy debate between the participants about the appropriate use of icons and symbols. One of the older persons said that icons and symbols could have different meaning according to the culture, so they could be interpreted in different ways. Fisk *et al*. (Komiyama, 2008) quoted that if the older adult is familiar with the icon, it can be more effective than text; as a result, it is necessary that the person learns the meaning of the icon before he or she uses it.

Regarding the last question, the participants suggested that computers and laptops using the Internet, mobile phones and television would be appropriate to present information about the older person. Presenting data through the Internet could be beneficial because end users could easily access this from their homes or workplaces. The use of mobile phones to communicate data to the end users was not considered because the DWIS system contained some graphs that might not be possible to be shown in a small device. Presenting well-being data through alternatives devices such as television was outside the scope of the current study.

As a summary, table 4-2 presents the concerns, requirements and user needs collected using workshops, brainstorming and focus group sessions.

| **Concerns, requirements and information needs** | **Stakeholder** | | | |
|---|---|---|---|---|
| | **Cared for** | **Informal carers** | **Professional carers** | **Technologists** |
| Reminder for medication, appointments and tasks | ✔ | ✔ | | |
| Environmental conditions (temperature and safety) | ✔ | ✔ | | |
| State of the occupant (mobility, personal hygiene, eating and drinking habits, sleeping patterns, health conditions, social interaction and psychological behaviour) | ✔ | ✔ | ✔ | ✔ |
| Data presentation preferences | Text | Text | Graphs, trends, text and icons | Graphs and trends |
| Appropriate devices to display information | Television, mobile phone, computer | Mobile (cell) phone, computer | Laptop, computer (using the Internet) | Laptop (using the Internet), mobile |

**Table 4-2: Concerns, requirements and information needs**

#### 4.5.1.3 Focus groups

After the workshop, the researcher contacted a small group of participants who expressed their interest in continuing to work as part of the design team. Two older people, one informal carer, one physiotherapist and two technologists attended a meeting to discuss the results found from the workshop. The purpose of this focus group was to refine the initial set of requirements and to establish the scope of DWIS.

Figure 4-2 illustrates the ‘busyness’ model of the DWIS system. The aim of the system was to check the well-being of older people and the home environmental conditions.

Each stakeholder could have access to specific information. For example, informal carers could monitor the well-being of the older person and check the environmental conditions; professional carers could identify the older person's physical, health, social and psychological needs.

Stakeholders have clear relationships among them. For instance, there is a relationship between the older person and the carers (informal and professional); researchers, designer and technologists should interact directly with end users in order to implement technological solutions suitable for them; and policy and decision makers should communicate policies to the stakeholders involved in the home-care system.

Taking into account the complexity of designing and developing a domestic well-being indicator system, the design team defined the scope of the DWIS system. The system focused on designing, developing and evaluating some user interfaces that present lifestyle, health and contextual data in visual and textual form related to areas of well-being: Mobility, sleeping, eating and drinking, personal hygiene, and health conditions.

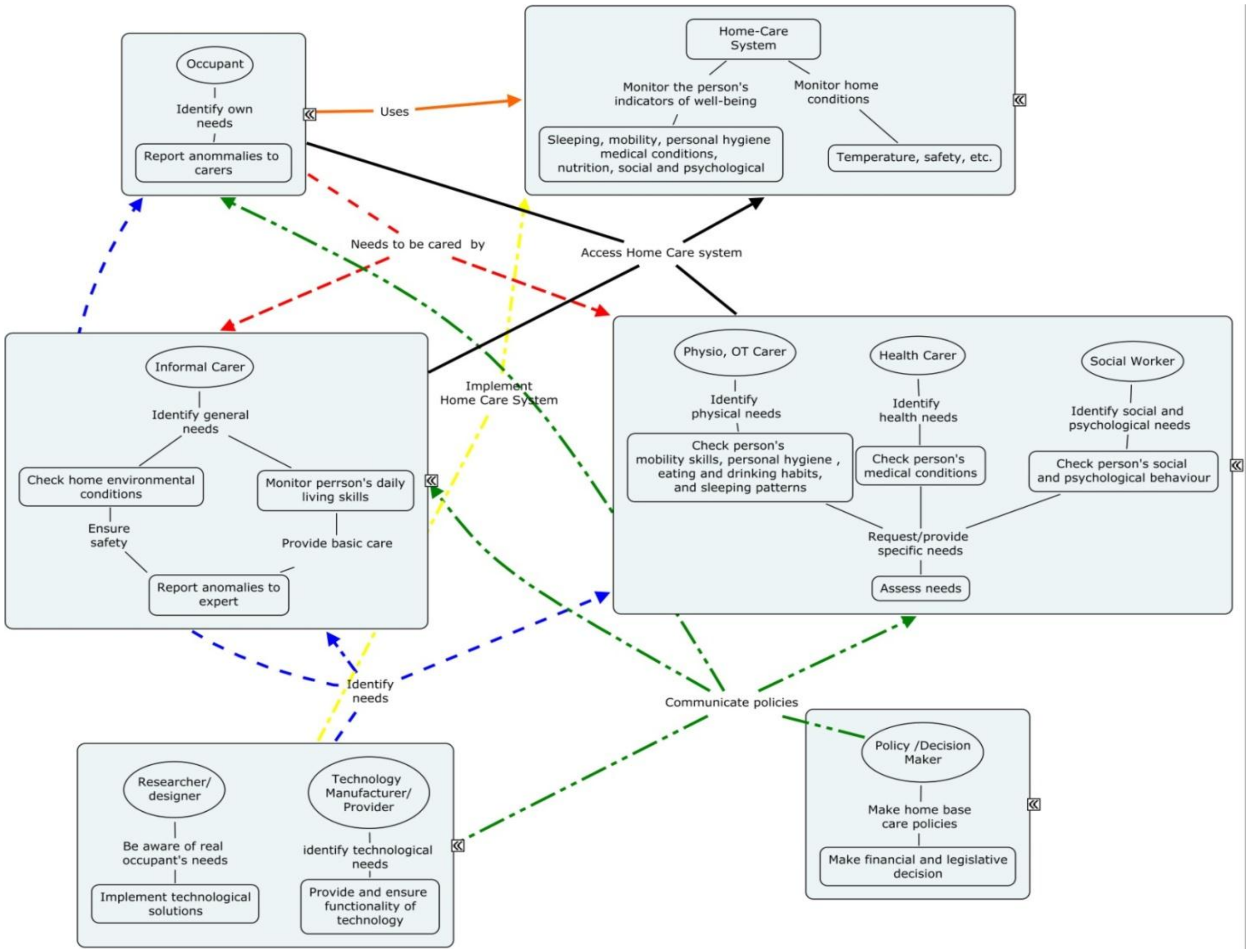



**Figure 4-2: 'Busyness' model of a domestic well-being indicator system (DWIS)**

### 4.5.2 Preliminary requirements

During a second meeting, the design team started to describe the functional level of the system. From the discussion, the following main functions were derived:

- **Registering stakeholders:** This function let the professional carer enter the personal details of occupants, informal, and professional carers.
- **Checking changes of well-being areas:** Allows the stakeholders (older person, informal and professional carers) to visualise areas of well-being (mobility, eating and drinking, personal hygiene, sleeping, and health conditions) through graphs and textual data at various levels of granularity (days, weeks, months).
- **Checking trends of well-being areas:** Allows the professional carer to analyse the older person's well-being by looking at their trends.
- **Checking the professional carer's workload:** This function allows the professional carers to check their workload and prioritise their work.
- **Registering actions:** It is used to register actions taken by informal and professional carers, who look after the older person.

Other non-functional requirements were discussed during the meeting as follows:

- The privacy of contextual, health and lifestyle data collected from sensors installed at home.
- Appropriate access control to the system. One participant suggested restricting access to sensitive data to specific users. For example, an informal carer might have access to data related to the person he or she looks after.

In addition, specific design issues were discussed with the group, including:

- Allowing users to reconfigure their display preferences: Colour, font, size of the text.
- Presenting data in visual and textual form.

The following section describes how to design intuitive and self-explanatory interfaces for older people and carers based on the preliminary requirements.

## *4.6 Re-designing a system involving all stakeholders*

As requirements were gathered, an overall vision of system functions and features began to materialize. The researcher (developer) needed to understand how these functions and features would be used by different stakeholders. To accomplish this, the group of participants and the researcher created a set of scenarios that identified a thread of usage for the system to be constructed (Foraker_Design, 2009). The team worked with a paper-based prototype to design the user interfaces.

### 4.6.1 Scenarios

The purpose of this technique was to illustrate some situations with which a potential user of the DWIS system would be faced. For this exercise, the group of participants consisted of two technologists, three older people (one cared for and two informal carers), and one professional carer working together.

Under the assumptions that all the technology was in place, the older person agreed to be monitored and the end-users (the cared for, the informal and professional carer) had access to the system. The following example scenarios were analysed during this discussion:

Scenario 1:

*Anne is 70 years old and is suffering from diabetes. She has a son called John, who is looking after her. He lives close to her. John wants to check Anne's daily well-being indicators (mobility, eating and drinking, seeping, and personal hygiene) and health conditions (blood sugar, blood pressure and pulse). He switches on his laptop, which is connected to the Internet and logs into the system. When he chooses the mobility patterns, he observes that Anne was moving around last night according to the graph and textual data. He wants to have a reference to compare with. Then, he goes to the* *health conditions to check Anne's blood sugar level. He finds that the blood sugar level is quite high according to the normal level. He is a bit concerned about his mother, so he decides to call her to find out what is happening.*

Scenario 2:

*Martha is working as the district nurse and is in charge of looking after several older people who are living alone. Recently, a system was installed in her office in order to optimise her time and improve the service provided to older people. She logs on to the system and chooses the workload for today. According to the data, there are two people that need to be visited urgently because there are some alarm conditions in their well-being indicators. She selects Anne, the first person, and the computer shows the detail of each well-being indicator. Martha realises that not only did Anne not sleep well last night but also the night before. So Martha decides to see a trend analysis of Anne's sleeping patterns during the last two weeks. She finds that the sleeping pattern is quite irregular. Martha phones Anne to find out if she is all right. Anne replies that she is not too bad. However, Martha makes an appointment with Anne to discuss her sleeping pattern.*

*Then, Martha chooses Peter, who is a person with low vision. Martha observes Peter's well-being indicator and the computer shows that Peter has been quite inactive during the last week. Afterwards, Martha selects the health conditions to see if there is a significant change. According to the graph, his blood sugar and pulse has been very low during the same period of time. Martha wants to find a correlation between the mobility patterns and health conditions. Then, she decides to phone Peter and makes an appointment to find out his real situation.*

*Finally, Martha checks the well-being and health conditions of the remaining occupants, but there is nothing urgent for the moment so she logs off from the system.*

## 4.6.2 Paper-based prototype

Following the scenario discussion, the design team had another meeting which aimed to design a paper-based prototype. On that occasion, two older people (one cared for and one informal carer), one professional carer, one technologist, one invited designer and the researcher attended the meeting. The participants were given a list of scenarios, an interface template and a set of pieces to start considering the best positioning of each element: Buttons, labels, graphs and text boxes.

The group of participants came out with an overall design for the following interfaces: Login into the system; registering stakeholders; checking the occupant's areas of well-being; checking the occupant's mobility (see figure 4-3); checking trends of personal hygiene; checking the occupant's blood sugars, and checking the professional carer workload.

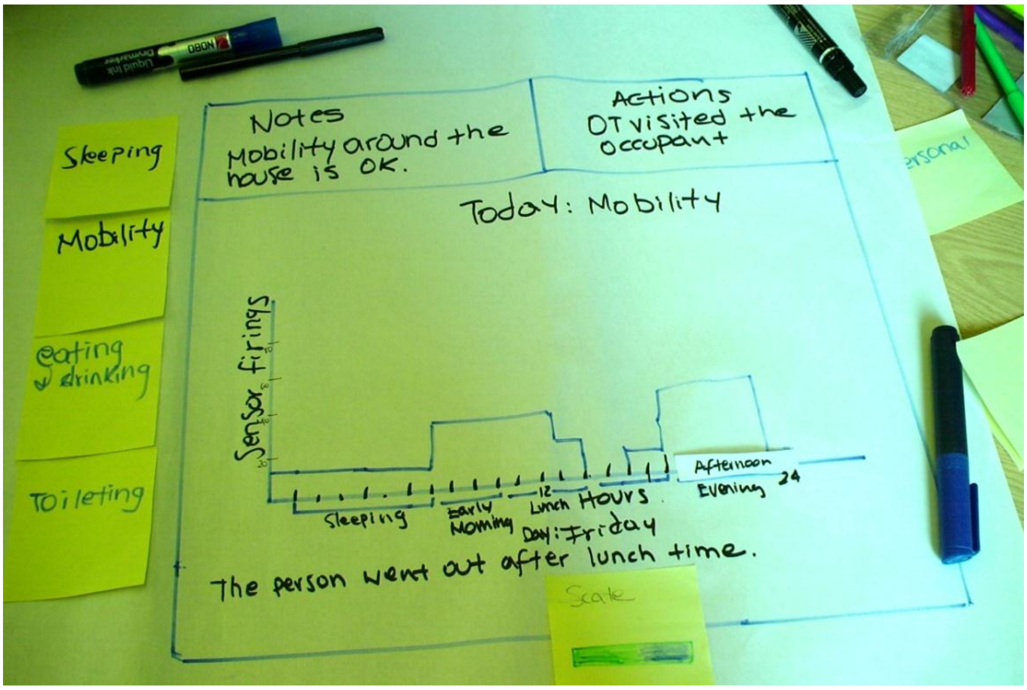



**Figure 4-3: Example of paper-based user interface**

## 4.6.3 Identifying further requirements

The following further requirements were collected from the scenarios, paper-based prototype discussions and use-cases:

- To replace the toileting label with personal hygiene because it means visits to the bathroom but not necessarily using the toilet; moreover, issues such as privacy and intrusion were discussed as follows:

- To allow the end user to reconfigure the level of monitoring of the system according to their needs. For example, if an older person feels well, he or she might want to restrict the sensor monitoring at night;
- To reduce the level of intrusion or obtrusiveness as much as possible.

Some design requirements were also discussed:

- To display easy and self-explanatory data. The group of participants suggested showing a bar with colour scales that represents the status of the well-being indicator consulted. For example, dark colour means that there is something wrong and light colours means that everything is fine.
- To have big buttons and big size of letters. Some older people had difficulties reading text and pointing at an object. Therefore, the minimum size of buttons was 4 x 2 centimetres, and fonts were 14 points for label and titles and 12 points for graph axes.
- To have a good colour contrast for text and background.
- To avoid the use of traffic light colour because of red-green colour blindness. Instead of a green-yellow-red representation, the team proposed to use a scale of colour to represent the level of activity or status, where light blue represented that everything was fine and dark blue meant that there was something wrong.
- To have meaningful icons to help users to remember how to use the system.

## *4.7 Building an interactive version of the system*

The third step in the interactive design process was to build an interactive version that aimed to provide an early model of the DWIS system so that the design could be evaluated and refined in consultation with the group of participants. This step implied the elaboration of some use-cases that described the interaction between the user and the system and the construction of interactive version of the system.

### 4.7.1 Use cases

Use cases were used to describe the system's behaviour under various conditions as the system responds to a request from one of its stakeholder. After careful review of the requirements, the DWIS system requires four actors: Occupant, professional carer, informal carer, and technologist. For instance, one of the use cases was described as follows.

Considering the situation in which the professional carer uses the system and wants to register a new occupant:

1. The professional carer initially sees a screen with a box where they can type the user name and password.
2. The system displays the following options: Registry, well-being, trends, workload, actions, admin, utilities and home.
3. The professional carer chooses the option "registry".
4. The system displays a screen with a list of options: register a new occupant, register a new carer and assign a carer to an occupant
5. The professional carer chooses the option "register a new occupant".
6. The system displays a screen to enter the personal information.
7. The professional carer enters the data required.
8. The system prompts the user for the carers involved.
9. The professional carer selects the carers involved.
10. The system checks if the carer exists in the database.
11. The professional carer selects the button "assign the carer to the occupant".

The list of uses cases described for the DWIS system was:

- Registering a customer
- Validating a user

- Checking well-being
- Checking trends of well-being
- Adding actions
- Updating the person's status
- Creating data cube

### 4.7.2 Incremental prototype

Based on the requirements gathering, the paper-based prototype, and the use-cases, the development of the DWIS system commenced. The DWIS system was developed using Visual Studio .NET, Dundas, and SQL Server 2005. Firstly, the user interfaces were coded and a very preliminary version was informally reviewed by two older people. They agreed with the design features of that version which did not have any functional requirement implemented.

Secondly, the "registering stakeholders" and "checking changes of well-being" functions were developed. The researcher had a meeting with three of the participants (two older people and one occupational therapist) on which a second version of the DWIS system was informally evaluated (see figure 4-4 and 4-5). They suggested making the following changes:

- Increasing the size of the fonts and buttons;
- Putting clear labels close to the image in the buttons that represent the well-being indicators;
- Adding labels to axes on each of the graphs that represent indicators of 'busyness' associated with well-being;
- Using a standard interface template for the web pages to avoid confusion;
- Explaining the meaning of each option that appears in the horizontal menu.

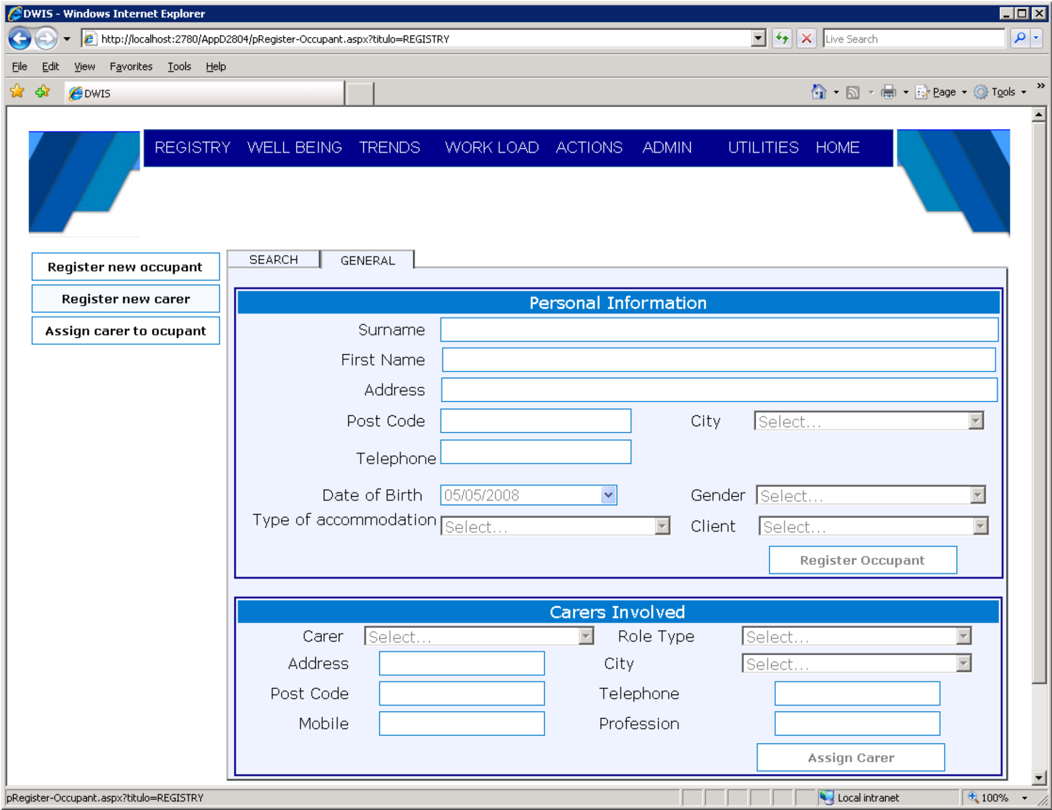



**Figure 4-4: Example of the "registering an occupant" interface**

All suggestions and changes from all users were implemented in the first version of the DWIS system. Finally, the checking trends of well-being, and checking the professional workload functions were developed. The registering actions function was not implemented because it was a complex management process that was beyond the scope of this thesis.

## *4.8 Preliminary evaluation of the system*

Once an operational DWIS system was created, it was evaluated to determine whether it met the needs of the users. The purpose of the preliminary evaluation of the DWIS system was to measure the usability, functionality, usefulness, and acceptability. Questionnaires were distributed to users to collect quantitative data of DWIS. At the time the DWIS system underwent preliminary evaluation some functions were already under construction.

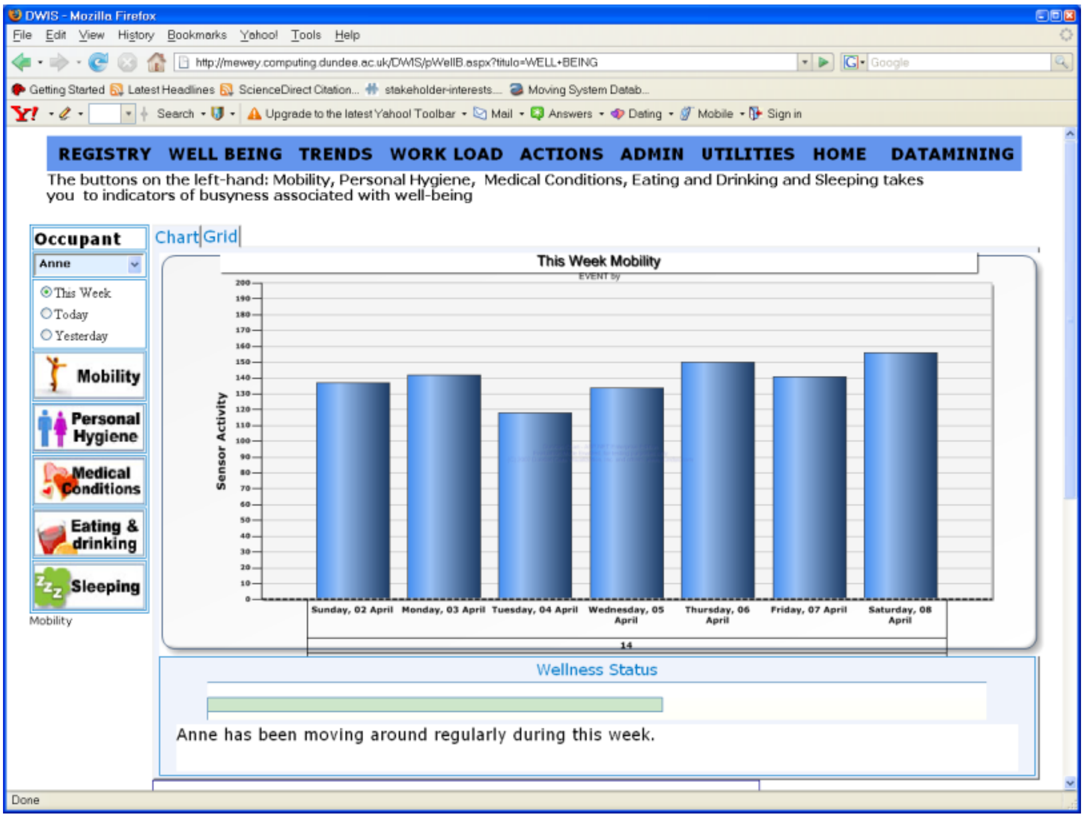



**Figure 4-5: Example of the "checking areas of well-being" interface**

## 4.8.1 Participant's profiles

Nine people were recruited for the preliminary evaluation of the DWIS system. There were two older couples (one cared for and one informal carer), three independent older adults (female), one occupational therapist, and one technologist. Some of them were involved and some were not in the design team.

## 4.8.2 Measures

While users were performing their tasks, an observer was taking notes. After the exercise, the participants were requested to fill in a questionnaire. Furthermore, each session was video recorded.

The following measures were evaluated as shown in table 4-3 (Hawthorn, July 2007; Massami *et al.*, 2007):

| Measure | Type of measure |
|---|---|
| Effectiveness: the degree to which an interface facilitates a user in accomplishing the task for which it was intended. | Usability |
| Learnability: the degree to which a user interface can be learned quickly and effectively. | Usability |
| Usefulness: the relevance of the information presented and the ability of the system to do the task selected by the participant. | Usefulness |
| Intuitive and self-explanative: the ability of the system to show data easy to understand for all the users | Usability |
| Memorability: the ability of the DWIS system to help the participant to remember how to use the system. | Usability |
| User satisfaction: the enjoyment and pleasure of the participant to work with the DWIS system. | Acceptability |
| Reliability: the capability of the DWIS system to maintain a specified level of performance when used under specified conditions. | Usability |
| System performance: time to logon and system response. | Usability |
| Appropriateness: the capability of the DWIS system to provide functions which meet the user's needs. | Functionality |

**Table 4-3: Measures collected**

### 4.8.3 Using the DWIS system

Six sessions were run; some of them were individual and some in small groups of two or three people. The participants were asked to explore the DWIS system for 5 minutes and verbalise their thoughts while carrying out the list of tasks for 50 minutes, which consisted of registering an occupant and a carer and checking the mobility, sleeping, eating and drinking, personal hygiene and health conditions of an older person. Table 4-4 shows the characteristics of each evaluation session.

The first session was carried out by a technologist partially involved in the design team and who had experience in telecare systems. The participant suggested communicating the state of the system after a process is completed (error or warning messages and confirmation messages); and removing the registering actions function.

| Session | Individual or group | User involved or not in the design team | Stakeholder |
|---|---|---|---|
| 1 | Individual | User partially involved | Technologist |
| 2 | Couple | Not involved | A cared for and an informal carer |
| 3 | Individual | Not involved | Independent older adult |
| 4 | Individual | Not involved | Independent older adult |
| 5 | Group of three people | Involved | A cared for and two informal carers |
| 6 | Individual | Not involved | Professional carer |

**Table 4-4: Characteristics of each evaluation session**

The second session was carried out by one pair (a cared for and an informal carer) who were not involved in the design team. They were not used to interpreting graphs even though, they were keen on doing the test. The researcher helped them to understand the meaning of the graphs. Because of this, grids and text were added to present the data in different ways.

The third and fourth sessions were run individually by two independent older female adults who were not involved in the design. There were no additional comments from them at this stage.

The fifth session was carried out by a group of three older adults (a cared for and two informal carers) involved in the design team. They suggested improving the colour contrast of the horizontal menu. The first version of the DWIS system had a different colour combination, for which participants expressed a higher degree of acceptation. Thus, the final version of the DWIS system had the best colour contrast.

The sixth session was performed by a professional carer not involved in the design team. The participant suggested implementing the ability to see data at a general level and in detail, and adding a function to report the occupant’s well-being.

At the end of each session, the participants were requested to fill out a questionnaire. All questions were evaluated using a 1-5 point Likert scale. For further details of the tasks and questionnaire see appendix C.

### 4.8.4 Data analysis and results

Quantitative analysis was used to analyse the data collected from questionnaires. In addition, comments and feedback were collected to improve the DWIS system. The questionnaire produced the following results as shown in table 4-5 and figure 4-6.

| Measure | Mean score | Standard deviation |
|---|---|---|
| Appropriateness: | 3.40 | 1.174 |
| Reliability | 3.50 | 0.850 |
| Memorability | 3.60 | 1.075 |
| Learnability | 3.80 | 0.422 |
| User satisfaction | 3.90 | 0.738 |
| Usefulness | 3.90 | 0.568 |
| Intuitive and self-explanative | 4.10 | 0.577 |
| Effectiveness | 4.20 | 0.422 |
| System performance | 4.30 | 0.675 |

**Table 4-5: Quantitative results from preliminary evaluation**

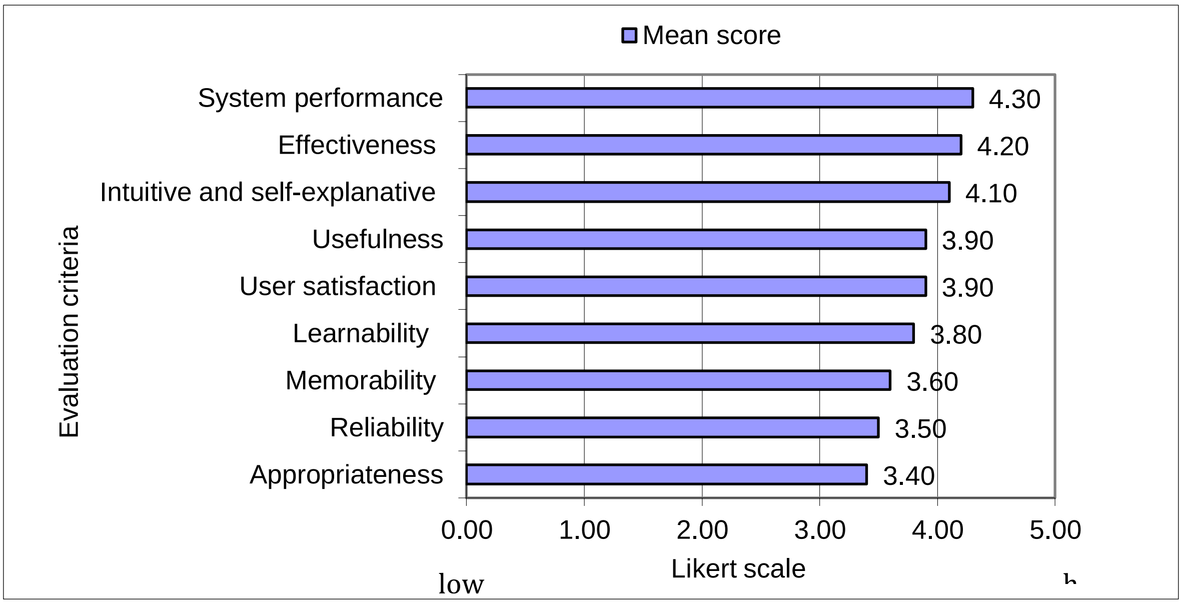



**Figure 4-6: Mean score from preliminary evaluation**

People gave a high score to aspects such as system performance, effectiveness and intuitive and self-explanative. The participants said that DWIS provided relevant information to end users, it was found easy to learn and to remember how to use the system, and it was pleasant to work with. Measures such as reliability and functionality were the lowest relative scores, although all scores were above 3 (out of 5).

## *4.9 Discussion*

### 4.9.1 Overall

The results of this study not only provide feedback to improve the DWIS system, but also, more importantly they provided evidence of the usefulness of the data presented, the usability, acceptability and functionality of the DWIS system. The system was easily used by both older people and carers because it presented the data through visually, clear and friendly user interfaces to all the stakeholders involved in the care of the older adult.

The first version of the DWIS system included four out of five functions described in the preliminary requirements section that were implemented, as follows:

- Registering stakeholders;
- Checking changes of well-being areas;
- Checking trends of well-being areas;
- Checking the professional carer's workload.

High colour contrast for text and background was one of the essential features when designing a user interface for older people. The "register an occupant" interface (see figure 4-4) had dark background and light text in the horizontal menu while the "checking areas of well-being" interface (see figure 4-5) had light background and dark text. The second interface was preferred by the participants.

### 4.9.2 Designing an integrated system

Lifestyle data collected from sensors represents the activity level of an older person and can be computed using OLAP cubes and some data mining techniques. However, these kinds of tools are not neither friendly nor easy to use for an 'average' end user.

Therefore, it is necessary to design an integrated system that presents the lifestyle data collected from sensor, health and contextual data so carers and the older person can interpret the meaning of changes in the data.

Lifestyle, health and contextual data need to be integrated within a system so all the stakeholder can discussed the symptoms, changes in behaviour, and find out how things are affecting the older person and their quality of life and well-being. For instance, when a person is about to go on holidays, their mobility patterns might change because the person is busier preparing their luggage.  To understand the real meaning of the change, it is necessary to contextualise the lifestyle data to make an assertive interpretation of this change.

As it was explained in chapter two, quality of life is a wide concept that consists in many aspects such as health, social relationships, participation, independence, autonomy, psychological, economical aspects among others. Therefore, rich data is needed to have a greater understanding of the life on an older person.

### 4.9.3 Working with various stakeholders

Regardless of the design process that has been presented to design user interfaces, it was very useful to involve the users from the beginning of the design process to have a more realistic view of the user needs, likes and dislikes. However, the design stage can be very time-consuming when the profile of end users is quite varied. Therefore, the researcher should make decisions to define the scope of the project, to filter the important needs of the varied group of participants, and to plan the necessary time in order to produce a solution suitable for all the stakeholders.

### 4.9.4 Level of complexity in the data presented

Based on experience in working with various stakeholders during the user requirements gathering, designing, building and evaluation stages of the DWIS system, the researcher established the following level of complexity of data for each stakeholder (see table 4-6).

| Level of complexity | Stakeholder | | | |
|---|---|---|---|---|
| | Cared for | Informal carers | Professional carers | Technologists |
| Daily data | ✔ | ✔ | | |
| Weekly data | ✔ | ✔ | ✔ | |
| Monthly data | | | ✔ | ✔ |
| Trends of data | | | ✔ | ✔ |

**Table 4-6: Level of complexity in the data presented**

The level of complexity is related to the level of granularity provided with the OLAP technology as mentioned in chapter three. OLAP could be an advantage when data needs to be presented to various stakeholders because it allows the end-user customises the data according to the specific needs.

One of the functionalities specified by the end-users was to present trends data to professional carers so they can have a quick overview of the older person's well-being.

### 4.9.5 Working in groups or individually

Some authors (Eisma *et al.*, 2004) recommend carrying out usability testing with users not involved in the design team while others argued that point (Desurvire, 1993). Comparing the performance between users involved and not involved in the design team, it was found that users involved made more comments than users not involved in the design team.

Individual and group performances were observed during the evaluation. The think aloud technique was successful with individuals involved in the design team; however, there was very little input from individuals not involved in the design team. The group performance with users involved in the design team took a longer time to carry out the task than with users not involved because they discussed a lot. Table 4-7 shows a summary of these issues.

| Modality | Users involved | User not involved |
| --- | --- | --- |
| Individual performance | Easy think aloud process.<br>Comments and feedback while performing the task. | Difficult think aloud process.<br>Few comments. |
| Group performance | Many comments and lots of discussion while performing the tasks.<br>Longer time to perform the tasks than the other modalities tested. | Lots of discussion during the session.<br>Longer time to perform the task. |

**Table 4-7: Observations from usability testing performance**

## *4.10 Conclusions*

Early user involvement and inclusive design process can be beneficial in the case of older adult users because it lets the researcher/designer/developer interact directly with end users to find out their real needs and take into account their experience to ensure that the final version of the DWIS system meets the requirements.

Having different stakeholder perspectives helped the researcher to have a clearer spectrum of a domestic well-being indicator system. On the other hand, it was a significant challenge to establish an appropriate set of requirements for each stakeholder.

An inclusive design process which included the use of different human- computer interaction (HCI) techniques, was demonstrated. It involved various stakeholders (cared for, informal and professional carers, technologists and researchers) from requirements gathering to the evaluation of the DWIS system. Likes and dislikes were considered during the process. A preliminary evaluation of the DWIS system was performed by users involved and not involved in the design team.

A domestic well-being indicator system that presents contextual, health and lifestyle data about older adults, who live independently in their homes has been designed and developed. The combination of various elements such as bar and trend graphs and textual data, and the views of the data at different levels of granularity provided a useful way to present well-being data about older people to various stakeholders.

The next chapter evaluates the value of presenting lifestyle, health and contextual data to enhance the dialogue of carer between older people and carers.

# 5 EVALUATING A DOMESTIC WELL-BEING INDICATOR SYSTEM (DWIS)

## 5.1 Introduction

The main purpose of this chapter is to evaluate the ability of the Domestic Well-being Indicator System (DWIS) to present lifestyle, health, and contextual data and to determine the contribution of the data presented to the dialogue of care between the older adult and the carer (professional or informal).

The evaluation of the DIWS system aims to answer the following research questions formulated in chapter two:

Can a well-being indicator system be used as a tool to enhance a conversation between the older person and the carer? If so

- Would a personalised user interface that provides lifestyle, health and contextual data be useful?
- Would data presented in the form of graphs and textual data help to communicate changes related to the well-being of an older person?
- Would the well-being data be useful to help the carers to detect a change in the life of the older person?

There are some background questions that also need to be asked, with regard to the acceptability of the prototype.

- Do participants want to have a system like this in their home or workplace?
- What are the ethical issues of gathering and distributing well-being data among the stakeholders involved?

Qualitative and quantitative analysis methods were used to analyse the data gathered from the evaluation of the domestic well-being indicator system DWIS. Older people, informal and professional carers, scheme managers, wardens and a social worker were asked to evaluate the DWIS system individually and in pairs (older adult and carer).

An experimental setup was designed to gather evaluation data via direct observation, questionnaires, semi-structured interviews and video recording to discover if the DWIS system could be used as a tool to enhance the dialogue of care between the older person and the carer.

The final evaluation of the DWIS system was done with users not involved in the design team. The results from the qualitative and quantitative analysis provided evidence that the DWIS system could improve the dialogue of care by presenting integrated data from various sources: Lifestyle, health and contextual data.

## *5.2 Methods*

The goals of the evaluation of the DWIS system were to measure some usability criteria, observe the user experience and evaluate the usefulness of the system to enhance the dialogue of care.

### 5.2.1 Participants' profile

The study was approved by the appropriate research ethics committee at the University of Dundee. Twenty people were recruited in person, by phone and by post. There were ten independent and autonomous older adults aged between 60 and 80 years, 5 females and 5 males (eight of them lived independently at their home and two lived at sheltered accommodation). Some of the participants attended IT classes at the user centre at the School of Computing in the University of Dundee. Ten female carers (three physiotherapists, two occupational therapists, two scheme managers, two wardens and one social worker). The participants had different levels of computer skills: Basic, intermediate and advanced. Some of them were familiar with reading graphs. Some participants were confident using technology (see table 5-1).

| Par_ ticipant | Age group | Gender | Stakeholder | Computing skills | Familiar with reading graphs (Yes/No) | Confidence with technology (Yes/No) |
|---|---|---|---|---|---|---|
| C1 | Under 30 | Female | Carer | Advanced | Yes | Yes |
| C2 | 50-59 | Female | Carer | Basic | No | No |
| C3 | Under 30 | Female | Carer | Advanced | Yes | Yes |
| C4 | Un-assign ed | Female | Carer | Basic | No | No |
| C5 | 40-49 | Female | Carer | Intermediate | Yes | Yes |
| C6 | 30-39 | Female | Carer | Basic | Yes | Yes |
| C7 | 50-59 | Female | Carer | Basic | No | Yes |
| C8 | 30-39 | Female | Carer | Intermediate | Yes | Yes |
| C9 | 40-49 | Female | Carer | Basic | No | No |
| C10 | 30-39 | Female | Carer | Intermediate | Yes | Yes |
| OP1 | 70-79 | Female | Older person | Basic | No | No |
| OP2 | 60-69 | Male | Older person | Basic | No | No |
| OP3 | 60-69 | Male | Older person | Advanced | Yes | Yes |
| OP4 | 70-79 | Male | Older person | Basic | No | No |
| OP5 | 70-79 | Female | Older person | Basic | No | No |
| OP6 | 60-69 | Male | Older person | Intermediate | Yes | Yes |
| OP7 | 70-79 | Female | Older person | Basic | No | No |
| OP8 | 60-69 | Female | Older person | Intermediate | Yes | Yes |
| OP9 | 60-69 | Female | Older person | Basic | Yes | Yes |
| OP10 | 70-79 | Male | Older person | Basic | Yes | Yes |

**Table 5-1: Participants' profile**

## 5.2.2 Experimental setup

There are various different approaches to evaluate a system: A laboratory-based demonstrator and a field trial. A laboratory-based demonstrator aims to evaluate the usability and usefulness of a specific prototype or product. A target group of user carry out a set of tasks and an evaluator controls the experiment. Quantitative data is collected by questionnaires and qualitative data by interviews and video. A field trial is usually installed in a natural environment, where the user is used to living. It is focused on observing the behaviour of the users using ethnographic methods. This approach is often used early in design to check that user's needs are being met or to assess problems. Qualitative data is collected using sketches, scenarios, quotes and anecdotes. Field trials of home care technology can be a time-consuming evaluation due to the installation and adjustment of technology (sensors, software) in place. For this thesis, a laboratory-based approach evaluation was selected because there were no resources to run a field trial (economic, time and human resources).

The experiments were carried out within a laboratory setting. The first part of the exercise was carried out individually. One older person and one carer were sitting together in the same room but with a different user interface, as shown in figure 5-1:

**Figure 5-1: Individual exercise**

The second part of the exercise was carried out in pairs either with user interface or none. Eight out of ten pairs of participants worked with user interface (four with the interface for older adults and four with the interface for carers) as shows in figure 5-2.

**Figure 5-2: Pairs exercise with user interface**

Two pairs of participants worked without user interface as shows in figure 5-3.

**Figure 5-3: Pairs exercise with no user interface**

After the second part the facilitator conducted a semi-structured interview with each pair of participants as illustrated in figure 5-4:

**Figure 5-4: Semi-structured interview**

### 5.2.3 Measures

While users were performing their tasks, an observer was taking notes. After each individual and pair task, the participants were requested to fill in a questionnaire. Furthermore, each session was video recorded as an extra source for the qualitative analysis of the data. After the pairs exercise, the facilitator conducted a semi-structured interview (see appendix D).

The evaluation of the prototype aimed to evaluate the usability criteria, the user experience and the usefulness of the prototype in terms of the measures shown in table 5-2.

In addition to these measures, the following user experience aspects were captured from observations and videos:

- Attitudes and feelings: Change in the confidence, enjoyment or pleasure, anxiety and nervous of the participants while doing the exercise;
- Perceptions: Participant feelings of both exercises;
- User preferences: Likes and dislikes of the user interface;
- User engagement: Interaction of the participants with the prototype.

| **Measures** | **Type of measure** | **Type of question** | **Part of the exercise** |
|---|---|---|---|
| Effectiveness: achievement of a task with accuracy and completeness | Usability | [1 - 5] Likert scale | Interview |
| Learnability: the degree to which a user interface can be learned quickly and effectively. | Usability | [1 - 5] Likert scale | Interview |
| Appropriateness: the relevance of the information presented and the ability of the system to do the task selected by the participant. | Usefulness | [1 - 5] Likert scale | Interview |
| Intuitive and self-explanative: the ability of the system to show data easy to understand for all the users | Usability | [1 - 5] Likert scale | Interview |
| Memorability: the ability of the DWIS system to help the participant to remember how to use the system. | Usability | [1 - 5] Likert scale | Interview |
| User satisfaction: the enjoyment and pleasure of the participant to work with the DWIS system. | User experience | [1 - 5] Likert scale | Individual |
| Reliability: the capability of the DWIS system to maintain a specified level of performance when used under specified conditions. | Usability | [1 - 5] Likert scale | Individual |
| System performance: time to logon and system response. | Usability | [1 - 5] Likert scale | Individual |
| Usefulness to support dialogue of care | Usefulness | [1 - 5] Likert scale | Pairs exercise |

**Table 5-2: Measures collected**

### 5.2.4 Methodology

The experimental setup described in section 5.2.2 was designed to gather evaluation data via direct observation, questionnaires, semi-structured interviews and video recording  to discover if DWIS could be used as a tool to enhance the dialogue of care between the older person and the carer.

#### 5.2.4.1 Orientation

At the beginning of each session, the facilitator explained the purpose and objective of the evaluation to the participants; gave a demonstration to show how the prototype worked (except for the first two sessions); and provided them with written instructions. The participants were requested to read and sign a consent form (see appendix D).

#### 5.2.4.2 Scenario

A scenario that described a diabetic person was given to the participants. This was a real case but the name was changed to maintain the privacy of the person. The scenario was as followed:

*‘Anne is suffering from a non-insulin dependent diabetes. The professional carer has been involved in monitoring her blood sugar levels for a considerable length of time before the start of the telecare project and has continued throughout the project. For some time Anne’s blood sugar levels were consistently out of the set range. Following the protocol the professional carer has been informing the GP about Anne’s blood sugar readings on a regular basis. As a result of this, the GP made a decision to change the medication on the 4th of March 2006. Unfortunately, this change of medication did not bring expected positive results and the participant’s blood sugar level remained high. Therefore, on 21st of April the GP decided to change the medication for the second time’.*

The data presented to the participants were contextual, health conditions and lifestyle data. The contextual and health data was gathered manually by informal and formal carers. The lifestyle data was gathered automatically from sensors installed in older adults’ homes.

- Contextual data: Patient's data such as changes in medication, hospitalisations, holidays, and falls could help the carers to build a real picture of the older person's well-being.
- Health conditions: Data such as blood sugar levels, blood pressure, pulse and other vital signals might help health staff to follow the status of a vulnerable older person.
- Lifestyle data: Data collected from sensors like PIRs (passive infrared sensors), bed and chair occupancy, door-usage (fridge, cupboard and wardrobe) and electrical-usage (kettle and lamp) could help the carer to have some indicators related to the older person's well-being such as mobility, sleeping, eating and drinking, and personal hygiene.

5.2.4.3 Exercise

Ten sessions were run, each with one older person and one carer. Each session had three parts: Individual, pairs exercise, and semi-structured interview. One or two sessions were conducted per day for two weeks. Each session lasted two-and-a-quarter-hours.

- **Individual exercise:** Participants were asked to explore the software for 5 minutes; and to verbalise their thoughts while carrying out the list of tasks for 45 minutes, which consisted in checking the mobility, sleeping, eating and drinking, personal hygiene and health conditions of an older person. In addition, the participants were asked to fill in a questionnaire that included questions about the data presented, usability, and usefulness of the DWIS system. Carers were requested to compare changes in the graphs before and after the medication event (described in the scenario). Each participant had a different set of tasks (see table 5-3), user interface (see figure 5-5 and 5-6), and questions during the first part according to their stakeholder group (older adults and carers).

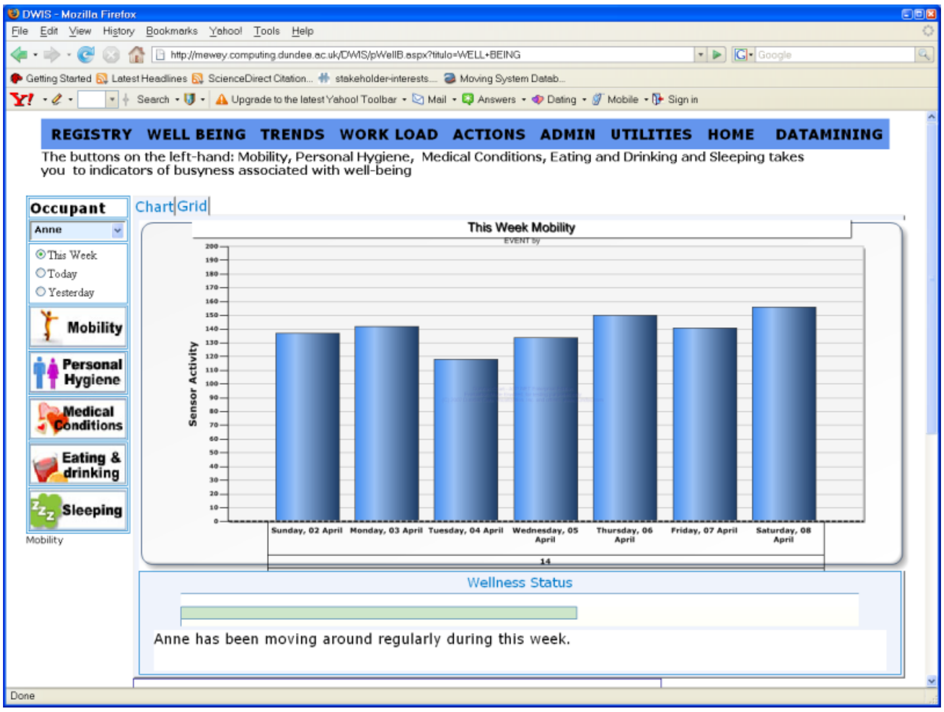



**Figure 5-5: User interface for older adults**

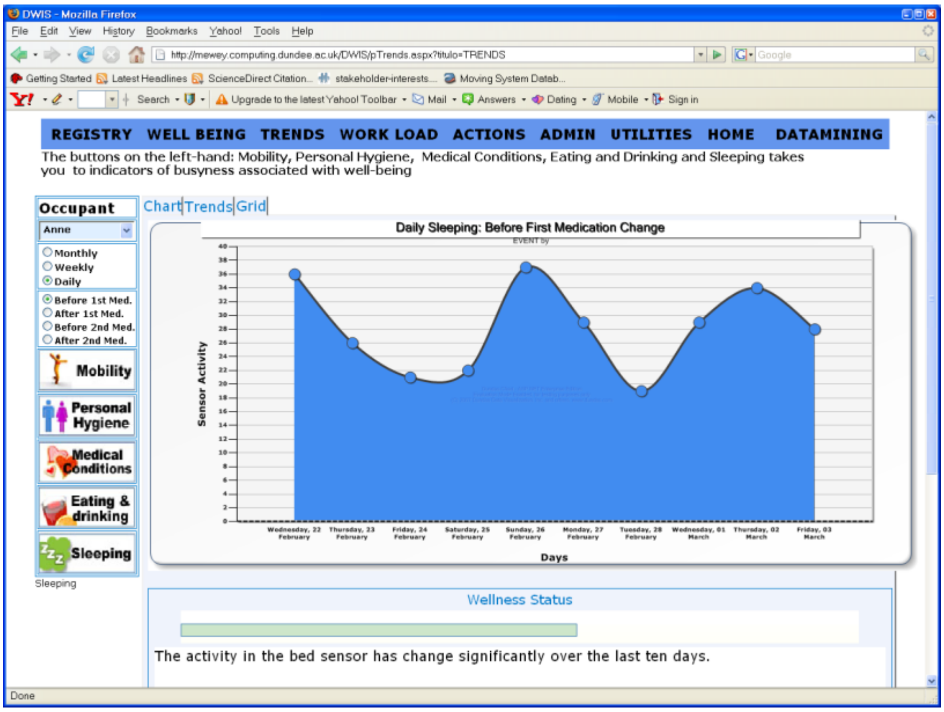



**Figure 5-6: User interface for carers**

- **Pairs exercise:** During the second part of the session, the older person and the carer worked together for 45 minutes using either the computer interface or none (see table 5-4). Each pair of participants had a different user interface: Older adults and carers interface (see figure 5-5 and 5-6) and a list of tasks (see table 5-5). The set of tasks was slightly different from the individual performance because participants were requested to discuss, check and compare changes in the graphs between days, weeks and months. In addition, the participants were asked to fill in a questionnaire that included questions about the data presented, usability, and usefulness of the DWIS system. There was a variation in the second part of the session, which consisted in asking the participants to discuss some hypothetical questions based on the scenario with no interface. Four out of ten sessions were carried out with the interface for older adults; four with the interface for carers; and two with no interface. The detail of each task is presented in appendix D.

| **Stakeholder** | **Task number** | **Task** |
|---|---|---|
| Informal and professional carer | 1 | Check health conditions by weeks |
| | 2 | Check daily well-being before / after first medication change |
| | 3 | Check daily well-being before / after second medication change |
| Older people | 1 | Check well-being for this week |
| | 2 | Check health conditions for this week |
| | 3 | Check well-being for today / yesterday |

**Table 5-3: Tasks list for the individual exercise**

For further details of the tasks see appendix D.

| **Participants** | **Type of user interface** |
|---|---|
| OP1 - C1 | Older adults |
| OP2 - C2 | None |
| OP3 - C3 | Older adults |
| OP4 - C4 | Carers |
| OP5 - C5 | Carers |
| OP6 - C6 | Carers |
| OP7 - C7 | Older adults |
| OP8 - C8 | Carers |
| OP9 - C9 | Older adults |
| OP10 - C10 | None |

**Table 5-4: Sessions Characteristics**

- **Semi-structured Interview:** After the second exercise, the facilitator conducted a semi-structured interview. The interview focused on discussing the issues that emerged during the individual and pairs exercise and evaluating the prototype as follows:
  - Participants' experience, preferences, and perceptions;
  - Participants' usability evaluation of the prototype;
  - Evaluation of the usefulness of the prototype as a tool to enhance the dialogue of care between the older person and the carer;
  - Participants' suggestions.

| **Type user interface** | **Task number** | **Task** |
|---|---|---|
| Older adults | 1 | Check well-being for this week |
| | 2 | Check well-being for today |
| | 3 | Check well-being for yesterday |
| Carers | 1 | Check well-being by months |
| | 2 | Check well-being by weeks |
| | 3 | Check health conditions by months and weeks |

**Table 5-5: Tasks list for the pairs exercise**

Specific, open and closed questions were used to evaluate the prototype individually and in pairs. Closed questions were evaluated using a 1-5-point Likert scale (1=very low, 5=very high). For further details of the questionnaire see appendix D.

### 5.2.5 Technical specifications

The database and the web application were running on a Windows 2003 server with SQL server 2005 and analysis services; and the two client stations, which had access to the DWIS system, were running on IMac using Firefox 2.0.012.

Having defined the participants' profile, the experimental setup, the measures to be collected, the methodology and the technical specifications, the next section describes the data analysis methods used during this evaluation study.

## *5.3 Data analysis*

Qualitative analysis methods (Holzinger, 2005; Abrahão, Iborra, and Vanderdonckt, 2008) (QSR, 2008) were employed to identify emerging categories from the evaluation data of the DWIS system collected from videos, questionnaires and interviews. Moreover, quantitative analysis was used to determine the mean score and deviation from the mean of each measure (Blythe, Monk, and Doughty, 2005).

### 5.3.1 Qualitative analysis

The information collected from videos, questionnaires and observations in the individual, pairs exercise  and semi-structured interview were transcribed and imported into NVivo 8 (Panek, Raujala, and Zagler, 2007) to start the data analysis.

To find the meaning of the data line by line coding was used at the beginning. Then, some preliminary categories were defined such as fear of technology, familiarity, data presentation, and training.

The initial categories were refined by making comparison among people based on the following factors: The user’s computing skills (basic, intermediate or advanced), the ability to read graphs, the stakeholder group (older adults and carers), the familiarity withreading graphs, the modality of the exercise (individual and in pairs) and the type of user interface (older adults, carers and none). Data was also compared at different points of time by observing the same participant: During the individual and pairs exercise; by comparing changes in the process such as becoming familiar with the DWIS system and becaming more relaxed.

Existing categories were refined and new categories were identified as described in section 5.4.1. Some cases, that characterised the participants who took part of this study, were identified. The results are shown in chapter 6.

### 5.3.2 Quantitative analysis

Descriptive statistics such as mean score, and standard deviation were used to analyse the data collected from questionnaires and semi-structured interviews. The mean gives a measure of how the average participant performs and evaluates the usability, user satisfaction and usefulness of the DWIS system.

The following section provides the results of the data analysis using the qualitative and quantitative methods described in this section.

## *5.4 Results*

The first part of this section described the categories that emerged from the qualitative analysis and provided some samples of the participants' opinion. Then, the remaining section presented the measures collected from the evaluation study described earlier in section 5.2.3 in terms of the usability, user experience and usefulness aspects.

### 5.4.1 Categories

The following categories emerged from the data analysis as shown in table 5-6.

| **Category** | **Properties** | **Related with** |
|---|---|---|
| Dialogue of care | Discuss evidence, focused conversation and share perceptions between stakeholders | Integrated data, user interface |
| Integrated data | Accessing data and purposes of data.<br>Data presentation: graphs, text and images with text. Quality of data: accuracy and reliability, refinement and normalisation | Ethical and safety, user interface |
| Ethical and safety | Privacy and security, confidentiality, informed consent | Integrated data, user interaction. |
| User interface | Navigation, visibility, personalisation and standardisation | User interaction, utility and benefits |
| User interaction | Struggle or cope with technology, achievement, familiarity and learning | Integrated data, user interface, utility and benefits and user experience |
| User experience | Attitudes and feelings (anxiety, nervousness, confidence), user engagement and enjoyment (motivation, involvement and satisfaction) | Integrated data, user interaction |
| Utility and benefits | Utilities: build a picture – make sense, monitor older adults, and raise questions. Benefits: better feedback and service, assertive decisions, on- | Dialogue of care, Integrated data and user |

| Category | Properties | Related with |
|---|---|---|
| | line data, quick overview and better use of time | interaction |
| Acceptability | Friendly, interesting, impressive, clear and visual | User interaction and user interface |

**Table 5-6: Emerged categories**

5.4.1.1 Dialogue of care

Figure 5-7 illustrates the category that emerged when the older person and the carer worked together in the second part of the exercise. It took place when the carer had access to the contextual, health and lifestyle data presented by the DWIS system to check and compare the key areas of well-being (mobility, eating and drinking, sleeping, personal hygiene and health conditions) of a hypothetical older person.


**Figure 5-7: Dialogue of care**

Participants said that the data provided by the DWIS system could be used in the following instances.

- **Discuss evidence:** According to several participants OP1, C1, OP7, OP8, C8, OP9, C9 and C10 the data could be used by carers as evidence of changes that might help them to raise questions to the older person. As an example, participant OP9 told us the following experience:

> ‘My mother is in a hospital mainly because she does not eat and drink, but she tells us that she did. So with something like this system, the carer would be able to say to my mother you are not eating.’

It is known that older adults don’t like to complain so they prefer to say that everything is fine when they do not feel very well. According to some participants, the DWIS system might help carers to interpret changes in the level of activity of the older person that could be related with changes in well-being.

- **Focused conversation:** Participants C3, C5, OP8, OP10 and C10 expressed that the data presented by the DWIS system could also enhance a focused conversation between the older person and the carer. For example, a conversation between an occupational therapist and an older person might focus on the mobility issues. In contrast, a conversation between a GP and an older person might focus on the health conditions.
- **Share perceptions between stakeholders:** Participants OP8, OP9, C0, OP10, C10 affirmed that having different points of view of the data collected from carers and medical staff might result in providing better feedback to the older person; making an assertive assessment of the older person’s needs; and suggesting a care plan or a new service. Participant C7 expressed:

> ‘It was much better because you have another person’s point of view.’

#### 5.4.1.2 Integrated data

This integrated data category emerged when participants were asked to look at the user interface. Participant C1 expressed that ‘It is good to know how the person is in terms of health conditions and level of activity’. And participant OP7 commented:

> ‘It will give you a true picture of what was happening at the house…. accurate data. Every time you are moving the sensors are recording.’

According to participant OP3, social interaction and emotional well-being are relevant areas of an older person’s well-being. He said:

> ‘Perhaps emotional and social well-being data is important. Based on the indicator presented maybe it is possible to build a picture about the emotional aspects’.

Accurate and reliable contextual, health and lifestyle data could be essential to help all the stakeholders involved in the care of the older person to make more assertive decisions.

Participants discussed the following aspects:

- **Accessing data:** Older adults could have access to the system from their home to check their own indicator of well-being; the informal and professional carers could have access to the system from their workplace and be aware of the older person’s well-being; and a family member could keep an eye on the older person by accessing the system on line from different places.

  Participant C3 said that ‘I think it would be useful to access the information as a professional in a laptop when you are visiting patients’. Participant C1 pointed out ‘The issue of letting an older person keeping an eye on her activity is really important’. Participant OP8 stated ‘I would imagine that this could be a valuable tool for the carer, professional or family member who cannot be present’.

- **Purposes of data:** The data could be accessed by different purposes according to the stakeholder. For instance an informal carer might be interested in knowing how the older person slept last night, whereas a physiotherapist might be interested in finding associations between different areas of well-being such as mobility and personal hygiene. Some participants were trying to find a relationship between the personal hygiene graph and the first medication change. For example:

‘Wednesday is the highest. On Sunday, there is less activity. Maybe the medication changed.’

- **Data presentation:** The data displayed in the user interface was represented in the following forms (see figures 5-5 and 5-6):
    - Graphs: Bar and trends graphs.
    - Text: A statement about the graph.
    - Images with text: Significant images and text to help users to remember the meaning of the option selected.

Both the older person’s and the carer’s interfaces had buttons with text and image, graph and a statement about the graph (see figures 5-5 and 5-6). All participants liked the buttons because the image helped them to remember the meaning of the option. Most of the participants expressed that graphs were clear and easy to read; however, participants OP1, OP5 and OP7 had difficulty in understanding the graphs at the beginning of the first session because they were not used to reading graphs. Participants C6 and C8 expressed that the trend graphs were better than bar graphs to see changes.  Some participants C1, C3 and C8 read the statement and agreed with it, but others disagreed with the statement.

- **Quality of data:** This category emerged when participants were doing the individual and pairs exercise. The quality of the data depends on the process of gathering data and the validation with the older person. The more quality of the data the better utility for all the stakeholders. According to the participants, the data presented should satisfy the following requirements:
    - **Accuracy and reliability:** The data presented need to be accurate, reliable, complete, correct, clear and coherent in order to help the user to make some analysis such as associations and correlation of different areas of well-being, recognise patterns, and make decisions. If the data presented was missing, inaccurate and ambiguous, it would provide little value to the end-user.

When the participants were working in pairs, some of them detected missing data, which was interpreted in different ways as follows. Participant OP3 said:

> ‘It is confusing to have the gap. I am a bit concerned whether the sensor activity is accurate. Why there is a gap.’

And participant OP7 commented ‘There is not activity until 2 a.m., then 5 p.m. perhaps she went to the toilet.’

Some participant also detected conflicting information. For example:

C3 said that ‘Quite conflicting information because if she went to bed at 6 p.m. why she is active in the evening*’.* OP3 added ‘I have faith that information presented is accurate and reliable’. C3 replied that *‘*In my experience working with community service there are problems with the sensors’.

The importance of the accuracy can vary according to the stakeholder. For example, for a professional carer, it is essential to have accurate data whereas, for an older person, it is not because he or she believes that the data is accurate.

- **Refinement:** The data presented also need to be detailed and specific but not to the point of being intrusive to the older person. For example, some carers C8, C9 and C10 wanted to know what the person is doing exactly, but older person OP10 argued that could be intrusive. He said: ‘You don't need to have a monitoring system with cameras, which is a big brother’.

  The DWIS system did not provide data about activities of daily living ADL. Instead, it provides the level of activity at different locations and periods of time. Using the concept of ‘busyness’ is possible to provide detailed data without being intrusive at different levels of granularity such as activity by room (bathroom, bedroom, hall kitchen and living room); by sensor (PIR, bed and chair occupancy, electrical and door usage); by time (month, week, day and hour) and by time zones (sleeping, morning, lunch, afternoon and evening).

- **Normalisation:** The data presented on graphs needs to show the normal range and the deviation of the activity from the normal according to several participants OP3, C3, C5, OP7, OP8, C8, C9, C10 and OP10. For example, the normal range for eating and drinking level of activity during the past ten weeks was 20 (sensor firings). The DWIS system should indicate the deviation from the normal on the graph. This feature was not implemented in the DWIS system, but it is recommended as a future work.

#### 5.4.1.3 Ethical and safety

The ethical and safety issues were discussed when the older person and the carer worked together and discussed the information presented. According to the participants, there were various ethical and safety issues to consider when contextual, health conditions and lifestyle data were gathered and provided to different stakeholders such as:

- **Privacy and security:** According to participants C7, C9 and OP10 monitoring older adults at their home could be perceived as an intrusive activity. For example:

  ‘Some older people find it intrusive to have pressure mats. Even in some cases, they don’t like a call in the morning. They want to be independent.’

  However, this issue could be reduced if the system let the end user configure the level of monitoring according to their needs. C10 commented that:

  ‘You need consultation with the individual to meet their needs. It needs to be personalised.’

- **Confidentiality:** Participant C10 said that the contextual, health conditions and lifestyle data are confidential. Therefore, in order to distribute this data among the various stakeholders, it is necessary to restrict the access to the appropriate medical or carer staff and to ensure the confidentiality of the data transmitted. This was one of the user requirements discussed with the participants who took part in the design of the DWIS system.

- **Informed consent:** Participant OP10 said that older adults should be informed to be monitored and they might agree to be asked specific questions that arise from the data collected.

#### 5.4.1.4 User interface

The user interface category appeared when the participants were asked to interpret the data presented in the DWIS system. According to the participants from the study, the most important characteristics of the user interface of a domestic well-being indicator system for older adults and carers were:

- **Navigation:** At the beginning of the individual exercise some older adults with basic computing skills had difficulty in using the mouse because the health conditions graphs had a horizontal scroll. However, when the participants worked in pairs the older person managed to use the mouse properly, because the carer explained how to use it. Hence, the user interface must avoid the use of horizontal scrolling.

- **Visibility:** Visual and clear user interface were important characteristics to consider when the data was presented to older adults and carers. Participants C5 and C7 expressed that it was easy to recognise changes in the activity level of the indicator of well-being by looking at the graphs. Furthermore, participant C2 said that it was easier to highlight changes by looking at the trend graphs rather than looking at papers. Participant C3 commented that ‘It is very clear to see the differences between before and after medication changes’. Participant OP3 said that ‘I am very happy with visual data’. Participant C1 added ‘you can monitor from one day to another and by weeks as well’.

- **Personalisation and standardisation:** Users might be able to personalise the user interface according to their preferences such as selecting the type of graph (bars and trends). Participant C8 said that 'I prefer to see the trends because it is easier to look at'.

  Carers were asked to compare two graphs, but the DWIS system did not present both graphs on the same screen. This was particularly unhelpful and difficult for some carers. Participant C9 commented that 'I would like to see everything in the same page'. And C4 added 'it would be more helpful to have both graphs in the same screen'.

  Participants were asked to evaluate the effectiveness of the textual wellness status at the bottom of the graph as a way to know the general well-being of the older person. Some of them liked it, others disliked it. Participant C9 pointed out that 'It gives you a guide of the wellness status but I prefer visual graphs'. OP10 commented 'Yes. I think it is a good pictorial way'. And OP7 observed that 'I read it a few times, but I suggest putting it in darker colour to draw the participant's attention'.

  The use of a standard user interface was essential to avoid misinterpretation of the data presented. The 'busyness' level of three of the four graphs (mobility, eating and drinking, and personal hygiene) meant: The more activity the busier the person was. These graphs were easy to understand and interpret. However, the 'busyness' in the sleeping graph meant the more activity, the less restless the person was. This was a bit confusing for participants OP7 and C7. Hence, it is recommendable to have a standard user interface template for all pages to avoid confusion among the participants.

#### 5.4.1.5 User interaction

This category referred to how the participants approached the exercise, how they learned to use the DWIS system, and how the behaviour of the participants changed throughout the exercise.

At the beginning of the first section, some participants had difficulty in understanding graphs and using the mouse; they got confused and felt lost with the user interface and disagreed with the graphical and textual data (struggled with technology). However, some participants found the exercise, graphs and user interface easy and simple to understand; and felt confident using the DWIS system (coped with technology). It also occurred when the participant became familiar with the DWIS system and managed to complete a task successfully either with help or no help (achievement).

Some older adults and carers felt unconfident, nervous and anxious at the beginning of the session . After they became familiar with the DWIS system, they were more relaxed (familiarity). Despite completing the task, however, participant OP1 still commented ‘I am not sure if I did the right job’.

The way that participants learned to use the DWIS system varied according to the modality of the exercise (individual or in pairs), the user computing skills, the ability to read graphs and the familiarity with the DWIS system.

Three different ways of learning were identified throughout the study:

- **Tutor – learner**: this happened when the participant learned by observing the demonstration and by asking some questions to the facilitator.
- **Self-learning:** this happened when the participant explored the DWIS system by himself or herself based on the demonstration and following the written instructions.

- **Peer-to-peer:** this appeared when the participants learned by interacting with a peer during the second part of the exercise.

5.4.1.6 User experience

The interaction between the participants and the DWIS system revealed the user experience, like attitudes and feelings, user engagement and enjoyment. These aspects varied according to the user computing skills, the confidence using technology, the stakeholder group, the modality of the exercise (individual or in pairs), and the familiarity with the DWIS system.

- **Attitudes and feelings:** The confidence, anxiety and nervousness of the participants while doing the exercise changed throughout the study. Some participants, who had basic computer skills, felt unconfident, nervous and anxious at the beginning of the individual exercise. Participant OP5 commented that 'I get mixed up. I am not sure if I am doing it properly'; and participant C2 expressed 'I don't know why I accepted to do this'.

  When participants worked in pairs and became familiar with the DWIS system, they were more confident and relaxed. When participant OP5 was asked to evaluate the DWIS system in the semi-structured interview, she expressed:

  'To begin with I found it quite difficult. Then, it becomes easier.'

- **User engagement and enjoyment:** The motivation, involvement, enjoyment, and satisfaction of the participants were observed. Some participants gave very little input during the individual performance, but when they worked in pairs, they were more engaged and provided more feedback to the exercise.

  Some participants expressed that the second part of the exercise was more enjoyable than the first part. Participant OP1 commented that 'I felt much pleasure doing the second part because the first part was particularly difficult'.

5.4.1.7 Utility and benefits

This category emerged when participants were carrying out their tasks and evaluating the DWIS system. According to the participants, having contextual, health conditions and lifestyle data together might provide some utility and benefits to the stakeholders (cared for, professional and informal carers). The following were the utilities found by the participants:

- **Build a picture – make sense:** By looking at the graphs both older adults and carers might be able to build a picture of the older person’s life based on the data provided by the DWIS system. For instance, poor sleeping and lots of mobility during the night might indicate an ongoing situation in the older person’s health. Participant OP9 expressed that ‘By reading the graph, you are able to build a picture in your head’. Participants OP8 and C8 wanted to correlate the medical information with the sleeping and mobility pattern to see how it affects each other.
- **Monitor older adults:** Participant C1 and C3 said that the DWIS system could help to monitor key areas of well-being such as sleeping, eating and drinking, mobility, personal hygiene and health conditions. Furthermore, it could help to see the effect of medication taken. Participant C3 commented:

  > ‘We can probably from physio or occupational therapist point of view see how the person is moving around the house and see if the medication has or not an effect.’

  Independent but vulnerable older adults could be monitored at their home instead of living in sheltered accommodation. Participant C8 said that the DWIS system might help to support people who want to be at their home and vulnerable people. She pointed out:

  > ‘I think people are living longer and they want to be at home as much as possible rather than ending in a 24-hour-carer house. I think that for those

> people the system could be very useful. And also for patients that are well one minute and unwell the other minute.'

Moreover, participant C3 found very useful the facility to show the data at different periods of time: Months, weeks, days, hours and period of time. Participant C2 commented:

> 'It is very useful. You can see and observe what happened for the whole week. It is useful to find out which day the person is not good.'

Participant C9 noted that the DWIS system could be a non-intrusive way of being aware of older adults without asking the older person all the time. By looking at the graphs, carers could analyse the 'busyness' level of each key area of well-being, recognise patterns and see changes easily.

- **Raise questions:** The DWIS system could help the carer to raise questions to the older person based on the data collected by different sources automatically or manually. For example, changes in the personal hygiene level of activity could be caused by changes in the eating and drinking habits or by changes in medications. In order to know the real meaning of the changes reported by the DWIS system, the carer must validate this information with the older person.

  Participant C3 said that the DWIS system is useful for supporting a dialogue of care because it gives carers a question to ask. For example, participant OP1 expressed:

> 'I got an idea that the carer and the older person sit together and the carer explained what was going on. The carer is able to see how frequently the older person visited the bathroom, so the carer can raise a question such as can you tell me why?'

According to the participants, the benefits could be enormous. If contextual, health conditions and lifestyle data are carefully collected and are safely available for all the stakeholders involved in the care of the older person. The following were the benefits identified:

- **Better feedback and service:** The DWIS system could support the carer by providing data from key areas of well-being. For example, the professional carer can suggest a care plan, provide feedback or a service to the older person; the GP might want to know the relationship between the blood sugar levels and the eating and drinking patterns of the older person. The physiotherapist might be interested in looking at the mobility and personal hygiene patterns. Participant C10 said:

  'It is easier to transfer data between different stakeholders: a district nurse, a GP. Obviously, this is confidential data but it makes it easier to feedback to the older person.'

- **Make assertive decisions:** Carers could have updated data to make more assertive decisions. Participant OP9 commented that 'If someone had a bad night because he or she is eating too much maybe medication needs to be moved slightly so you can sleep better at night'.

- **On-line data:** Having data available on-line for older adults, family members and carers might help them to check the well-being of the older person from any place at any time. Participant OP8 expressed that 'I would imagine that this could be a valuable tool for the carer, professional or family members who cannot be present'.

- **Quick overview:** Some carers liked the issue of presenting well-being indicators and health conditions together as a valuable tool to keep an eye on the older person, because at the present, they have to report verbally or on paper to other carer the status of the older person. Several participants C1, OP2, C2, OP4, C4 and OP9 found the DWIS system very useful to highlight changes in the activity of 'busyness' related with well-being; because the system presents visual data that make it easier to see changes. For example, participant C2 said:

> ‘It is very useful. You can see and observe what happened for the whole week. It is useful to find out which day the person is not good.’

Participant C4 added:

> ‘It is definitely useful. I think it is a good way to put the information together. At the moment you have to make phone calls to find out how the person is going’.

Participant C6 commented:

> ‘It is very informative and handy. I am working for a sheltered house and sometimes I forget to tell somebody about a tenant but if we would have this system you can check over the computer and keep an eye.’

Participant OP7 pointed out:

> ‘It will give you a true picture of what was happening at the house. Every time you are moving the sensors are recording.’

- **Better use of time:** Carers could use their time more effectively and efficiently. Participant C3 said:

> ‘I think this DWIS system is incredibly useful for using my time more effectively and efficiently. From the practical point of view, before visiting a person look at the graph and raise your questions.’

#### 5.4.1.8 Acceptability

In order to know the acceptability of the system, the participant were asked to answer the following questions during the semi-structured interview:

What do you think about putting this kind of software into the older person’s home, who requires care, and into the carer’s workplace and about allowing both the carer and the older person to use the DWIS system?

Some people would like to have a system like this, but others would use it depending on the circumstances of the older person. Participant OP5 said that ‘I would like to have a system in my home because carer will be able to see the changes’. Participant OP9 added ‘Personally, I think it is a good thing to install the system in my house if I am a lot older or more ill’. In contrast Participant C10 pointed out:

> ‘I think some people will accept it, but others won’t. You need consultation with the individual to meet their needs. It needs to be personalised.’

Some people thought it was a good idea to let the older person to have access to the system, but others considered that it was not appropriate. Participant C1 commented ‘The issue of letting an older person keep an eye on her activity is really important’. However, the pair of participants OP3 - C3 though ‘It’s probably not a good idea to provide this information to the older person if they have disabilities or they don’t bother to know about it’.

Some participants made some positive comments and gave feedback of the DWIS system at the end of the semi-structured interview. For example, participant C7 found the DWIS system friendly, impressive and clear. Participant OP10 added ‘This software is very friendly, better than other that I used for my job’. Participant C9 said that ‘Quite impressed but have no previous experience of this to compare’. And participant C5 pointed out that ‘I think this is a fantastic assessment tool’.

### 5.4.2 Usability evaluation

According to many authors (Blythe *et al.*, 2005), the usability of a system should be evaluated taking into account the effectiveness, learnability, memorability and user satisfaction. The effectiveness of the DWIS system was evaluated using some quantitative measures. The learnability and memorability were rated using a 1-5 point Likert scale (1=very low, 5 =very high). In addition to these measures, the appropriateness of the set of functions, the intuitiveness and self-explanative characteristics of the data presented, the system performance and the reliability were evaluated using the same Likert scale. Some measures were evaluated individually and others in pairs. The user satisfaction measure will be discussed in detail in section 5.4.3.

#### 5.4.2.1 Effectiveness

The effectiveness of the DWIS system was evaluated as the ability of the system to help the participant to achieve his/her tasks. It was measured using the Common Industry Format (CIF) for usability test: The completion rate and the number of assists (Blythe *et al.*, 2005). The completion rate is the percentage of task completed without assistance or with assistance.

| Participant | Without assistance task completion rate % | Assistance task completion rate % | Time to complete task mins:secs | Time for assistance mins:secs | Number of assists |
|---|---|---|---|---|---|
| OP1 | 99.04 | 0.96 | 14:36 | 00:20 | 2 |
| OP2 | 94.13 | 5.87 | 18:52 | 01:23 | 4 |
| OP3 | 100.00 | 0.00 | 12:39 | 00:00 | 0 |
| OP4 | 94.57 | 5.43 | 20:24 | 00:57 | 2 |
| OP5 | 94.08 | 5.92 | 14:02 | 00:56 | 4 |
| OP6 | 100.00 | 0.00 | 16:48 | 00:00 | 0 |
| OP7 | 92.97 | 7.03 | 27:26 | 01:32 | 5 |
| OP8 | 100.00 | 0.00 | 27:18 | 00:00 | 0 |
| OP9 | 100.00 | 0.00 | 13:02 | 00:00 | 0 |
| OP10 | 90.86 | 9.14 | 20:32 | 01:53 | 4 |
| **Mean** | **96.56** | **3.44** | **18:34** | **01:10** | **2.10** |

**Table 5-7: Effectiveness for older adults**

| Task: subtask | Average of without assistance task completion rate % | Average of assistance task completion rate % | Number of assists |
|---|---|---|---|
| **Task 1** | | | |
| Subtask 1: Mobility this week | 93.68 | 6.32 | 4 |
| Subtask 2: Sleeping this week | 92.44 | 7.56 | 4 |
| Subtask 3: Eating and drinking this week | 99.42 | 0.58 | 1 |
| Subtask 4: Personal hygiene this week | 100.00 | 0.00 | 0 |
| **Total task 1** | **96.38** | **3.62** | **9** |
| **Task 2** | | | |
| Subtask 1: Health conditions this week | 94.28 | 5.72 | 4 |
| **Total task 2** | **94.28** | **5.72** | **4** |
| **Task 3** | | | |
| Subtask 1: Mobility for today | 97.71 | 2.29 | 2 |
| Subtask 2: Sleeping for today | 91.74 | 8.26 | 2 |
| Subtask 3: Eating and drinking for today | 100.00 | 0.00 | 0 |
| Subtask 4: Personal hygiene for today | 100.00 | 0.00 | 0 |
| **Total task 3** | **97.36** | **2.64** | **4** |

**Table 5-8: Decomposition of effectiveness for older adults**

- **Individual exercise:** Participants were asked to complete a set of tasks individually. They were also asked to fill in a questionnaire that included questions about the data presented, usability, and usefulness of the DWIS system. The time taken to complete the questionnaire was not taken into account to calculate the effectiveness because these tasks included to write down the answers on paper, which might bias the measure.

Table 5-7 showed the effectiveness for older adults in executing the set of tasks. It illustrated that, on average, an older adult took 18 minutes 34 seconds to complete the set of tasks. The data also showed that four out of ten participants successfully completed the set of tasks without assistance and that six out of ten completed the tasks with assistance.

According to table 5-8, task 1 is the one for which participants required more assists (nine times). Subtask 1 and 2 required four assists, followed by subtask 3 with one assist. Subtask 4 did no required assistance. It was observed by looking at the video that some participants got lost at the beginning of the individual exercise; they did not know what to do when they approached subtask 1. The difficulty in subtask 2 was that the sleeping graph meant the more activity the less restless the person was, while three of the other graphs meant the more activity the busier the person was. The lack of a standard in the data presentation made the user misunderstand the meaning of the data presented.

Table 5-9 showed the effectiveness for carers in executing the set of tasks. It was observed that the carer took an average of 20 minutes 5 seconds to complete the set of tasks. In terms of effectiveness, three out of ten participants successfully completed the set of tasks without assistance and that seven out of ten completed the tasks with assistance.

| Participant | Without assistance task completion rate % | Assistance Task completion rate % | Time to complete task mins:secs | Time for assistance mins:secs | Number of Assists |
|---|---|---|---|---|---|
| C1 | 100.00 | 00.00 | 15:39 | 00.00 | 0 |
| C2 | 95.23 | 4.77 | 25:18 | 01:08 | 3 |
| C3 | 99.65 | 0.35 | 13:19 | 00:09 | 1 |
| C4 | 79.23 | 20.77 | 13:25 | 03:37 | 5 |
| C5 | 92.51 | 7.49 | 24:56 | 02:53 | 5 |
| C6 | 100.00 | 0.00 | 14:40 | 00.00 | 0 |
| C7 | 96.93 | 3.07 | 36:58 | 01:08 | 2 |
| C8 | 91.09 | 8.91 | 21:01 | 02:13 | 2 |
| C9 | 100.00 | 0.00 | 21:44 | 00.00 | 0 |
| C10 | 95.61 | 4.39 | 13:50 | 00:39 | 2 |
| **Mean** | **95.03** | **4.97** | **20:05** | **01:41** | **2.00** |

**Table 5-9: Effectiveness for carers**

| Task: subtask | Average of without assistance task completion rate % | Average of assistance task completion rate % | Number of assists |
|---|---|---|---|
| **Task 1** | | | |
| Subtask 1: Health conditions this week | 89.20 | 10.80 | 4 |
| **Total task 1** | **89.20** | **10.80** | **4** |
| **Task 2** | | | |
| Subtask 1: Daily mobility before medication change | 99.05 | 0.95 | 1 |
| Subtask 2: Daily sleeping before medication change | 96.10 | 3.90 | 3 |
| Subtask 3: Daily eating and drinking before medication change | 96.56 | 3.44 | 1 |
| Subtask 4: Daily personal hygiene before medication change | 97.48 | 2.52 | 2 |
| **Total task 2** | **97.30** | **2.70** | **7** |
| **Task 3** | | | |
| Subtask 1: Daily mobility after medication change | 88.06 | 11.94 | 3 |
| Subtask 2: Daily sleeping after medication change | 93.81 | 6.19 | 1 |
| Subtask 3: Daily eating and drinking after medication change | 83.25 | 16.75 | 1 |
| Subtask 4: Daily personal hygiene after medication change | 100.00 | 0.00 | 0 |
| **Total task 3** | **91.28** | **8.72** | **5** |

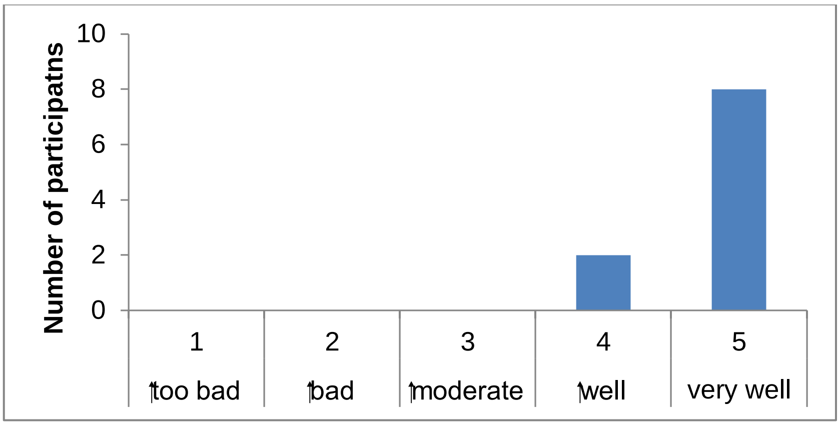
**Table 5-10: Decomposition of effectiveness for carers**

According to table 5-10, task 2 was the one for which participants required more assists (seven times). Subtask 2 required three assists, followed by subtask 4 with two assists, and subtask 1 and 3 with one assist.

Carers had the same problem as older adults in understanding the meaning of the sleeping graphs. In subtask 4, the carers asked for the meaning of the personal hygiene because they wanted to have more details to know what exactly the occupant was doing in the bathroom.

The effectiveness of the DWIS system was also measured by asking the participants to rate how well they accomplished their task goals. The following were the results by stakeholder group using a 1-5 point Likert scale:

a)




b)

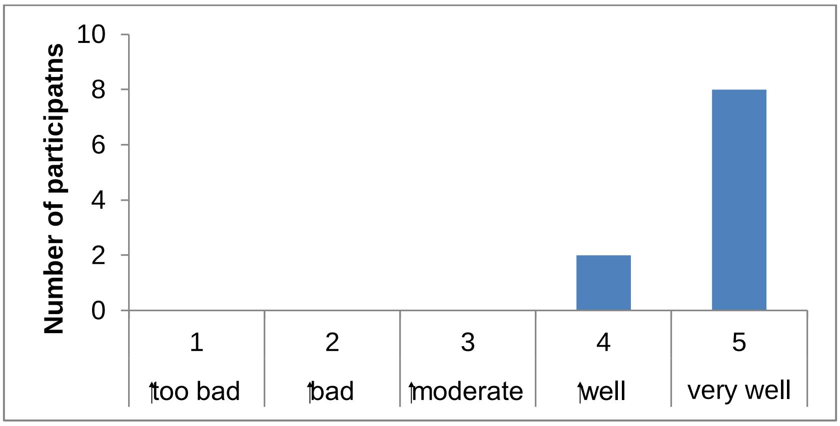



**Figure 5-8: Effectiveness a) older adults b) carers**

Figure 5-8 a) and b) showed that the effectiveness was rated equally by older adults and carers. It illustrated that in total 16 out of 20 participants gave a score of 5 and only 8 gave a score of 4 to this measure. The mean score was 4.80 with a standard deviation of 0.422.

The quantitative and qualitative data confirmed that the DWIS system was very effective to let the participants complete their tasks.

- **Pairs exercise:** The pairs of participants carried out different set of tasks and questionnaires. Four pairs of participants worked with the user interface for older adults, four with the one for carers and 2 with no interface. The following were the results:

| Pairs of participants | Without assistance task completion rate % | Assistance Task completion rate % | Time to complete task mins:secs | Time for assistance mins:secs | Number of Assists |
|---|---|---|---|---|---|
| OP1 - C1 | 100.00 | 0.00 | 17:44 | 00:00 | 0 |
| OP3 - C3 | 100.00 | 0.00 | 32:31 | 00:00 | 0 |
| OP7 - C7 | 84.37 | 15.63 | 30:49 | 08:45 | 6 |
| OP9 - C9 | 99.46 | 0.54 | 19:13 | 00:10 | 1 |
| **Mean** | **95.96** | **4.04** | **25:04** | **04:28** | **1.75** |

**Table 5-11: Effectiveness using the older adults' interface**

Table 5-11 showed the effectiveness in executing the set of tasks in pairs using the interface for older adults. It illustrated that on average, the participants took 25 minutes 4 seconds to complete the set of tasks. The data also showed that half of the pair of participants successfully completed the set of tasks without assistance and that the other half completed the tasks with assistance. The pair of participant OP7 – C7 required 6 assists because the carer was so concerned about the accuracy of the data presented by the DWIS system. For example, the sleeping graph showed that there was activity in the bed sensor at 6 p.m. and at the same hour, there was activity in the kitchen and in the bathroom. The explanation given to the carer was that a person could move at different places in a period of 1 hour.

Table 5-12 showed that, task 2 was the one for which participants required more assists (four times). Subtask 2 required two assists, followed by subtask 3 and 4 with one assist each and subtask 1 with no assist.

| Task: subtask | Average of without assistance task completion rate % | Average of assistance task completion rate % | Number of assists |
|---|---|---|---|
| **Task 1** | | | |

| **Task: subtask** | **Average of without assistance task completion rate %** | **Average of assistance task completion rate %** | **Number of assists** |
|---|---|---|---|
| Subtask 1: Mobility this week | 100.00 | 0.00 | 0 |
| Subtask 2: Sleeping this week | 95.96 | 4.04 | 1 |
| Subtask 3: Eating and drinking this week | 98.26 | 1.74 | 1 |
| Subtask 4: Personal hygiene this week | 100.00 | 0.00 | 0 |
| **Total task 1** | **98.56** | **1.44** | **2** |
| **Task 2** | | | |
| Subtask 1: Mobility for today | 100.00 | 0.00 | 0 |
| Subtask 2: Sleeping for today | 89.49 | 10.51 | 2 |
| Subtask 3: Eating and drinking for today | 92.98 | 7.02 | 1 |
| Subtask 4: Personal hygiene for today | 93.32 | 6.68 | 1 |
| **Total task 2** | **93.95** | **6.05** | **4** |
| **Task 3** | | | |
| Subtask 1: Mobility for yesterday | 100.00 | 0.00 | 0 |
| Subtask 2: Sleeping for yesterday | 79.48 | 20.52 | 1 |
| Subtask 3: Eating and drinking for yesterday | 100.00 | 0.00 | 0 |
| Subtask 4: Personal hygiene for yesterday | 100.00 | 0.00 | 0 |
| **Total task 3** | **94.87** | **5.13** | **1** |

**Table 5-12: Decomposition of effectiveness for pairs exercise using the interface for older adults**

Table 5-13 showed the effectiveness in executing the set of task in pairs using the interface for carers. It was observed that the pair of participants took an average 17 minutes 15 seconds to complete the set of tasks. In terms of effectiveness, half of the pair of participants successfully completed the set of tasks without assistance and the other half completed the tasks with assistance.

| **Pairs of participants** | **Without assistance task completion rate %** | **Assistance Task completion rate %** | **Time to complete task mins:secs** | **Time for assistance mins:secs** | **Number of Assists** |
|---|---|---|---|---|---|
| OP4 - C4 | 100.00 | 0.00 | 10:52 | 00:00 | 0 |
| OP5 - C5 | 99.70 | 0.30 | 22:29 | 00:05 | 1 |
| OP6 - C6 | 100.00 | 0.00 | 10:46 | 00:00 | 0 |
| OP8 - C8 | 99.46 | 0.54 | 24:53 | 00:10 | 1 |
| **Mean** | **99.79** | **0.21** | **17:15** | **00:08** | **0.50** |

**Table 5-13: Effectiveness using the interface for carers**

By looking at table 5-14, subtask 1 of task 1 was the one for which participants required assistance (twice). The reason was that the pair of participants chose the wrong interface at the beginning of the pairs exercise.

| Task: subtask | Average of without assistance task completion rate % | Average of assistance task completion rate % | Number of assists |
|---|---|---|---|
| **Task 1** | | | |
| Subtask 1: Mobility by months | 97.26 | 2.74 | 2 |
| Subtask 2: Sleeping by months | 100.00 | 0.00 | 0 |
| Subtask 3: Eating and drinking by months | 100.00 | 0.00 | 0 |
| Subtask 4: Personal hygiene by months | 100.00 | 0.00 | 0 |
| **Total task 1** | **99.31** | **0.69** | **2** |
| **Task 2** | | | |
| Subtask 1: Mobility by weeks | 100.00 | 0.00 | 0 |
| Subtask 2: Sleeping by weeks | 100.00 | 0.00 | 0 |
| Subtask 3: Eating and drinking by weeks | 100.00 | 0.00 | 0 |
| Subtask 4: Personal hygiene by weeks | 100.00 | 0.00 | 0 |
| **Total task 2** | **100.00** | **0.00** | **0** |
| **Task 3** | | | |
| Subtask 1: Health conditions by months | 100.00 | 0.00 | 0 |
| **Total task 3** | **100.00** | **0.00** | **0** |

**Table 5-14: Decomposition of effectiveness for pairs exercise using the interface for carers**

The pairs of participants OP2 – C2 and OP10 – C10 completed a questionnaire with no user interface. Therefore, the effectiveness was not calculated.

#### 5.4.2.2 Learnability

Participants were requested to evaluate this measure individually during the semi-structured interview. The following were the results using a 1-5 point Likert scale.

Figure 5-9 showed the learnability evaluated by older adults. It illustrated that 6 out of 10 participants gave a score of 5; 3 gave a score of 4 and 1 gave a score of 3. The mean for the learnability was 4.50 with a standard deviation of 0.707. The standard deviation was a little bit bigger than for the effectiveness.

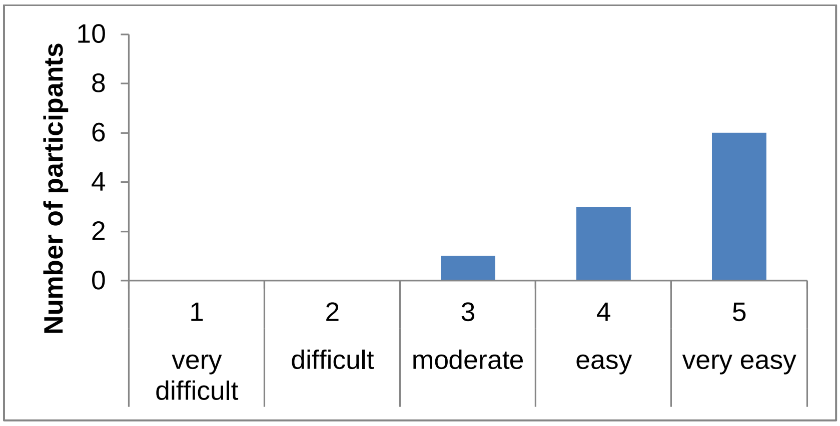



**Figure 5-9: Learnability (older adults)**

Figure 5-10 showed the learnability evaluated by carers. It was observed that 7 out of 10 participants gave a score of 5 and 3 gave a score of 4. The mean for the carers was 4.70 with a standard deviation of 0.483.

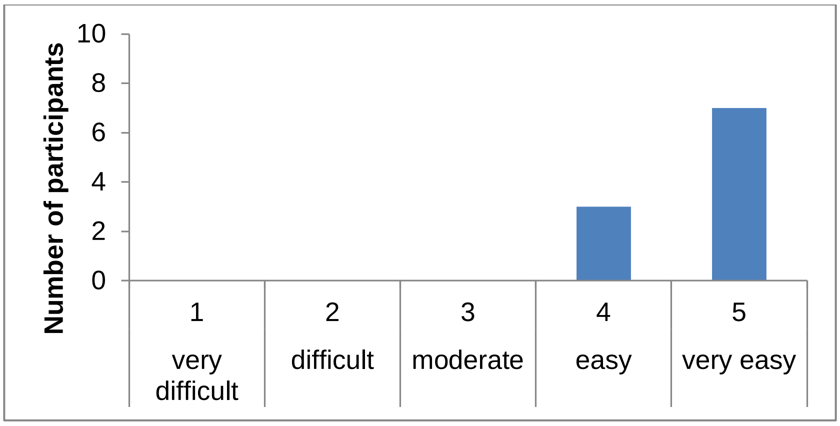
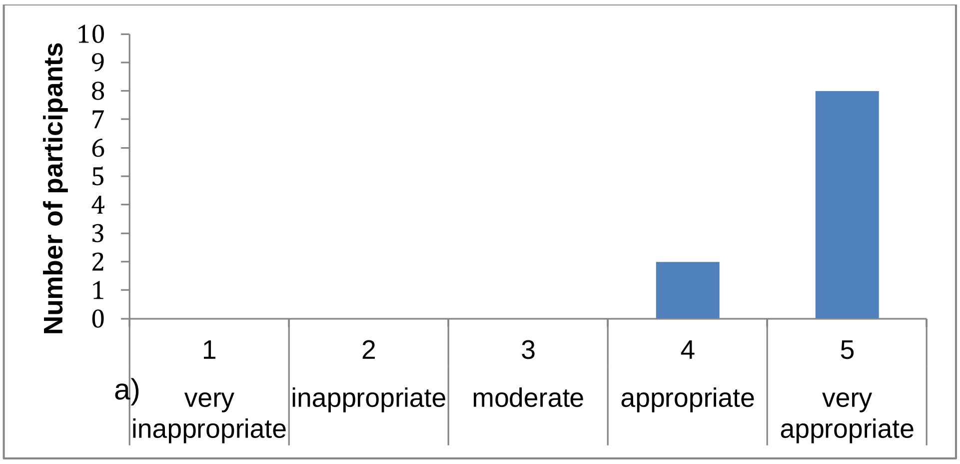



**Figure 5-10: Learnability (carers)**

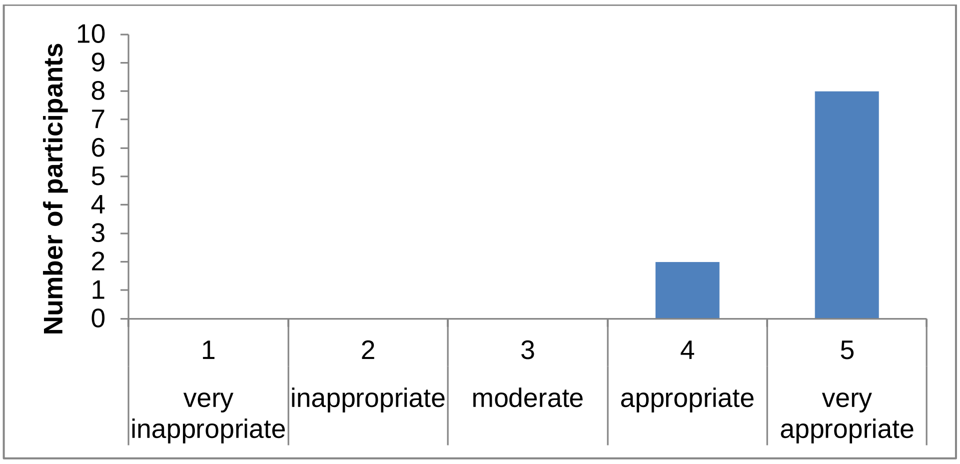
Learning the DWIS system and understanding the graphs was a problem for some participants, who had basic computer skills, who were not used to reading graphs, and who were unconfident using the computer at the beginning of the individual exercise. However, when the participants became familiar with the DWIS system and worked together with their peers, the degree of understanding graphs increased, because participants helped each other to understand the meaning of the graphs.

### 5.4.2.3 Appropriateness

This measure was evaluated individually during the semi-structured interview. The following were the results:




a)




b)

**Figure 5-11: Appropriateness a) older adults b) carers**

According to figure 5-11 a) and b) the appropriateness of the DWIS system was evaluated equally by carers and older adults. It illustrates that 16 out of 20 participants gave a score of 5 and only 4 gave a score of 4 to this measure. The mean was 4.80 with a standard deviation of 0.422. This measure had the same behaviour as the effectiveness.

Having an appropriate set of functions was highly qualified by both older adults and carers. For example, C1 commented that ‘It is good to know how the person is in terms of health conditions and level of activity’. OP9 pointed out ‘Very appropriate. It covers everything that you need for a care package.’ In addition, the participant C5 expressed that the DWIS system could be potentially used as an assessment tool to help carers to establish a care plan for the older adults.

5.4.2.4 Intuitiveness and self-explanative

Participants evaluated the intuitiveness and self-explanative nature of data presented in the DWIS system during the individual exercise. The following were the results using a 1-5 point Likert scale:

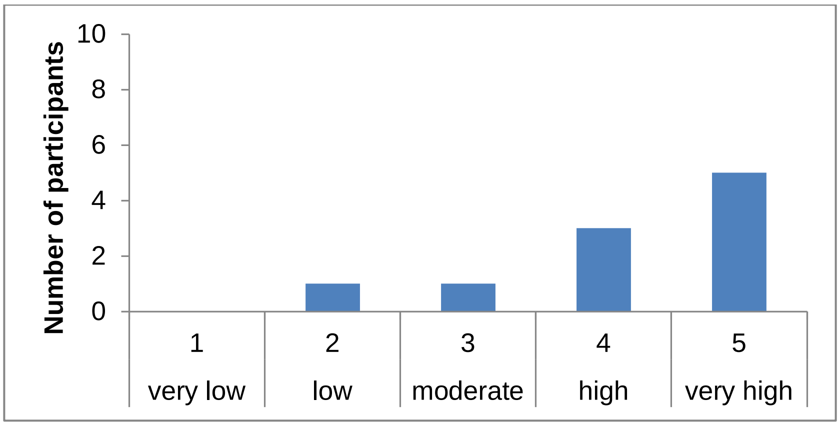



**Figure 5-12: Intuitiveness and self-explanative (older adults)**

Figure 5-12 showed the intuitiveness and self-explanative nature of the DWIS system evaluated by older adults. It illustrated that half of the participants gave a score of 5; 3 gave a score of 4, 1 gave a score of 3 and 1 gave a score of 2. The mean was 4.20 with a standard deviation of 1.033. Because the values of the score were dispersed between 2 and 5, the standard deviation was bigger than the other measures analysed before.

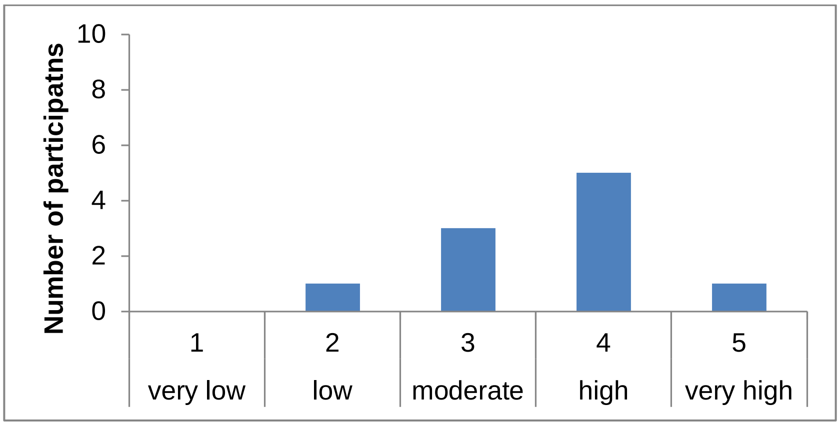


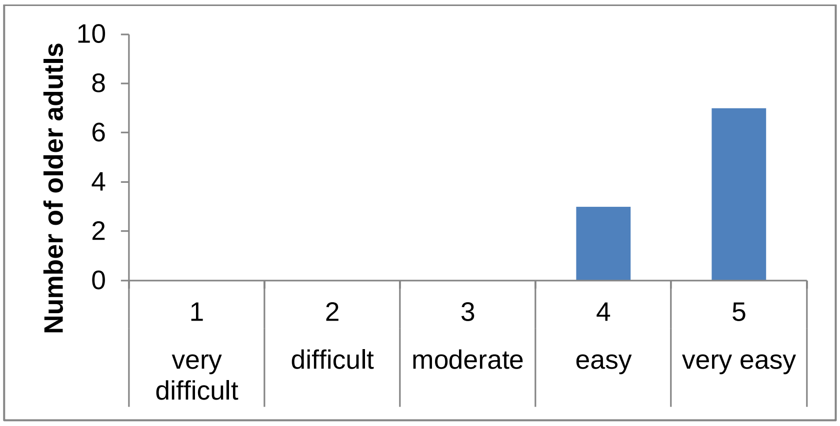

**Figure 5-13: Intuitiveness and self-explanative (carers)**

According to figure 5-13, only 1 carer gave a score of 5; 5 participants gave a score of 4; 3 gave a score of 3, and 1 gave a score of 2. The mean for this measure was 3.60 with a standard deviation of 0.843. Some participants had problems in understanding the graphs because they were not used to reading graphs. In contrast, some participants found the graphs clear and easy to understand by looking at them. Some participants disagreed with the summary at the bottom of the graph because it was too general and ambiguous. However, others agreed and said that it was good to have a summary. Some carers found difficulty in making comparison between graphs because the DWIS system did not show two graphs on the same screen.

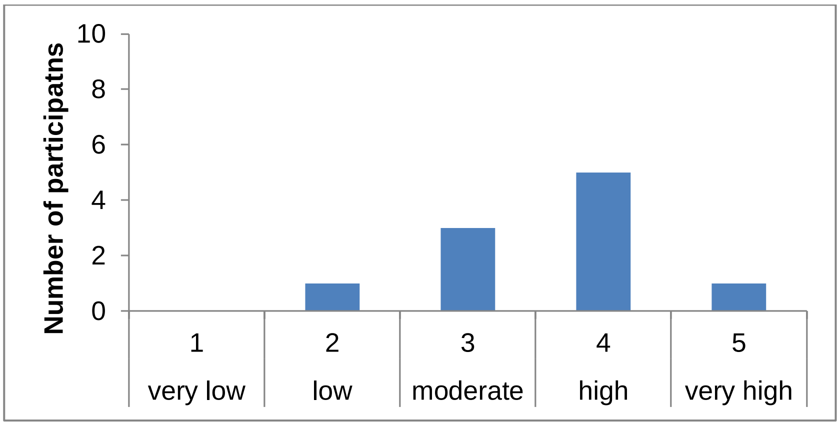
#### 5.4.2.5 Memorability

Participants were asked to evaluate individually how easy it was to remember the DWIS system during the semi-structured interview using a 1-5 point Likert scale. They carried out a set of tasks individually and after a short break of 15 minutes, they did a set of tasks in pairs which provided the possibility to measure this aspect at different circumstances. In the first part, they saw a short demonstration of how to use the DWIS system. Then, in the second part, they were familiar with the DWIS system. The following were the results:

According to figure 5-14 a) and b) this measure was evaluated equally for older adults and carers. It shows that 14 out of 20 participants found the DWIS system very memorable and 6 found it memorable. The mean for the memorability was 4.70 with a standard deviation of 0.483.




a)




b)

**Figure 5-14: Memorability a) older adults b) carers**

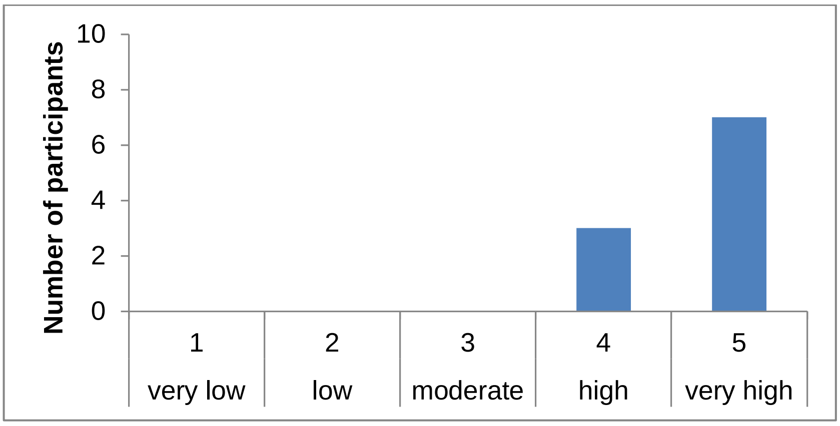
Most of the participants found the DWIS system very memorable because significant images and the visual interface helped them to remember how to use the DWIS system. Some participants had difficulty in remembering how to use the DWIS system at the beginning of the individual exercise so they made some mistakes such as selecting the wrong option from the menu. Nevertheless, when the participant became familiar with the DWIS system, they coped very well with the tasks.

The memorability was not measured by comparing the time taken to complete a task in the first and second part of the exercise because in the first part of the exercise, the participants worked individually and in the second part they worked in pairs.

5.4.2.6 Reliability

Participants were asked to evaluate whether the DWIS system was reliable to use (fail or not). This measure was evaluated individually during the semi-structured interview. The following were the results:

a)




b)

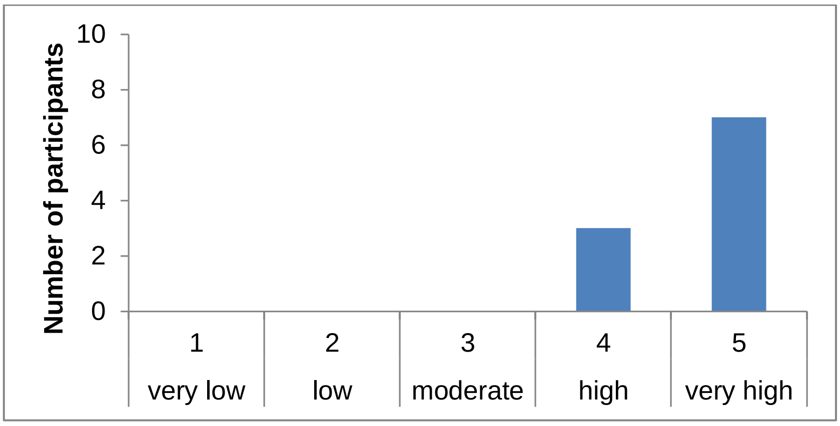
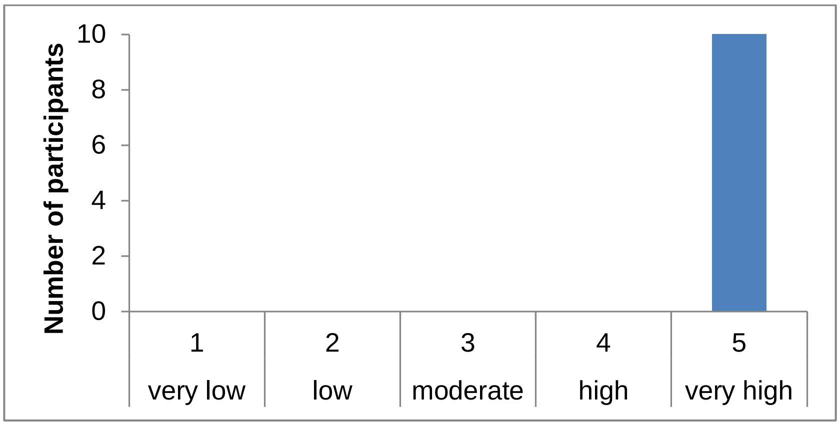



**Figure 5-15: Reliability a) older adults b) carers**

According to figures 5-17 a) and b) this measure was evaluated equally by older adults and carers. It shows that 14 out of 20 participants gave a score of 5; and 6 gave a score of 4. The mean for the reliability of the DWIS system was 4.70 with a standard deviation of 0.483.

5.4.2.7 System performance

The satisfaction with the DWIS system in terms of time to logon to the system and system response time was evaluated during the semi-structured interview. Figures 5-18 a) and b) showed that all participants gave a score of 5 to the system performance.

a)


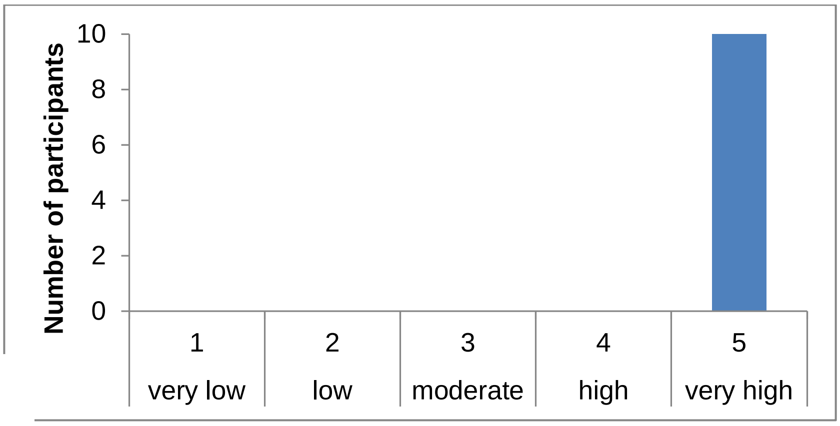

b)



**Figure 5-16: System performance a) older adults b) carers**

### 5.4.3 User experience

The user experience was measured by asking the participant to rate the following aspects the level of satisfaction with the DWIS system,

#### 5.4.3.1 Satisfaction with the DWIS system

Participants were asked to rate their level of satisfaction with the DWIS system during the individual exercise. The following were the results:

Figure 5-15 showed the satisfaction with the DWIS system evaluated by older adults. It illustrated that only 2 participants gave a score of 5; half of the participants gave a score of 4; and 3 gave a score of 3. The mean for the user satisfaction was 3.90 with a standard deviation of 0.738. Because of the values of this measure ranged between 3 and 5, the standard deviation was a little large.

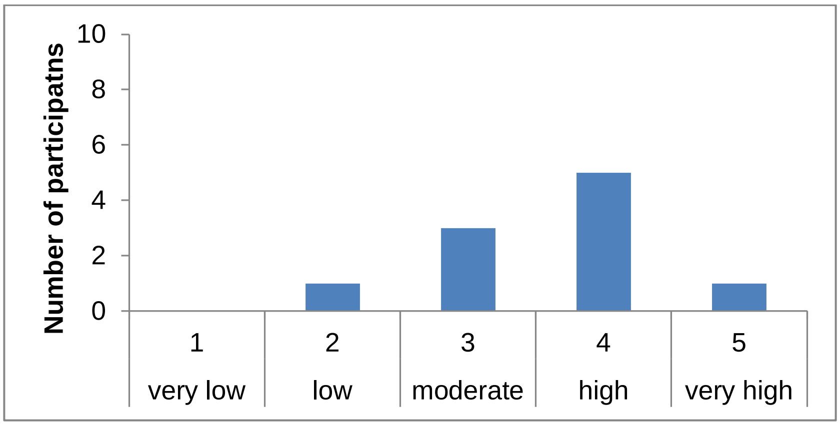



**Figure 5-17: User satisfaction (older adults)**

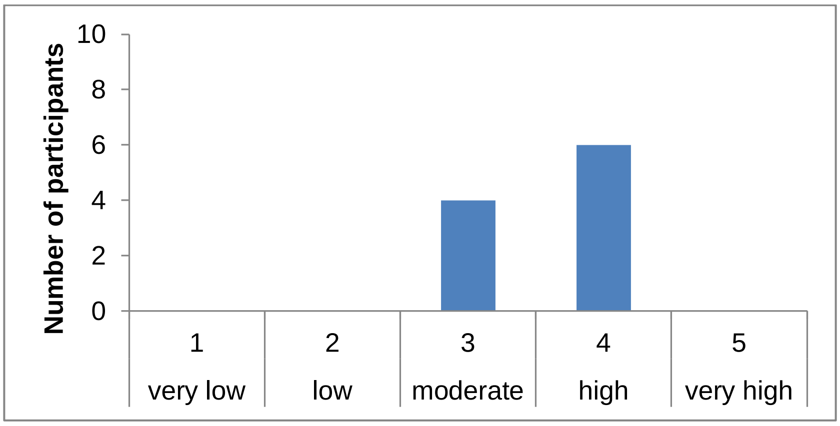



**Figure 5-18: User satisfaction (carers)**

According to figure 5-16, 6 out of 10 carers gave a score of 4; and 4 gave a score of 3. The mean for the user satisfaction was 3.60 with a standard deviation of 0.516.

The level of satisfaction of the participants with the DWIS system as a whole was the lowest score because some participants detected some errors in the DWIS system and missing information in some graphs (sensors did not record data when there was no activity); some carers disagreed with the statement about the graphs; and other participants wanted to have more detail and refined data.

### 5.4.4 Usefulness of the DWIS system

Participants discussed the usefulness of the DWIS system to enhance the dialogue of care during the pairs exercise and in the semi-structured interview. The following were the results:

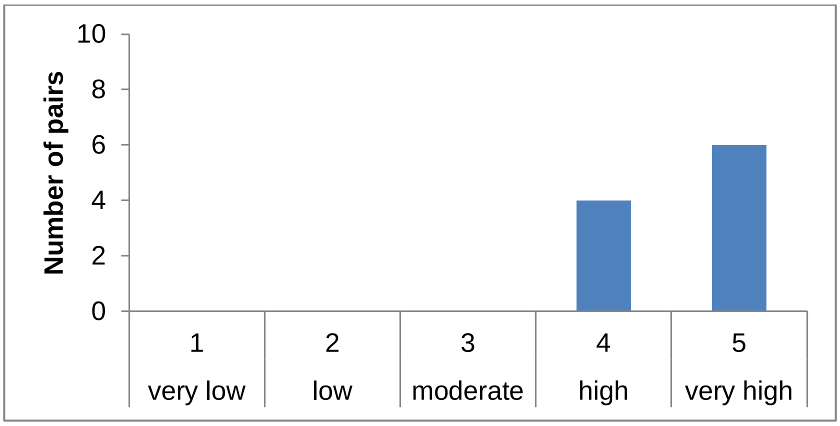



**Figure 5-19: Usefulness for enhancing the dialogue of care (pairs evaluation)**

According to figure 5-19, 6 out of 10 pairs of participants gave the highest score to the DWIS system as a very useful tool to support the dialogue of care. Four pairs of participants evaluated the DWIS system as a useful tool. The mean for this measure was 4.60 with a standard deviation of 0.516.

All participants found the DWIS system beneficial as a tool that provided additional information of the older person's well-being. Participant expressed that the DWIS system provided information that might help to raise questions to the older person.

The following is an example of the dialogue of care between an older person and a carer:

'The carer is looking at the DWIS system and observes the following changes in the data of the older person: The older person did not sleep very well on Tuesday night, her blood sugar levels were too high, her mobility patterns were less active than usual and there was less activity in the kitchen on Wednesday.

- *Carer: Why were you not able to sleep on Tuesday?*
- *Older person: Because my blood sugar levels was too high. So I woke up, went to the toilet and then I took my medications.*
- *Carer: It seems that you are not eating as regular as you do.*
- *Older person: I don't feel hungry so I don't eat too much food. Perhaps because I drunk many cups of tea.*
- *Carer: You know that you are not allow to stop eating because of your diabetic conditions.*
- *Older Person: Yeah. I know but I don't feel hungry those days, so I prefer to drink tea and some biscuits.*
- *Carer: I noticed that you were less active than usual on Wednesday. Is this related with your lack of appetite?*
- *Older person: I think so. Because I did not sleep very well on Tuesday night I spent most of the time reading and watching TV in the living room on Wednesday.*
- *Carer: I understand. Perhaps I need to ask the GP to change your medication to normalize you blood sugar levels.*

The next chapter describes the cases that emerged and highlights the main findings from the evaluation study. After that, it  describes the potential risks using technology for caring for older adults at their home, some usability problems and feedback given by the participants of the study. Finally, some conclusions of the evaluation study are presented.

# *6. USEFULNESS OF A DOMESTIC WELL-BEING INDICATOR SYSTEM (DWIS)*

## *6.1. Introduction*

The main purpose of this chapter is to evaluate the value of presenting lifestyle, health and contextual data in the dialogue of care between the older person and the carer. In the evaluation of the DWIS system, some cases were identified among the participants according to their user profile and experience with technology while they were carrying out the set of tasks individually and in pairs. The user experience was also observed in terms of user's attitudes and feelings, perceptions, user preferences and user engagement. The usefulness of the DWIS system as a tool to enhance the dialogue of care was tested when the older adult worked with the carer in the second part of the exercise.

### 6.1.1. Emerging cases

6.1.1.1. Individual Exercise

- **Checking well-being:** Some cases that characterised the participants during the individual exercise were identified as follows:
  - **Case 1**: Figure 6-1 showed the case when the participant was not used to reading graphs, had basic computing skills and was not confident using the DWIS system. The participant had trouble doing the tasks (struggled with technology), did not understand the graphs, read only the summary at the bottom of the graph and had problems with the mouse. The facilitator helped the participant to understand the exercise and clarify some doubts. The learning process at this stage was "tutor-learner".

    The process changed when the participant became familiar with the DWIS system (familiarity). As a consequence, the participant understood the graphs and described changes. The learning process also changed because the participant discovered new things by him/herself (self-learning). At the end of the individual exercise, all the participants successfully completed the set of tasks with assistance (achievement).

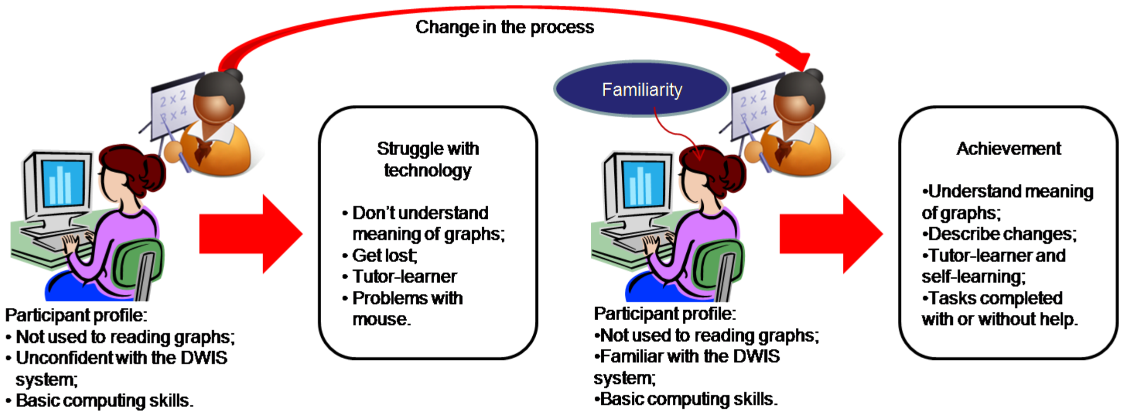



**Figure 6-1: Individual exercise. Case 1**

- **Case 2:** Figure 6-2 illustrated the case when the participant was used to reading graphs, had intermediate or advanced computing skills, and was confident with the DWIS system. The participant successfully coped with the list of tasks without assistance (coped with technology); was able to understand the meaning of the graphs and to analyse changes in the well-being indicators. The learning process was different in this case because the participant mainly learnt by him/herself (self-learning). In some cases, the participant asked a few questions to clarify the meaning of the graphs (tutor-learner). When the participants became familiar with the DWIS system, they made interpretations of the data presented and recognised patterns in the well-being indicators. The participant also discovered some errors in the software and made some suggestions to improve the DWIS system.

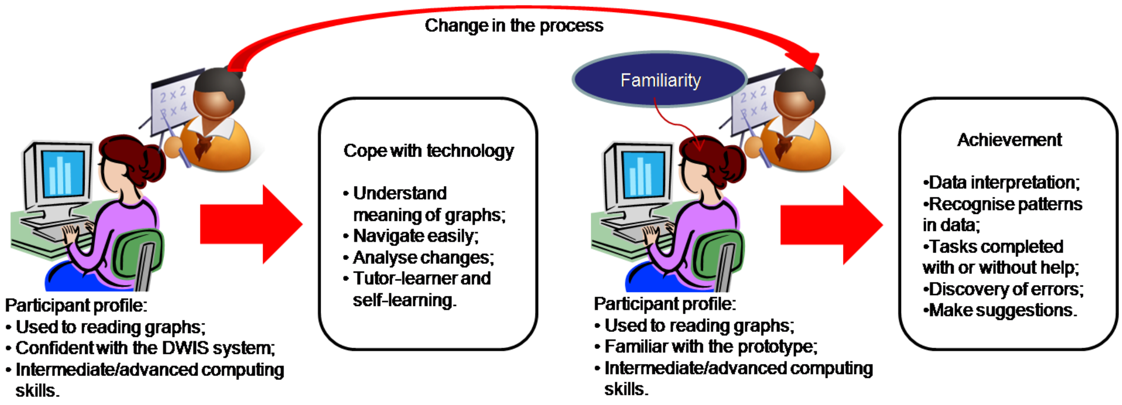



**Figure 6-2: Individual exercise. Case 2**

- **Comparing well-being graphs:** When carers were asked to compare changes between two graphs at different periods of time: before and after medication (according to scenario), the following cases appeared:
  - **Case 3:** Figure 6-3 illustrated the case when the carer was not used to reading graphs and had basic computing skills. The participant had trouble comparing graphs because the DWIS system did not show two graphs on the same screen (struggled with technology). The facilitator assisted the participant to cope with some tasks. The learning process at this stage was “tutor-learner”. When the carer became familiar with the DWIS system, the participant managed to make some comparison between graphs and to complete successfully the set of tasks with and without assistance (achievement). The learning process was tutor-learner and self-learning.
  - **Case 4: :**Figure 6-4 displayed the case when the carer was used to reading graphs and had intermediate or advanced computing skills. The participant was able to compare different graphs and to navigate easily throughout the DWIS system (coped with technology). The participant learned to use the DWIS system very easily by him/herself (self-learning) and by asking the facilitator (tutor-learner). When the participant became familiar with the DWIS system, the carer interpreted the data presented in the form of graphs and text. The carer carried out the list of tasks with and without assistance.

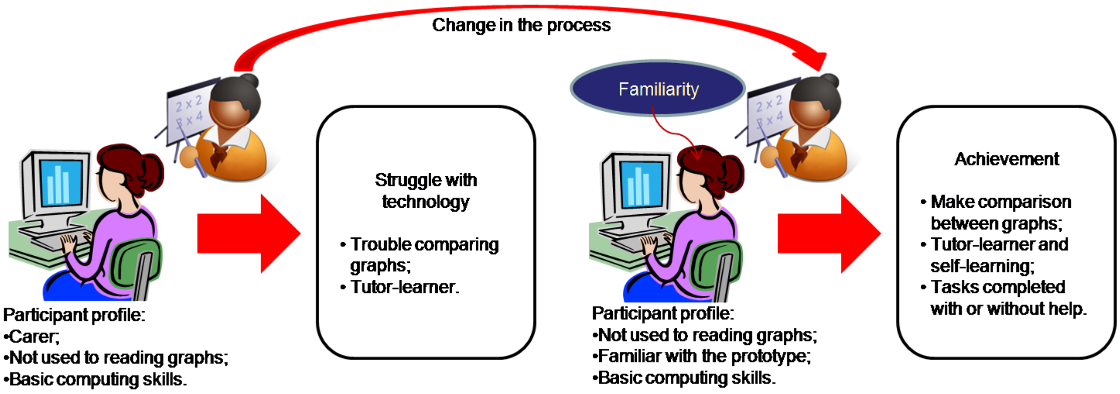



**Figure 6-3: Individual exercise. Case 3**

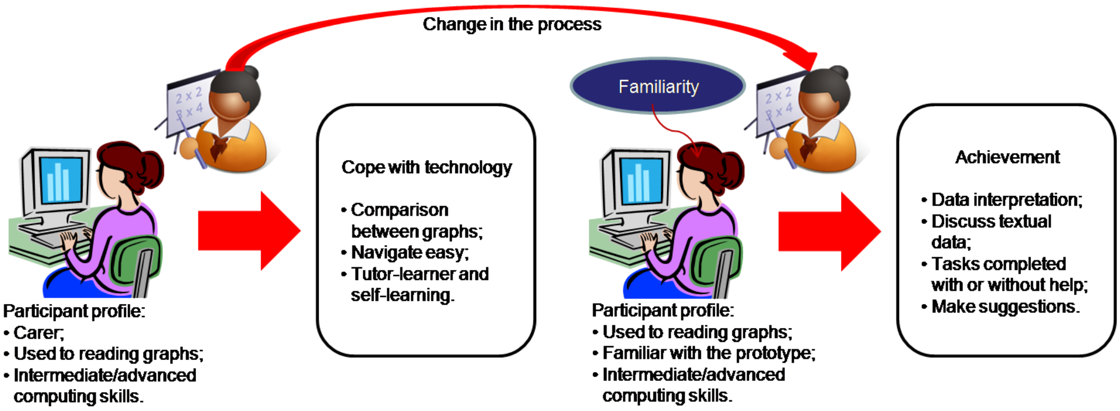



**Figure 6-4: Individual exercise. Case 4**

#### 6.1.1.2. Pairs exercise

The main output from the pairs exercise was the dialogue of care between the older person and the carer while they were looking at the user interface. There were two pairs of participants who worked without user interface. The output from the pairs exercise varied according to the user computing skills and the ability to read graphs.

- **Working with user interface:** All participants were familiar with the DWIS system in the second part of the exercise. Eight pairs of participants worked either with the older adults' or the carers' interface. They were asked to check and compare the indicators of well-being of an older person (based on scenario). The following cases were identified:

- **Case 1:** Figure 6-5 represents the case when the older adult and the carer worked together, both of them had basic computer skills, they were familiar with the DWIS system and they were not used to reading graphs. They had a good discussion (dialogue of care) based on the data presented (contextual, health conditions and lifestyle data); they understood most of the graphs, described changes and correlated different areas of well-being (mobility, eating and drinking, personal hygiene and health conditions). However, they still had trouble understanding the meaning of the sleeping graphs so they asked for clarification (tutor-learner). They completed the set of tasks successfully with and without assistance.

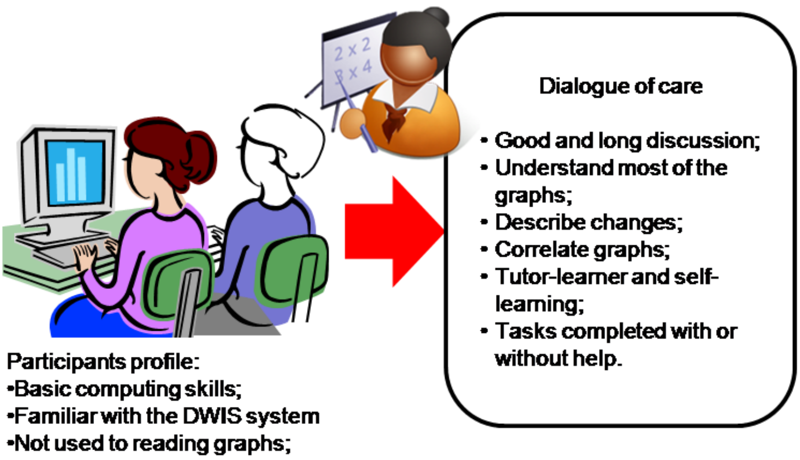



**Figure 6-5: Pairs exercise. Case 1**

- **Case 2:** Figure 6-6 illustrated the case when one of the participants had basic computing skills and the other one had intermediate or advanced computing skills, they were familiar with the DWIS system, and one of them was used to reading graphs. They had a good discussion (dialogue of care); they understood all the graphs, they interpreted the data presented, correlated various graphs, and the participant who was not used to reading graphs learned from their peer the meaning of the graphs (peer-to-peer learning). They completed the set of tasks successfully without assistance.

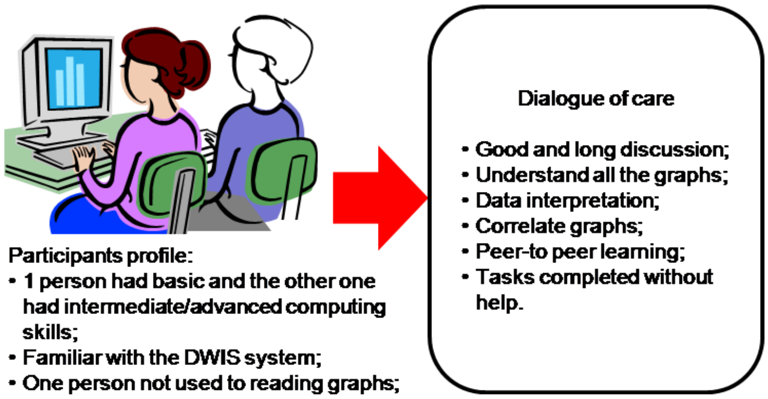



**Figure 6-6: Pair exercise. Case 2**

- **Case 3:** Figure 6-7 showed the case when the pair of participants had intermediate or advanced computing skills, they were familiar with the DWIS system, and they were used to reading graphs. They had a good discussion (dialogue of care) working together and made an analytical and critical evaluation of data presented and the DWIS system. In addition, the participants suggested some changes in the DWIS system such as presenting the graphs using the same scale on the X and Y axis, and to show the five graphs together (mobility, eating and drinking, sleeping, personal hygiene and health conditions). They learned from each other (peer-to-peer learning). They completed the set of tasks successfully without assistance.

- **Working without user interface:** Two pairs of participants worked with no user interface. They were asked to discuss some hypothetical questions based on the scenario given. The following case emerged:
  - **Case 4:** Figure 6-8 illustrates the case when the pair of participants worked without user interface. In comparison with the participants who worked with user interface, there was a shorter discussion (dialogue of care) between the older person and the carer. They completed the questionnaire without assistance. Participants OP2 and C2 expressed that working with user interface would be better because they could have factual data to discuss rather than assumptions based on a hypothetical case.

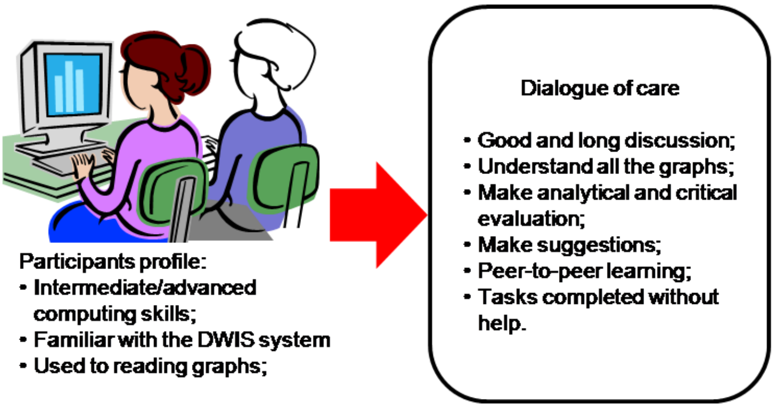



**Figure 6-7: Pairs exercise. Case 3**

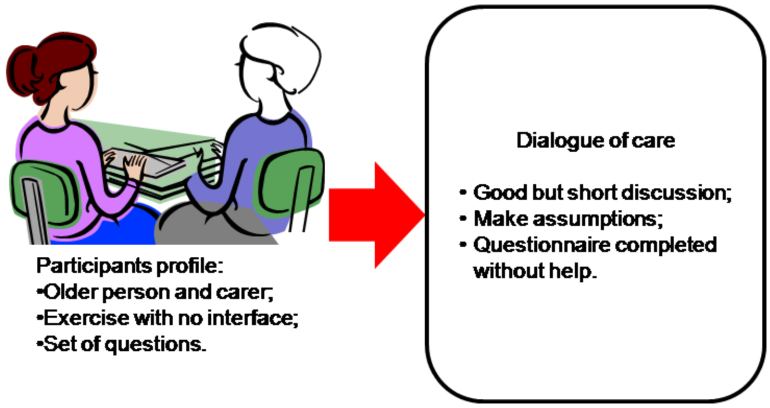



**Figure 6-8. Pairs exercise. Case 4**

## *6.2. Discussion*

### 6.2.1. Overall

Analysing the data collected from the evaluation of the DWIS system using qualitative and quantitative methods helped the researcher to answer the questions stated at the beginning of chapter five.

A personalised user interface that provides contextual, health and lifestyle data could communicate changes of well-being of an older person and enhance the dialogue of care between an older person and her/his carers. Participants found that the data presented in the form of graphs and textual data was clear and visual and helped them to recognise changes in an easy way. Participants expressed that presenting integrated data of key areas of well-being (mobility, sleeping, eating and drinking, personal hygiene, health conditions) and contextual data might help carers to know the well-being of the older person and make an assertive interpretation. They also found very useful the facility of presenting the data at different periods of time (months, weeks, days and hours) and time zones.

### 6.2.2. Enhancing the dialogue of care

Presenting contextual, health and lifestyle data to older adults and carers demonstrated that the well-being indicator DWIS system could help to enhance the dialogue of care between the older person and the carer. Data could also assist carers to raise questions for the older person based on the well-being data presented by the DWIS system. In addition, the DWIS system could help to provide better feedback to the older person by having updated data. It might help all the stakeholders to make assertive decisions based on the integrated data presented. As well, carers can use their time more effectively and efficiently by having a quick overview of the older adult's well-being and anticipating their needs.

### 6.2.3. Communicating changes

A personalised user interface that presents lifestyle, health and contextual data of an older person helped all the stakeholder to know the well-being of the elderly. Lifestyle and health data were represented using bar and trend graphs. Contextual data that describe events of the key area of well-being (mobility, eating and drinking, sleeping, personal hygiene and health conditions) were presented in the form of text. For instance, a carer selected the personal hygiene area and the system displayed the changes in the personal hygiene patterns during the last week. At the bottom of the graphs, there was an event telling that the General Practitioner ordered to change the medication the week before. Hence, the carer can understands the meaning of the lifestyle by reading the contextual data that explains the reason for change.

### 6.2.4. Interpreting data

Lifestyle data related to four key areas of well-being: Mobility, sleeping, personal hygiene, eating and drinking. Health conditions and contextual data were presented to the participants of the study. Participants expressed that by looking at the user interface and observing changes in the data carers might be able to discuss this evidence with the older person and make an interpretation of the older person's well-being.

Various stakeholders involved in the care of the older person could obtain relevant data to the older person's well-being and quality of life. When a significant change happened the carer and the older person could interpret the meaning of those changes through a dialogue of care. In addition, carers could have contextual data such as changes in medications, falls, and any event that might produce changes in the normal behaviour of the older person.

### 6.2.5. Limitations of the evaluation

The results reported on this thesis were based on a demonstrator system using a laboratory setting. The results might be different when the DWIS system is run in a field trial using a real home environment. The following limitations appeared using a laboratory-based demonstrator:

- Older people and carers might behave in a different way because they were observed by researchers.
- The data presented to the participants was real; however, this data was not collected from the older person's home, who is evaluating the system. Therefore, evaluating a demonstrator became a hypothetical case for the evaluators.
- Given that the older person and the carer did not have a previous relationship before the evaluation, the dialogue of care might be different in a real-life situation.

### 6.2.6. Acceptability

Some older adults wanted to have a system (like the DWIS system presented in this study) in their home because it could let the carers see changes in the older person's well-being. Some people would consider having the system if they became more vulnerable. Some carers considered the issue of letting the older person monitor their well-being very important, but others said that it might be inappropriate if they have disabilities or don't have an interest in knowing their well-being.

### 6.2.7. Ethical issues

There were various ethical issues when contextual, health and lifestyle data is gathered and distributed among different stakeholders. Participants were particularly concerned about privacy and security, the confidentiality of the data collected, and the consent of the older adult to be monitored.

The privacy of personal data of the older adult being monitored and the security of the data collected and transmitted were important issues discussed in the evaluation of the DWIS system. Data protection of the information collected should be consider as well (Panek *et al.*, 2007).

Using security mechanisms such as encryption, virtual private networks (VPN), control of access to the data and appropriate level of permission to each user, it might be possible to ensure the security and confidentiality of the data collected and transmitted. For example, an occupational therapist might have access to the mobility patterns and the health conditions to make a sound decision.

Collecting contextual, health conditions and lifestyle data about an older person must be confidential and restricted. Therefore, in order to distribute this data among the various stakeholders, it is necessary to restrict the access to the appropriate medical or carer staff and to ensure the confidentiality of the data transmitted. In addition, older adults should be informed if they are to be monitored and they might agree to be asked specific questions that arise from the data collected.

### 6.2.8. Working individually vs. in pairs

The first part of the exercise was carried out individually and the second part in pairs. Some participants had problems to verbalise their thoughts in the first part because they forgot the “think aloud” technique. In contrast, there was a beneficial discussion between the older person and the carer in the second part of the exercise. Some participants had difficulties in understanding the graphs in the first part because they were neither familiar with the DWIS system nor used to reading graphs. The participants preferred the second part more because they were more relaxed and enjoyed the exercise; they helped each other to understand the meaning of the graphs and they discussed their perspectives. Some participants got lost and felt confused at the beginning of the first part, but when they worked together they enjoyed the exercise. Table 6-1 shows the comparison between working individually and in pairs:

| **Working Individually** | **Working in Pairs** |
|---|---|
| Some participants had problems to verbalise their thoughts | Beneficial discussion between the older person and the carer |
| Some participants had difficulties in understanding the graphs | Participants helped each other to understand the meaning of the graphs |
| Some participants got lost and felt confused at the beginning of the first part | Participants were more relaxed and enjoyed the exercise. |

**Table 6-1: Comparison between working individually or in pairs**

### 6.2.9. Working with user interface vs. non-user interface

| **With user interface** | **Non-user interface** |
|---|---|
| Factual data | Hypothetical case |
| Good and long discussion working together | Short discussion |
| Analysis based on data presented | Assumptions based on a hypothetical case |
| Long time to complete the set of tasks | Short time to complete the set of tasks |

**Table 6-2: Comparison between working with user interface and with no interface**

Eight pairs of participants worked with user interface and two with no user interface. Table 6-2 illustrates the differences between these two modalities:

### 6.2.10. User experience changes with familiarity and working in pairs

Some people felt uncomfortable when they were doing the set of tasks individually because of the following reasons:

- They were not used to reading graphs;
- They were anxious at the beginning of the session;
- They had trouble verbalising their thoughts during the individual exercise.

When the participants became familiar with the DWIS system the user experience changed as follows:

- They understood the meaning of most of the graphs;
- They were more relaxed and comfortable doing the set of tasks.

Furthermore, when the participants worked in pairs the user experience was different because of the following reasons:

- They learned from each other;
- They had a good beneficial conversation based on the data presented. They analysed the data, interpreted of the data presented;
- They shared their perceptions and opinions with regard to the data presented and the scenario given to be analysed;
- They enjoyed working together.

### 6.2.11. Risks associated with using technology for caring older adults

Technology might assist to provide care to older adults living independently at their home; however, there is a danger of increasing social isolation (Gil, Hine, and Arnott, 2008). For many older adults who live alone, it is a pleasure to meet people, talk to someone for a few minutes, or go for shopping because it is a social activity. In addition, Panek *et al.* commented that ‘technology should never replace personal contact but should augment and support the social contacts of elderly persons and their carers’ (McGee-Lennon and Clark, 2008).

### 6.2.12. Customisation needs

During the user requirement gathering, the participants requested to let the occupant customise the user interfaces and reduce the level of intrusion as much as possible (A.D. Fisk *et al.*, 2004). McGee-Lennon et al. reported that technology should be configurable but further exploration is necessary to satisfy the user needs (Cook, Augusto, and Jakkula, 2009).

The user interface also needs to be more flexible and configurable to allow the user to select the type of graph, and the level of detail of the data presented. In order to have a good acceptability, the user interface needs to be personalised according to the user preferences, abilities and skills.

### 6.2.13. Usability problems

Some participants had trouble in understanding some graphs because they were not used to reading graphs. Some participants said that the textual summary of some graphs were ambiguous. Some carers had difficulties making comparisons because the DWIS system did not present two or more graphs in the same screen. In contrast, there were some participants who found the DWIS system’s interfaces were clear and easy to understand.

In addition, some problems were detected in the DWIS system such as unnecessary steps (when the user wanted to select the first option of the radio button list on the left hand side of the screen they had to start from the beginning). There was evident: inconsistence in the meaning of the summary of the graphs, a lack of standardisation in the presentation of the graphs, and no feedback for user selection.

Some of the comments and suggestions included:

- Having two graphs on the same screen to make it easier to perform comparisons.
- Highlighting the last option selected.
- Having a clear and unambiguous summary at the bottom of the graphs.
- Presenting a normal range of the activity for each indicator of well-being as a reference to evaluate the grade of change.

## *6.3. Conclusions*

This study was presented to evaluate the usefulness of a domestic well-being indicator system to enhance the dialogue of care between the older adult and the carer. In addition, the usability and acceptability of two user interfaces that were designed with a group of participants (described in chapter five) was evaluated. The DWIS system was evaluated individually and in pairs. The results were collected using qualitative and quantitative methods. The methods included video, notes taken by two researchers, two post-task questionnaires and a semi-structured interview with each pair of participants.

It was found that lifestyle, health and contextual data could communicate changes related to the quality of life and well-being of an older person and could enhance the dialogue of care between the older person and their cares. These data need to be presented in a clear a visual way so all the stakeholders could recognise changes easily, extract the meaning of the data, make an interpretation and make a decision towards enhancing the life of the older person.

The output from the individual exercise was the interaction between the participant and the DWIS system. There were some participants who found the DWIS system easy to understand and learn. However, there were some participants who had trouble understanding the graphs at the beginning of the first part because they were not used to reading graphs. When the participants became familiar with the DWIS system, all of them managed to complete their tasks successfully.

The main output from the paired exercise was the dialogue of care between the older person and the carer while they were looking at the user interface. It was observed that all the participants had a good discussion working together; they learned from each other and they enjoyed the exercise. However, this dialogue of care might be different when the DWIS system is tested within a real-home environment.

Testing the DWIS system with older adults and carers had three important aspects to take into account: The user interface, the reliability and the user interaction. The user interface needs to be easy to navigate, clear and visual, to have standard templates and to be flexible as far as possible. The data presented to all the stakeholders involved in the care of the older adult need to be reliable. The user interaction could vary according to the previous experience using computers, the ability to read graphs, the computing skills, the stakeholder group and the modality of the exercise (individual or in pairs).

The results of this study not only provided evidence of how a domestic well-being indicator system could enhance the dialogue of care between the older person and the carer, but also provided feedback to improve the DWIS system. All participants felt the interface did enhance the dialogue of care between the older adult and the carer, because better data promoted greater understanding and gave greater confidence in the quality and relevance of the care being given. The customisation needs and the usability problems mentioned earlier revealed that users want to see data in different ways, to control the level of monitoring and to have clear and intuitive data.

As mentioned in the discussion section, a demonstrator has limitations because it is run using a controlled environments; however, the methodology employed in this experiment and the output from the evaluation could be the basis for a real field trial.

The next chapter summarises the main findings, spells out the contribution of this research study and states the further work needed in this domain.

# 7. GENERAL CONCLUSIONS AND FURTHER WORK

This chapter summarises the work by revisiting the original research questions stated in chapter 1. It begins by describing the overall purpose of this thesis and answering the research questions. This is followed by describing the contribution to knowledge. Finally, the chapter discusses the potential further work.

The purpose of this research study is to analyse the lifestyle, health and contextual data gathered in older people's homes and the contribution of this data to the dialogue of care between older people and carers. The following are the research questions stated at the beginning of this thesis.

Question 1:

Can data be collected and computed to extract phenomena in the data that might reflect changes in the well-being of an older person living independently?

The first question specifically focuses on the issues of knowing the data characteristics, analysing and attempting to understand the meaning of the data. Lifestyle data was analysed using some computing tools to show the level of activity 'busyness' of an older person. In addition, health and contextual data were used to understand the meaning of the sensor data. This question will be discussed in **Sections 7.1 and 7.2.**

Question 2:

What is the best way to present the well-being data in a usable system reflecting the needs and interests of various stakeholders including the older person, informal and professional carers, technologists, researchers, and policy makers?

The second question focuses on the issues of collaborating with various stakeholders (older person, informal and professional carers, technologists, researchers, and policy makers) and using an inclusive design process to gather requirements, design, build and evaluate a domestic well-being indicator system (DWIS). This question is discussed in **Section 7.3**.

Question 3:

Can a well-being indicator system be used as a tool to enhance a conversation between the older person and the carer? If so

- Would a personalised user interface that provides lifestyle, health and contextual data be useful?
- Would data presented in the form of graphs and textual data help to communicate changes related to the well-being of an older person?
- Would the well-being data be useful to help the carers to detect a change in the life of the older person?

The third question, which is the backbone of this thesis, focuses on evaluating the value of presenting lifestyle, health and contextual data in the dialogue of care between the older person and the carer. This question is discussed in **Section 7.4.**

Given the complexity of these questions, and given the variety of topics they touch, the answers are illustrated by highlighting a set of steps to achieve the purpose of this thesis as follows:

- Knowing the data characteristics.
- Analysing and attempting to understand the meaning of the data.
- Gathering requirements, designing, building and evaluating a system involving various stakeholders.
- Using the data in the dialogue of care with the objective of continually improving the quality of care and the ‘support’.

## 7.1. Knowing the data characteristics

Lifestyle data can be varied and unpredictable because sensors can fail, people's lives get interrupted and modulated. The sensors need to be properly configured during installation and regularly maintained to ensure that the data collected is reliable. People's lives can be interrupted by many unexpected events. For example, illnesses, hospitalisations, and funerals. Also their lives can be modulated by many different events such as birthdays and anniversaries. Despite this, however, the data could still show where important changes on fundamental phenomena occur in the lives of older people that needed to be carefully analysed.

## 7.2. Analysing and attempting to understand the meaning of the data

Analysing changes in the level of activity 'busyness' of an older person might help to detect changes related to a person's behaviour. However, merely analysing lifestyle data collected from sensors was not enough to construct a real picture of a person's life. It was necessary to match lifestyle data with contextual data such as changes in medication, holidays, hospitalisation, anniversaries, and health data (blood pressure, blood sugar, pulse) in order to extract the meaning of the data. The following methodology was used to analyse and attempt to understand the meaning of the data:

- **Data storage:** Sensors generated potentially enormous volumes of data; therefore, data needed to be organised into databases, data warehouses, and data cubes to explore this large amount of data in a meaningful way.
- **Data segmentation:** The data could be segmented by characteristics. For example, time zones, functional areas and location to explore changes that can reveal patterns in people's lives. The phenomena in the data could be lost if this step is not undertaken carefully.

- **Data visualisation:** OLAP is a data modelling technique useful in the visualisation of the data and looking for phenomena. OLAP technology has been widely explored in various business areas such as retail, marketing, and sales. However, OLAP has not been used before to model, explore and analyse lifestyle data collected from sensors.

  According to the results from the study described in chapter six, it showed that OLAP technology could be effective in providing richer and more focused data to various stakeholders (older people, informal and professional carers). Some stakeholders wanted to have detailed data, some at a higher level, so in order to satisfy these requirements it was necessary to use a tool able to visualise the data at different levels of granularity.

- **Phenomena discovery:** The discovery of phenomena that reflects changes in well-being and the extraction of patterns can be done by using simple data mining techniques such as decision trees. OLAP can visualise phenomena, but there are also hidden artefacts in the data that can be revealed by mining the data.

  Data mining has been used by many researchers to recognise activities of daily living (ADL), to detect whether current behaviour is normal or unusual and to predict people's behaviour. For instance, the University of Virginia used cluster and probabilistic algorithms to train a model with a data set collected from sensors installed in a Lab house with the purpose of recognising activities and detecting deviation from the norm (Intille *et al.*, 2004). The University of Texas at Arlington used Lezi algorithms to predict people's behaviour based on historical data generated synthetically (A.D. Fisk *et al.*, 2004). The results reported by these studies were quite accurate and reliable. However, there were no results using these algorithms with data collected from older adults' homes.

  In this study, some supervised learning techniques such as decision trees, clusters, and regression analysis were used to extract phenomena in the busyness data that might be related to the well-being and quality of life of the older person. The accuracy of the decision trees algorithms was lower in comparison to results presented by other researcher using the same data mining techniques (Sharp *et al.*, 2007). The reason could be explained by the fact that this study trained and tested the decision trees algorithms with real data collected from an older person's home, while the cited study collected data from a living laboratory.

- **Data contextualisation:** The lifestyle data showed only sensor firing not the human behaviour. The contextual data about the older person could help one to know what the data means and the cause of phenomena in the data. For example, hospitalisation, holidays, medication changes, and high blood sugar levels. Therefore, the lifestyle data could be analysed in conjunction with health and contextual data because this data could make it easier to understand the life of a person rather than relying only on the data collected from sensors.
- **Data meaning:** Data collected from older people's home can be varied and unpredictable so that the meaning of the data is uncertain. Having details of unexpected and special events and health data could help in understanding the life of a person. Providing this integrated data to each stakeholder (physiotherapist, general practitioner, informal carer, and professional carer), who look after the older person, and helping them to interpret the data is currently more sensible than building a person's profile based on data collected automatically and attempting to make an interpretation.

Several researchers around the world have implemented sophisticated algorithms for the monitoring and modelling of specific activities of daily living ADL, tracking peoples' movements, and making automatic interpretations based on the data collected. However, there are many factors that introduce fluctuations in the data, making the data interpretation difficult in many cases.

Some research projects have used hundred of sensors with the aim of collecting good data. However, this solution was not useful either due to the massive amount of data collected without meaning or the high cost of the sensors.

Knowing the limitation of technology in understanding the meaning of the data and making an interpretation from lifestyle data collected from older peoples' home, it was necessary to use another way of attempting to understand the meaning of this data. One sensible approach was to design a personalised user interface to present lifestyle, health and contextual data to different stakeholders (older people, informal and formal carers) and asked people to discuss changes in the data and make an interpretation.

A prototype was built to present data collected from a previous telecare project and to validate the value of this data as a tool to enhance the dialogue of care between the older person and their carers.

## *7.3. Gathering requirements, designing, building and evaluating a system involving different stakeholders*

Having analysed the data, the next step was to gather the user requirements, design and build the user interfaces for a Domestic Well-being Indicator System 'DWIS' that presented visual and textual data about an older person for various stakeholders (older people, informal and professional carers). Then, in order to evaluate the usability, functionality, usefulness and acceptability of the prototype, the well-being data was presented to different stakeholders. There were three main aspects as follows:

- **Relevance of the data for each stakeholder:** It was important to find out the value of the data for each stakeholder. The use of a variety of techniques (workshops, brainstorming, and focus groups) revealed that older people and informal carers wanted to have reminders for medication, appointments and task, and to be aware of environmental conditions such as temperature; all the stakeholders would like to know the state of the occupant in terms of mobility skills, personal hygiene, eating and drinking habits, sleeping patterns, health conditions, social interaction and psychological behaviour.

- **Designing an appropriate user interface:** The second aspect was to find out the preferences in data presentation for each stakeholder. Presenting data to various stakeholders in different ways such as icons, symbols, graphs and text shows that:
    - Most of the older adults do not like symbols because they can convey different meanings. However, there is evidence that if the older adult is familiar with the icon, this can be more effective than text so it is necessary that the person learns the meaning of the icon before he or she uses it (Kimball *et al.*, 1998).
    - Graphs and text are well-accepted by all the participants; however, they need to be used to reading graphs.
    - Icons with text are very useful to represent areas of well-being.
- **Building a system:** Based on the preferences in data presentation for each stakeholder, a domestic well-being indicator system DWIS was built. The system has two user interfaces: One for older adults and the other for carers. The difference between the user interfaces is that carers could see data for a long period of time while older adults could explore data for a given day or week. Professional carers could also compare patterns of data between two periods of time.
- **Evaluating the system:** Having built the DWIS, the next step was to present the data to older adults and carers with the aim of discussing the relevance of the data and evaluating the user interfaces in terms of: Usability, functionality, usefulness and acceptability.

The results of this study not only provide feedback to improve the DWIS system, but also, more importantly it provided evidence of the usefulness of the data presented, the usability, acceptability and functionality of the DWIS system. The system was easily used by both older people and carers because it presented the data through visually, clear and friendly user interfaces to all the stakeholders involved in the care of the older adult.

## *7.4. Using the data in the dialogue of care*

A personalised user interface run in a laboratory-based demonstrator provided lifestyle, health and contextual data of the older person, could be useful to enhance the dialogue of care between the older person and the carer. The important issue was to let the older person and the carer discuss the meaning of the changes in the data and make an interpretation rather than using computing algorithms to make automatic interpretations.

Having richer contextual data that provided details of unexpected and special events, as well as health data might help to understand the life of a person. As mentioned in section 7.2 asking people to interpret the data might provide better results than relying only in computing algorithms. Thus, a personalised user interface that presented contextual and integrated data could help to discuss the meaning of the data and enhance the dialogue of care.

The results of this study provided evidence of the usefulness of the DWIS system to enhance the dialogue of care between the older person and the carer based on the lifestyle, health and contextual data presented in the evaluation study. All participants felt the interface did enhance this dialogue of care, because better data promoted greater understanding and gave greater confidence in the quality and relevance of the care and support being given. The combination of a number of elements such as bar and trend graphs, textual data and the views of the data at different levels of granularity provided a useful way to communicate changes that can be related to the well-being of an older one.

Participants found very useful the contextual data presented about the older person in order to understand the reason for change. Therefore, informal and professional carers could make an interpretation of a change in the life of the older person and discuss these changes with the older person.

## *7.5. Contribution to knowledge*

The objective of this thesis was to explore the lifestyle data collected from sensors installed in older people's homes and to enrich this data with health and contextual data so that carers could make an interpretation in changes related to the older person's well-being.

An important contribution of this study was the introduction of two key concepts 'busyness' and 'dialogue of care'. Busyness was introduced as a concept and its usefulness was demonstrated using a laboratory-based demonstrator. The dialogue of care term was explained through graphical representation of the dialogue that can take place between an older person and a carer.

The objective of the study was to demonstrate the usefulness of a domestic well-being indicator system DWIS system to enhance the dialogue of care between an older person and a carer. Thus, home-care technology is valuable when integrated and reliable data is presented to different stakeholders through personalised, visually, and friendly user interface. It could provide the following benefits:

- Carers and older people can have a focussed conversation based on the data presented by the system, discuss changes in the data and make an interpretation.
- Older people can be aware of their own well-being.
- Carers can provide better health and social services to older people by using a domestic well-being indicator system.
- Carers can use their time more effectively and efficiently.

To summarise, the contributions of this thesis are:

- From a social, psychological and health perspective, to provide older adults and carers, but particularly formal and informal carers, with lifestyle, health and contextual data, so that they can discuss this data in the dialogue of care.
- From a methodological perspective, the proposal of a systematic and innovative methodology to gather requirements, design, develop and evaluate a demonstrator of the DWIS system using an inclusive design process. Several stakeholders including older people, informal and professional carers, technologists, researchers and policy makers were involved throughout the process.
- From a technological perspective, to discuss the enhancement of home-care technology by revealing individual patterns in the life of an older person through analysing the ‘busyness’ (level of activity) in their dwelling, so that care can be better tailored to their needs and changing circumstances.

## *7.6. Future work*

Gathering data from sensors needs further work to ensure that the data collected is reliable, complete and accurate. The configuration of the sensors is a key factor in collecting the correct data. For example, a person with a special condition such as dementia might need a customised configuration according to their needs. The maintenance of the sensors is also important to ensure that they are working properly and the data collected is reliable, complete and accurate.

In addition, it is necessary to plan what kind of sensor and the quantity required according to the purpose of the care required for an individual. For example, if the carer intents to collect motion perhaps, Passive Infrared sensors (PIRs) could be a suitable solution.  In contrast, if the purpose of the carer is to track an object or discover the interaction of the resident with an object perhaps, Radio Frequency Identification (RFID) tags could be a possible solution. The number of sensors can vary according to many factors: The older person’s conditions, the cost of the sensors, the redundancy required, among other technical factors.

Further research on data processing needs to be done: Exploring new data segmentation techniques to show the relevant characteristics of the data. Finding out the optimal size of data collected from people's homes. Collecting the right contextual data useful to help interpret the meaning of the lifestyle and health data. For example, people's hobbies and the weather conditions provide contextual clues.

Various data analysis techniques could be used to find more relevant patterns in the lifestyle, health and contextual data. Further research on data analysis in this area might help to provide better results. However, it is necessary to obtain clean, consistent, complete data and in large amounts.

Gathering the user requirements needs further work to ensure that the data presented is suitable for each stakeholder. The conduct of the requirements gathering with a mixed group of users could be biased by the preferences of one or two members of the team.

The design of the user interface is also important to ensure the acceptability and usability of the system. For instance, the execution of several experiments to compare different user interfaces with various stakeholders (older people, informal and professional carers, technologists and designers) in a real home environment.

Moreover, further work needs to be done to personalise the interfaces of the DWIS system according to the user preferences and needs. A possible solution is to let the user personalise the interface such as selecting the types of graphs, and the level of detail of the data. There is also a need to investigate whether metaphorical representations that show the status of well-being indicator might be more helpful to communicate changes than using graphs and textual data.

Modelling multiple occupancy still needs more work because with the sensor data is difficult to determine who is at different places. This area has been investigated for location tracking with single occupancy but with multiple occupancy is still an open question and big challenge. For example, when a person has visitors, the number of sensor firings increase. This issue can be interpreted in different ways if the data is interpreted automatically by algorithms. So, it is necessary to find techniques to recognise when the house has more than one occupant without asking people to report those events or using intrusive computing systems.

The results reported on this thesis were based on a demonstrator system using a laboratory setting. The results might be different when the DWIS system is run in a field trial using a real home environment. The following limitations appeared using a laboratory-based demonstrator:

- Older people and carers might behave in a different way because they were observed by researchers.
- The data presented to the participants was real; however, this data was not collected from the older person’s home, who is evaluating the system. Therefore, evaluating a demonstrator became a hypothetical case for the evaluators.
- Given that the older person and the carer did not have a previous relationship before the evaluation, the dialogue of care might be different in a real-life situation.

In addition, there were other limitations of the study such as the number of participants, their profile, the techniques used to collect the measures, and the length of time given to the participants to learn the DWIS system. All these aspects might affect the results if the researcher would carry out the study with different profile of participants and using different techniques.

As presented in section 7.5, the DWIS system can provide potential benefits; however, to know the overall impact of the system it might be necessary to run a field trial with all the stakeholders involved in the care of an older person living alone. It also implies the installation of sensors according to the person’s needs, the adjustment of the DWIS system to present data on-line in real time, and the configuration of the whole home-care system to be connected among the different stakeholders (older person, family members, informal and professional carers). In addition, it is necessary to train all the users involved in advance to ensure that the users are familiar with the system. Contextual data about the older person should be recorded carefully because it is the key element to understand the meaning of changes.

Having setup the field trial, it is important to define the measures of the evaluation. The key would be to evaluate how a real-world dialogue of care could be facilitated. It is also important to use an appropriate methodology to collect relevant data to know the real-life impact of the system on the quality of life and well-being of older people. For example, change in self-esteem, depression, and social interaction. A pre-field trial assessment will be useful to compare it with the results obtained after using the DWIS system.

## *7.7. Finally*

The majority of older people (including many of the very frail) want to live in their own home for as long as possible as they age. In recent years, home-care technology has begun to have a more significant role to assist older people who want to live independently in their homes.

The impact of technology in the quality of life and well-being of older people have been discussed. Some authors found that technology alone does not provide any benefits; however, other researchers found potential benefits. Thus, technology should be treated as a tool that might provide some benefits when it is carefully introduced in the process of care on an older person.

The purpose of this project was to analyse lifestyle data gathered in older people’s homes and focus on the contribution of this data to the dialogue of care between older people and carers. Exploring the lifestyle data collected from sensors installed in older people’s homes and validating this data with field notes to ensure that the data collected was accurate, complete, and reliable was the first mandatory step. Then, analysing the level of activity ‘busyness’ in their dwelling using a number of computing techniques revealed phenomena in the life of a person that reflected changes in well-being.

Showing the busyness data of key areas of well-being (sleeping, eating and drinking, personal hygiene and mobility) has advantages in comparison with activity monitoring such as busyness is less intrusive, busyness requires less computation and data is interpreted by people through a dialogue of care.

Collaborating with various stakeholders (older people, informal and professional carers, technologists and researchers) and using an inclusive design process to gather requirements, design, build and evaluate a domestic well-being indicator system (DWIS) provided an effective way to know the real needs and preferences in data presentation for each stakeholder.

The inclusive design process adapted from the interaction design model proposed by (Roiger, 2003) and some human-computer interaction techniques were used. This process was focused on the inclusion of all stakeholders (older people, informal and professional carers, technologists and researchers) and the performance of very specific tasks to ensure the participation of the stakeholders throughout the design.

Having designed a domestic well-being indicator system (DWIS) that stores contextual data such as symptoms, changes in behaviour, health conditions, and lifestyle (sensor) data, the next step was to test the usefulness of the system to provide data to both the older person and their carer toward a conversation to find what things are affecting the person and their quality of life.

The direct dialogue of care between an older person and a carer is an informal conversation based on the symptoms, pains and concerns reported by the older person and changes perceived by his/her carer. However, this direct dialogue is limited when the older person is not able to express his/her feelings, concerns and thoughts due to any physical or mental impairment. A DWIS system that presents lifestyle, health and contextual data could be useful to have a proactive dialogue of care between the person and his/her carers by providing data in advance.

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# *Appendix A - Data analysis techniques*

Data warehouse

According to Han and Kamber (Berry and Linoff, 2004) data warehouse systems have the following features:

- Subject-oriented: A data warehouse is organised around major subjects, such as customer, provider, product and sales.
- Integrated: A data warehouse systems allow the integration of multiple heterogeneous data sources such as relational data bases, flat files, and on-line transactional records. It provides high performance because data is restructured into one semantic data store.
- Time-variant: A data warehouse provides historical information. It means that it doesn't contain current data.
- Non-volatile:  Data collected into a data warehouse doesn't change.

Dimensional model

The main components of a dimensional model are fact tables and dimension tables. The fact table is the primary table in each dimensional model that contains measures of the business. Every fact table represents a many-to- many relationship and every fact table contains a set of two or more foreign keys that join to their respective dimension tables. The most useful fact tables contain one or more numerical and additive attributes that are the basis for aggregating data.

A dimension table has a primary key that serves as the basis for referential integrity with any given fact table to which it is joined. Most dimension tables contain many textual attributes that are the basis for constraining and grouping within data warehouse queries.

The dimensional model has the following strengths:

- The dimensional model is predictable, and standard. It means that database system, end users query tools, report writers and user interfaces can make strong assumptions about the data to make the user interfaces more understandable, and to make the processing more efficient.
- The predictable framework of the star join schema withstands unexpected changes user behaviour. Every dimension has the same number of entries as the fact table; the user interfaces are symmetrical; the query strategies are symmetrical, and the SQL generated against the dimensional model is symmetrical.
- The dimensional model allows the user to make changes.
- There are many administrative tools to manage and aggregate the data avoiding hardware upgrades and allowing high performance queries.

On-Line analytical processing (OLAP)

The basic OLAP operations include slice and dice, roll-up, drill-down, and pivoting. The slice operation selects data on a single dimension of an OLAP cube. The dice operation extracts a subcube from the original cube by selecting two or more dimensions. Roll-up or aggregation is a combination of cells for one of the dimensions defined within a cube to explore data at a general level. Drill-down explores data at level of greater level.

Types of OLAP

- Relational OLAP (ROLAP): A set of user interfaces and applications that uses a relational database to present the data to the client as a multidimensional environment. The metadata resides in relational tables and describes the facts, dimensions, attributes, relationships, metrics, aggregate navigation, and user profiles. All these data are centrally stored on an application server and the queries are made by desktop front-end applications. ROLAP technology has greater scalability than MOLAP technology.

- Multidimensional OLAP (MOLAP): This architecture is similar to the ROLAP approach but it incorporates a middle-tier between the relational data warehouse and the user. This middle-tier is a multidimensional vies of data. The advantage of using a data cube is that it allows fast data computing. The desktop front-end queries are managed by the OLAP server, which either sends it to the OLAP cube or passes it to the warehouse if the answer can be generated by the data cube. The MOLAP tools were built for decision support useful for applications like forecasting and budgeting.
- Hybrid OLAP (HOLAP): This architecture combines ROLAP and MOLAP technology, benefiting the greater scalability from ROLAP and the faster computation from MOLAP.

Data mining

Data mining styles

The data mining process is sometimes referred to as knowledge discovery or KDD (knowledge discovery in databases) and can be done in different ways. Directed data mining attempts to explain or categorise some particular target field such as income or response. This often takes the form of predictive modelling, where the data miner knows exactly what is looking for. Undirected data mining attempts to find patterns or similarities among groups of records without a particular target field or collection of predefined classes. This is an interactive process where the user gains insight into the data by exploring and visualising (Berry and Linoff, 2004). Undirected data mining might suggest important patterns in the data, but the data miner needs to interpret the significance of the patterns.

Types of data mining algorithms

There are essentially two types of data mining algorithms: Descriptive and predictive. Descriptive data mining describes a given set of relevant data in a concise and summarative manner, and presents interesting general properties of the data. Predictive data mining analyses the data in order to construct one, or a set of models, and attempts to predict the behaviour of new data sets.

Data mining tasks

The following tasks can be done with data mining: Classification, estimation, prediction, association rules, clustering, and description and profiling (Kass, 1980).

- Classification: It consists in examining a set of data and assigning it to one predefined set of classes. For example, classifying the credit applicants as low, medium or high risk. The outcome for classification is a discrete value such as yes or no.
- Estimation: It deals with continuous values. Given some input data, estimation comes up with a value for some unknown continuous variable such as income, or credit card balance.
- Prediction: Is the same as classification or estimation, except for the records which are classified according to some predicted future behaviour or estimated future value.  For example, predicting which customer will leave within the next 6 months.
- Affinity grouping or association rules: Determining which things can go together. Association rules can also be used to identify cross-selling opportunities and to design packages or grouping products or services.
- Clustering: Is a task of segmenting a heterogeneous population into a number of homogeneous subgroups or clusters. In clustering, there are no predefined classes and no examples. The records are grouped together on the basis of self-similarity.

- Description and profiling: Data mining can also be used to describe people, products or processes. The first step for analysing data is to understand the behaviour of the data.

Data mining techniques

There are some data mining techniques according to the type of task that the data miner is attempting to carry out as follows:

- Decision trees: This is a powerful and popular data mining technique for classification, estimation and prediction tasks. The output of a decision tree algorithm is a set of rules that can be easily interpreted. A decision tree is a structure that can be used to divide a large collection of records into successively smaller sets of records by applying a sequence of simple decision rules until the record reaches a leaf or terminal node of the tree.
  The most popular decision tree algorithms are the Classification and Regression Trees (CART), the C4.5 pruning algorithm, and the Chi-squared Automatic Interaction Detector (CHAID) (Kachigan, 1986).

  The CART algorithm was published by Leo Breiman, Jerome Friedman, Richard Olshen, and Charles Stone in 1984. The CART algorithm grows binary trees and continues splitting as long as new splits can be found that increases purity using numerical values. Then, it identifies a set of subtrees as candidate models. These candidate subtrees are applied to the validation set and the tree with the lowest validation set misclassification rate is selected as the final model .

  The C4.5 pruning algorithm has been refined for many years by J. Ross Quinlan. The C4.5 algorithm grows binary as the CART one; however, the first one makes multiway splits on categorical values. The C4.5 algorithm grows an overfit tree and then prunes it back to create a more stable model. Then, it uses the same data to grow the tree and to decide how the tree should be pruned .

The CHAID algorithm only works with categorical and numerical attributes. It uses a chi-squared statistical test of significance to determine candidate attributes for building the decision tree. It is one of the oldest tree classification methods originally proposed by CHAID builds non-binary trees (i.e., trees where more than two branches can attach to a single root or node), based on a relatively simple algorithm that is particularly well suited for the analysis of larger datasets. This algorithm was implemented in statistical packages like SAS and SPSS.

- Memory based reasoning (MBR): This is a data mining technique that takes a set of known instances as a model to predict unknown instances. MBR is a k-nearest neighbours approach. It determines the nearest neighbour using a distance function such as the Euclidean and Manhathan methods. The next step is to choose the number of neighbours and combine these values to classify and predict new values.
- Neural networks: This is a versatile data mining tool based on biological model of how the brain works. It consists of a interconnected group of artificial neurons connected together. Each neuron takes various inputs, combines them and produces an output. There is an activation function that takes the weighted sum of the inputs and applies an S-shaped functions to it. The result is a node that can be linear or non-linear. In most cases, a neural network is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase.

  Neural networks can be constructed for supervised learning as well as unsupervised clustering. The most common network is the feed-forward, a supervised learner model, for predictive modelling.

  Neural networks have several disadvantages such as they don't work well when there are many input variables, and the results are too difficult to interpret.

- Regression models: Regression analysis is a technique for finding the equation that best describes the nature of the relationship between two variables . In addition, regression analysis supplies measures to know the accuracy with which the regression equation can predict values. The most common model is linear regression. It attempts to fit a straight line or linear function through the observed X and Y pairs in a sample. Once the line has been established, it can be used to predict a value for Y given any X and vice versa.

- Association rules: This is a technique used to find an association between two variables. A famous example is the association rule found between beer and diapers on Friday nights in a supermarket.

  The generated rules can be classified in three categories. The actionable rules explain useful relationships that were perhaps unexpected. The trivial rules explain relationships that are already known by anyone familiar with the business. And the inexplicable rules that do not make sense.

- Automatic cluster detection: This is an undirected data mining technique that can be used to learn the structure of complex data sets. By breaking complex data set into simpler clusters, automatic clustering can be used to improve the performance of more directed techniques. By choosing different distance measures, automatic clustering can be applied to almost any kind of data.
  Clustering algorithms rely on similarities that indicate whether two records are close or distant. One of the most popular algorithms for automatic cluster detection is K-means. The K-means algorithm is an iterative approach to find K clusters based on distance. Gaussian mixture models are a variation on the K-means idea that allows for overlapping clusters. Divisive clustering builds a tree of clusters by successively dividing an initial large cluster.

The TwoStep Cluster Analysis procedure (implemented in SPSS) is an exploratory tool designed to reveal natural groupings (or clusters) within a data set that would otherwise not be apparent. The algorithm employed by this procedure has several features that differentiate it from traditional clustering techniques: The ability to create clusters based on both categorical and continuous variables; the automatic selection of the number of clusters; and the ability to analyze large data files efficiently.

## *Appendix B – Training and testing data with some data mining techniques*

Results using C 4.5 decision trees for resident J

```
Scheme:       weka.classifiers.trees.J48 -C 0.25 -M 2
Relation:     TDRooms
Instances:    380
Attributes:   6
              Bath
              Bed
              Hall
              Kitchen
              Living
              zone
Test mode:    evaluate on training data Week 17-24, granularity weekday

=== Classifier model (full training set) ===

J48 pruned tree
------------------

Living <= 10
|   Bed <= 8
|   |   Living <= 0
|   |   |   Bed <= 0
|   |   |   |   Hall <= 0: Evening (2.0)
|   |   |   |   Hall > 0: Lunch (3.0/1.0)
|   |   |   Bed > 0: Late_Evening (33.0/1.0)
|   |   Living > 0
|   |   |   Kitchen <= 4
|   |   |   |   Bed <= 4: Lunch (37.0/4.0)
|   |   |   |   Bed > 4
|   |   |   |   |   Living <= 8: Late_Evening (3.0)
|   |   |   |   |   Living > 8: Early_Morning (2.0/1.0)
|   |   |   Kitchen > 4: Early_Morning (4.0)
|   Bed > 8
|   |   Bed <= 12
|   |   |   Bath <= 2: Late_Evening (17.0/6.0)
|   |   |   Bath > 2: Early_Morning (2.0/1.0)
|   |   Bed > 12: Sleeping (48.0/3.0)
Living > 10
|   Hall <= 6
|   |   Bed <= 1
|   |   |   Kitchen <= 1: Evening (4.0/1.0)
|   |   |   Kitchen > 1: Afternoon (42.0/4.0)
|   |   Bed > 1
|   |   |   Living <= 22
|   |   |   |   Bed <= 14
|   |   |   |   |   Kitchen <= 5
|   |   |   |   |   |   Bed <= 7
|   |   |   |   |   |   |   Hall <= 2
|   |   |   |   |   |   |   |   Bath <= 1: Late_Evening (3.0/1.0)
|   |   |   |   |   |   |   |   Bath > 1: Early_Morning (2.0)
|   |   |   |   |   |   |   Hall > 2
|   |   |   |   |   |   |   |   Bed <= 4
|   |   |   |   |   |   |   |   |   Living <= 19: Lunch (5.0/2.0)
|   |   |   |   |   |   |   |   |   Living > 19: Early_Morning (2.0/1.0)
|   |   |   |   |   |   |   |   Bed > 4: Early_Morning (4.0/1.0)
|   |   |   |   |   |   Bed > 7
|   |   |   |   |   |   |   Living <= 13: Early_Morning (2.0/1.0)
|   |   |   |   |   |   |   Living > 13
|   |   |   |   |   |   |   |   Bath <= 2: Evening (2.0)
|   |   |   |   |   |   |   |   Bath > 2: Late_Morning (5.0/2.0)
|   |   |   |   |   Kitchen > 5: Early_Morning (26.0/2.0)
```

```
|   |   |   |   Bed > 14
|   |   |   |   |   Bed <= 20: Late_Morning (2.0)
|   |   |   |   |   Bed > 20
|   |   |   |   |   |   Living <= 15: Sleeping (3.0)
|   |   |   |   |   |   Living > 15: Lunch (2.0/1.0)
|   |   |   Living > 22
|   |   |   |   Bath <= 3
|   |   |   |   |   Living <= 29
|   |   |   |   |   |   Kitchen <= 6: Evening (14.0/5.0)
|   |   |   |   |   |   Kitchen > 6
|   |   |   |   |   |   |   Kitchen <= 8: Afternoon (2.0)
|   |   |   |   |   |   |   Kitchen > 8: Early_Morning (5.0/1.0)
|   |   |   |   |   Living > 29
|   |   |   |   |   |   Bed <= 7
|   |   |   |   |   |   |   Kitchen <= 4: Evening (14.0/2.0)
|   |   |   |   |   |   |   Kitchen > 4: Afternoon (7.0/1.0)
|   |   |   |   |   |   Bed > 7: Evening (20.0)
|   |   |   |   Bath > 3
|   |   |   |   |   Bed <= 11: Late_Morning (2.0)
|   |   |   |   |   Bed > 11: Evening (2.0)
|   Hall > 6
|   |   Bath <= 3
|   |   |   Hall <= 8
|   |   |   |   Living <= 26: Early_Morning (4.0/1.0)
|   |   |   |   Living > 26: Late_Morning (2.0/1.0)
|   |   |   Hall > 8: Late_Morning (4.0)
|   |   Bath > 3
|   |   |   Kitchen <= 6: Late_Morning (37.0/3.0)
|   |   |   Kitchen > 6
|   |   |   |   Kitchen <= 7: Lunch (4.0/1.0)
|   |   |   |   Kitchen > 7: Late_Morning (8.0/2.0)

Number of Leaves  :        38

Size of the tree :  75

Time taken to build model: 0.18 seconds

=== Evaluation on training set ===
=== Summary ===

Correctly Classified Instances         330               86.8421 %
Incorrectly Classified Instances        50               13.1579 %
Kappa statistic                          0.8465
Mean absolute error                      0.0577
Root mean squared error                  0.1698
Relative absolute error                 23.5522 %
Root relative squared error             48.5308 %
Total Number of Instances              380

=== Detailed Accuracy By Class ===

TP Rate   FP Rate   Precision   Recall  F-Measure   ROC Area  Class
  0.873     0.009      0.941     0.873     0.906      0.992    Sleeping
  0.786     0.028      0.83      0.786     0.807      0.971    Early_Morning
  0.929     0.025      0.867     0.929     0.897      0.992    Late_Morning
  0.857     0.027      0.824     0.857     0.84       0.977    Lunch
  0.836     0.015      0.902     0.836     0.868      0.979    Afternoon
  0.893     0.025      0.862     0.893     0.877      0.99     Evening
  0.906     0.024      0.857     0.906     0.881      0.986    Late_Evening
=== Confusion Matrix ===

  a  b  c  d  e  f  g   <-- classified as
 48  0  0  0  0  0  7 |  a = Sleeping
  0 44  3  3  1  4  1 |  b = Early_Morning
  0  3 52  1  0  0  0 |  c = Late_Morning
  0  1  2 42  3  1  0 |  d = Lunch
  0  2  1  3 46  3  0 |  e = Afternoon
  0  2  2  1  1 50  0 |  f = Evening
  3  1  0  1  0  0 48 |  g = Late_Evening
```

```
Testing Data
Scheme:       weka.classifiers.trees.J48 -C 0.25 -M 2
Relation:     TDRooms
Instances:    380
Attributes:   6
              Bath
              Bed
              Hall
              Kitchen
              Living
              zone
Test mode:    user supplied test set: 186 instances

J48 pruned tree
------------------

Living <= 10
|   Bed <= 8
|   |   Living <= 0
|   |   |   Bed <= 0
|   |   |   |   Hall <= 0: Evening (2.0)
|   |   |   |   Hall > 0: Lunch (3.0/1.0)
|   |   |   Bed > 0: Late_Evening (33.0/1.0)
|   |   Living > 0
|   |   |   Kitchen <= 4
|   |   |   |   Bed <= 4: Lunch (37.0/4.0)
|   |   |   |   Bed > 4
|   |   |   |   |   Living <= 8: Late_Evening (3.0)
|   |   |   |   |   Living > 8: Early_Morning (2.0/1.0)
|   |   |   Kitchen > 4: Early_Morning (4.0)
|   Bed > 8
|   |   Bed <= 12
|   |   |   Bath <= 2: Late_Evening (17.0/6.0)
|   |   |   Bath > 2: Early_Morning (2.0/1.0)
|   |   Bed > 12: Sleeping (48.0/3.0)
Living > 10
|   Hall <= 6
|   |   Bed <= 1
|   |   |   Kitchen <= 1: Evening (4.0/1.0)
|   |   |   Kitchen > 1: Afternoon (42.0/4.0)
|   |   Bed > 1
|   |   |   Living <= 22
|   |   |   |   Bed <= 14
|   |   |   |   |   Kitchen <= 5
|   |   |   |   |   |   Bed <= 7
|   |   |   |   |   |   |   Hall <= 2
|   |   |   |   |   |   |   |   Bath <= 1: Late_Evening (3.0/1.0)
|   |   |   |   |   |   |   |   Bath > 1: Early_Morning (2.0)
|   |   |   |   |   |   |   Hall > 2
|   |   |   |   |   |   |   |   Bed <= 4
|   |   |   |   |   |   |   |   |   Living <= 19: Lunch (5.0/2.0)
|   |   |   |   |   |   |   |   |   Living > 19: Early_Morning (2.0/1.0)
|   |   |   |   |   |   |   |   Bed > 4: Early_Morning (4.0/1.0)
|   |   |   |   |   |   Bed > 7
|   |   |   |   |   |   |   Living <= 13: Early_Morning (2.0/1.0)
|   |   |   |   |   |   |   Living > 13
|   |   |   |   |   |   |   |   Bath <= 2: Evening (2.0)
|   |   |   |   |   |   |   |   Bath > 2: Late_Morning (5.0/2.0)
|   |   |   |   |   Kitchen > 5: Early_Morning (26.0/2.0)
|   |   |   |   Bed > 14
|   |   |   |   |   Bed <= 20: Late_Morning (2.0)
|   |   |   |   |   Bed > 20
|   |   |   |   |   |   Living <= 15: Sleeping (3.0)
|   |   |   |   |   |   Living > 15: Lunch (2.0/1.0)
|   |   |   Living > 22
|   |   |   |   Bath <= 3
|   |   |   |   |   Living <= 29
|   |   |   |   |   |   Kitchen <= 6: Evening (14.0/5.0)
|   |   |   |   |   |   Kitchen > 6
```

```
|   |   |   |   |   |   |   Kitchen <= 8: Afternoon (2.0)
|   |   |   |   |   |   |   Kitchen > 8: Early_Morning (5.0/1.0)
|   |   |   |   |   Living > 29
|   |   |   |   |   |   Bed <= 7
|   |   |   |   |   |   |   Kitchen <= 4: Evening (14.0/2.0)
|   |   |   |   |   |   |   Kitchen > 4: Afternoon (7.0/1.0)
|   |   |   |   |   |   Bed > 7: Evening (20.0)
|   |   |   |   Bath > 3
|   |   |   |   |   Bed <= 11: Late_Morning (2.0)
|   |   |   |   |   Bed > 11: Evening (2.0)
|   Hall > 6
|   |   Bath <= 3
|   |   |   Hall <= 8
|   |   |   |   Living <= 26: Early_Morning (4.0/1.0)
|   |   |   |   Living > 26: Late_Morning (2.0/1.0)
|   |   |   Hall > 8: Late_Morning (4.0)
|   |   Bath > 3
|   |   |   Kitchen <= 6: Late_Morning (37.0/3.0)
|   |   |   Kitchen > 6
|   |   |   |   Kitchen <= 7: Lunch (4.0/1.0)
|   |   |   |   Kitchen > 7: Late_Morning (8.0/2.0)

Number of Leaves  :        38

Size of the tree :  75

Time taken to build model: 0.05 seconds

=== Evaluation on test set ===
=== Summary ===

Correctly Classified Instances         135               72.5806 %
Incorrectly Classified Instances        51               27.4194 %
Kappa statistic                          0.6792
Mean absolute error                      0.0968
Root mean squared error                  0.2592
Relative absolute error                 39.5439 %
Root relative squared error             74.0854 %
Total Number of Instances              186

=== Detailed Accuracy By Class ===

TP Rate   FP Rate   Precision   Recall  F-Measure   ROC Area  Class
  0.679     0.019      0.864     0.679     0.76       0.891    Sleeping
  0.714     0.101      0.556     0.714     0.625      0.86     Early_Morning
  0.857     0.057      0.727     0.857     0.787      0.921    Late_Morning
  0.68      0.025      0.81      0.68      0.739      0.884    Lunch
  0.821     0.025      0.852     0.821     0.836      0.909    Afternoon
  0.821     0.044      0.767     0.821     0.793      0.893    Evening
  0.429     0.048      0.529     0.429     0.474      0.736    Late_Evening
=== Confusion Matrix ===

  a  b  c  d  e  f  g   <-- classified as
 19  5  0  0  0  0  4 |  a = Sleeping
  0 20  4  1  1  0  2 |  b = Early_Morning
  0  2 24  2  0  0  0 |  c = Late_Morning
  0  1  2 17  1  2  2 |  d = Lunch
  0  1  0  0 23  4  0 |  e = Afternoon
  0  0  3  0  2 23  0 |  f = Evening
  3  7  0  1  0  1  9 |  g = Late_Evening
```

## Results using C 4.5 decision trees for resident E

```
Scheme:       weka.classifiers.trees.J48 -C 0.25 -M 2
Relation:     TDRoomsE2
Instances:    441
Attributes:   6
              Bath
```

```
              Bed
              Hall
              Kitchen
              Living
              zone
Test mode:    evaluate on training data: WEEKS 5, 7,8, 13, 15, 16,21 22
Testing data: WEEKS 23-26


=== Classifier model (full training set) ===

J48 pruned tree
------------------

Kitchen <= 18
|   Bed <= 20
|   |   Hall <= 0
|   |   |   Kitchen <= 0
|   |   |   |   Bed <= 9: Late_Evening (37.0/6.0)
|   |   |   |   Bed > 9: Sleeping (12.0/3.0)
|   |   |   Kitchen > 0: Early_Afternoon (2.0)
|   |   Hall > 0
|   |   |   Living <= 8
|   |   |   |   Bed <= 12
|   |   |   |   |   Hall <= 2
|   |   |   |   |   |   Hall <= 1
|   |   |   |   |   |   |   Kitchen <= 3
|   |   |   |   |   |   |   |   Bed <= 4: Lunch (7.0/2.0)
|   |   |   |   |   |   |   |   Bed > 4
|   |   |   |   |   |   |   |   |   Kitchen <= 0: Early_Afternoon (3.0/1.0)
|   |   |   |   |   |   |   |   |   Kitchen > 0: Late_Evening (4.0/1.0)
|   |   |   |   |   |   |   Kitchen > 3: Late_Evening (2.0)
|   |   |   |   |   |   Hall > 1
|   |   |   |   |   |   |   Bath <= 1
|   |   |   |   |   |   |   |   Bed <= 5
|   |   |   |   |   |   |   |   |   Kitchen <= 3
|   |   |   |   |   |   |   |   |   |   Kitchen <= 0: Early_Afternoon (2.0)
|   |   |   |   |   |   |   |   |   |   Kitchen > 0: Lunch (8.0/2.0)
|   |   |   |   |   |   |   |   |   Kitchen > 3: Early_Afternoon (3.0)
|   |   |   |   |   |   |   |   Bed > 5: Lunch (5.0/3.0)
|   |   |   |   |   |   |   Bath > 1: Early_Afternoon (2.0/1.0)
|   |   |   |   |   Hall > 2: Lunch (45.0/19.0)
|   |   |   |   Bed > 12
|   |   |   |   |   Hall <= 2: Late_Evening (6.0/3.0)
|   |   |   |   |   Hall > 2: Early_Afternoon (7.0/3.0)
|   |   |   Living > 8
|   |   |   |   Bed <= 15
|   |   |   |   |   Bath <= 3
|   |   |   |   |   |   Bath <= 0
|   |   |   |   |   |   |   Hall <= 3: Early_Afternoon (6.0)
|   |   |   |   |   |   |   Hall > 3
|   |   |   |   |   |   |   |   Bed <= 6: Late_Morning (2.0)
|   |   |   |   |   |   |   |   Bed > 6: Early_Afternoon (4.0/1.0)
|   |   |   |   |   |   Bath > 0
|   |   |   |   |   |   |   Bed <= 8
|   |   |   |   |   |   |   |   Living <= 16
|   |   |   |   |   |   |   |   |   Hall <= 5: Lunch (6.0/3.0)
|   |   |   |   |   |   |   |   |   Hall > 5: Late_Morning (8.0/1.0)
|   |   |   |   |   |   |   |   Living > 16: Lunch (4.0)
|   |   |   |   |   |   |   Bed > 8
|   |   |   |   |   |   |   |   Living <= 18: Early_Afternoon (7.0/1.0)
|   |   |   |   |   |   |   |   Living > 18: Late_Morning (6.0)
|   |   |   |   |   Bath > 3: Late_Morning (11.0/1.0)
|   |   |   |   Bed > 15
|   |   |   |   |   Bath <= 1: Lunch (3.0)
|   |   |   |   |   Bath > 1: Sleeping (2.0)
|   Bed > 20
|   |   Bath <= 5: Sleeping (49.0/10.0)
|   |   Bath > 5: Early_morning (3.0/1.0)
Kitchen > 18
```

```
|   Bed <= 12
|   |   Bed <= 11
|   |   |   Bath <= 0: Lunch (4.0/2.0)
|   |   |   Bath > 0: Late_Morning (19.0/4.0)
|   |   Bed > 11: Lunch (2.0/1.0)
|   Bed > 12
|   |   Bath <= 7
|   |   |   Hall <= 13
|   |   |   |   Bath <= 3
|   |   |   |   |   Bed <= 16: Evening (5.0/1.0)
|   |   |   |   |   Bed > 16
|   |   |   |   |   |   Hall <= 8
|   |   |   |   |   |   |   Hall <= 6: Late_Afternoon (5.0/1.0)
|   |   |   |   |   |   |   Hall > 6: Evening (2.0)
|   |   |   |   |   |   Hall > 8: Late_Afternoon (10.0)
|   |   |   |   Bath > 3
|   |   |   |   |   Kitchen <= 48: Evening (41.0/5.0)
|   |   |   |   |   Kitchen > 48: Late_Afternoon (8.0/3.0)
|   |   |   Hall > 13
|   |   |   |   Bath <= 5: Late_Afternoon (17.0/1.0)
|   |   |   |   Bath > 5
|   |   |   |   |   Hall <= 14: Early_morning (3.0)
|   |   |   |   |   Hall > 14: Late_Afternoon (5.0/2.0)
|   |   Bath > 7
|   |   |   Bed <= 26
|   |   |   |   Bath <= 8: Late_Afternoon (3.0)
|   |   |   |   Bath > 8
|   |   |   |   |   Hall <= 13: Evening (6.0/1.0)
|   |   |   |   |   Hall > 13: Early_morning (4.0/1.0)
|   |   |   Bed > 26
|   |   |   |   Kitchen <= 56: Early_morning (42.0/1.0)
|   |   |   |   Kitchen > 56
|   |   |   |   |   Bed <= 33: Late_Afternoon (5.0/1.0)
|   |   |   |   |   Bed > 33: Early_morning (4.0/1.0)

Number of Leaves  :        46

Size of the tree :  91


Time taken to build model: 0.27 seconds

=== Evaluation on training set ===
=== Summary ===

Correctly Classified Instances         354               80.2721 %
Incorrectly Classified Instances        87               19.7279 %
Kappa statistic                          0.7746
Mean absolute error                      0.0741
Root mean squared error                  0.1925
Relative absolute error                 33.8819 %
Root relative squared error             58.2082 %
Total Number of Instances              441


=== Detailed Accuracy By Class ===

TP Rate   FP Rate   Precision   Recall  F-Measure   ROC Area  Class
  0.893     0.034      0.794     0.893     0.84       0.977    Sleeping
  0.929     0.01       0.929     0.929     0.929      0.995    Early_morning
  0.727     0.016      0.87      0.727     0.792      0.972    Late_Morning
  0.963     0.083      0.619     0.963     0.754      0.968    Lunch
  0.518     0.018      0.806     0.518     0.63       0.935    Early_Afternoon
  0.804     0.021      0.849     0.804     0.826      0.966    Late_Afternoon
  0.839     0.018      0.87      0.839     0.855      0.984    Evening
  0.75      0.026      0.796     0.75      0.772      0.969    Late_Evening

=== Confusion Matrix ===

  a  b  c  d  e  f  g  h   <-- classified as
```

```
 50  0  0  0  1  0  0  5 |  a = Sleeping
  0 52  0  0  0  3  1  0 |  b = Early_morning
  0  0 40 11  2  1  0  1 |  c = Late_Morning
  0  0  0 52  2  0  0  0 |  d = Lunch
  1  0  4 18 29  0  0  4 |  e = Early_Afternoon
  2  1  2  0  0 45  6  0 |  f = Late_Afternoon
  1  3  0  1  0  4 47  0 |  g = Evening
  9  0  0  2  2  0  0 39 |  h = Late_Evening


Testing Data
Scheme:       weka.classifiers.trees.J48 -C 0.25 -M 2
Relation:     TesttRoomsE2
Instances:    441
Attributes:   6
              Bath
              Bed
              Hall
              Kitchen
              Living
              zone
Test mode:    user supplied test set: 211 instances

=== Classifier model (full training set) ===

J48 pruned tree
------------------

Kitchen <= 18
|   Bed <= 20
|   |   Hall <= 0
|   |   |   Kitchen <= 0
|   |   |   |   Bed <= 9: Late_Evening (37.0/6.0)
|   |   |   |   Bed > 9: Sleeping (12.0/3.0)
|   |   |   Kitchen > 0: Early_Afternoon (2.0)
|   |   Hall > 0
|   |   |   Living <= 8
|   |   |   |   Bed <= 12
|   |   |   |   |   Hall <= 2
|   |   |   |   |   |   Hall <= 1
|   |   |   |   |   |   |   Kitchen <= 3
|   |   |   |   |   |   |   |   Bed <= 4: Lunch (7.0/2.0)
|   |   |   |   |   |   |   |   Bed > 4
|   |   |   |   |   |   |   |   |   Kitchen <= 0: Early_Afternoon (3.0/1.0)
|   |   |   |   |   |   |   |   |   Kitchen > 0: Late_Evening (4.0/1.0)
|   |   |   |   |   |   |   Kitchen > 3: Late_Evening (2.0)
|   |   |   |   |   |   Hall > 1
|   |   |   |   |   |   |   Bath <= 1
|   |   |   |   |   |   |   |   Bed <= 5
|   |   |   |   |   |   |   |   |   Kitchen <= 3
|   |   |   |   |   |   |   |   |   |   Kitchen <= 0: Early_Afternoon (2.0)
|   |   |   |   |   |   |   |   |   |   Kitchen > 0: Lunch (8.0/2.0)
|   |   |   |   |   |   |   |   |   Kitchen > 3: Early_Afternoon (3.0)
|   |   |   |   |   |   |   |   Bed > 5: Lunch (5.0/3.0)
|   |   |   |   |   |   |   Bath > 1: Early_Afternoon (2.0/1.0)
|   |   |   |   |   Hall > 2: Lunch (45.0/19.0)
|   |   |   |   Bed > 12
|   |   |   |   |   Hall <= 2: Late_Evening (6.0/3.0)
|   |   |   |   |   Hall > 2: Early_Afternoon (7.0/3.0)
|   |   |   Living > 8
|   |   |   |   Bed <= 15
|   |   |   |   |   Bath <= 3
|   |   |   |   |   |   Bath <= 0
|   |   |   |   |   |   |   Hall <= 3: Early_Afternoon (6.0)
|   |   |   |   |   |   |   Hall > 3
|   |   |   |   |   |   |   |   Bed <= 6: Late_Morning (2.0)
|   |   |   |   |   |   |   |   Bed > 6: Early_Afternoon (4.0/1.0)
|   |   |   |   |   |   Bath > 0
|   |   |   |   |   |   |   Bed <= 8
|   |   |   |   |   |   |   |   Living <= 16
```

```
|   |   |   |   |   |   |   |   |   Hall <= 5: Lunch (6.0/3.0)
|   |   |   |   |   |   |   |   |   Hall > 5: Late_Morning (8.0/1.0)
|   |   |   |   |   |   |   |   Living > 16: Lunch (4.0)
|   |   |   |   |   |   |   Bed > 8
|   |   |   |   |   |   |   |   Living <= 18: Early_Afternoon (7.0/1.0)
|   |   |   |   |   |   |   |   Living > 18: Late_Morning (6.0)
|   |   |   |   |   Bath > 3: Late_Morning (11.0/1.0)
|   |   |   |   Bed > 15
|   |   |   |   |   Bath <= 1: Lunch (3.0)
|   |   |   |   |   Bath > 1: Sleeping (2.0)
|   Bed > 20
|   |   Bath <= 5: Sleeping (49.0/10.0)
|   |   Bath > 5: Early_morning (3.0/1.0)
Kitchen > 18
|   Bed <= 12
|   |   Bed <= 11
|   |   |   Bath <= 0: Lunch (4.0/2.0)
|   |   |   Bath > 0: Late_Morning (19.0/4.0)
|   |   Bed > 11: Lunch (2.0/1.0)
|   Bed > 12
|   |   Bath <= 7
|   |   |   Hall <= 13
|   |   |   |   Bath <= 3
|   |   |   |   |   Bed <= 16: Evening (5.0/1.0)
|   |   |   |   |   Bed > 16
|   |   |   |   |   |   Hall <= 8
|   |   |   |   |   |   |   Hall <= 6: Late_Afternoon (5.0/1.0)
|   |   |   |   |   |   |   Hall > 6: Evening (2.0)
|   |   |   |   |   |   Hall > 8: Late_Afternoon (10.0)
|   |   |   |   Bath > 3
|   |   |   |   |   Kitchen <= 48: Evening (41.0/5.0)
|   |   |   |   |   Kitchen > 48: Late_Afternoon (8.0/3.0)
|   |   |   Hall > 13
|   |   |   |   Bath <= 5: Late_Afternoon (17.0/1.0)
|   |   |   |   Bath > 5
|   |   |   |   |   Hall <= 14: Early_morning (3.0)
|   |   |   |   |   Hall > 14: Late_Afternoon (5.0/2.0)
|   |   Bath > 7
|   |   |   Bed <= 26
|   |   |   |   Bath <= 8: Late_Afternoon (3.0)
|   |   |   |   Bath > 8
|   |   |   |   |   Hall <= 13: Evening (6.0/1.0)
|   |   |   |   |   Hall > 13: Early_morning (4.0/1.0)
|   |   |   Bed > 26
|   |   |   |   Kitchen <= 56: Early_morning (42.0/1.0)
|   |   |   |   Kitchen > 56
|   |   |   |   |   Bed <= 33: Late_Afternoon (5.0/1.0)
|   |   |   |   |   Bed > 33: Early_morning (4.0/1.0)

Number of Leaves  :       46

Size of the tree :  91


Time taken to build model: 0.1 seconds

=== Evaluation on test set ===
=== Summary ===

Correctly Classified Instances         130               61.6114 %
Incorrectly Classified Instances        81               38.3886 %
Kappa statistic                          0.5613
Mean absolute error                      0.1107
Root mean squared error                  0.2699
Relative absolute error                 50.5987 %
Root relative squared error             81.6293 %
Total Number of Instances              211


=== Detailed Accuracy By Class ===
```

| TP Rate | FP Rate | Precision | Recall | F-Measure | ROC Area | Class |
|---|---|---|---|---|---|---|
| 0.821 | 0.027 | 0.821 | 0.821 | 0.821 | 0.96 | Sleeping |
| 0.643 | 0.027 | 0.783 | 0.643 | 0.706 | 0.901 | Early_morning |
| 0.5 | 0.016 | 0.824 | 0.5 | 0.622 | 0.867 | Late_Morning |
| 0.88 | 0.156 | 0.431 | 0.88 | 0.579 | 0.875 | Lunch |
| 0.16 | 0.027 | 0.444 | 0.16 | 0.235 | 0.873 | Early_Afternoon |
| 0.643 | 0.104 | 0.486 | 0.643 | 0.554 | 0.868 | Late_Afternoon |
| 0.5 | 0.044 | 0.636 | 0.5 | 0.56 | 0.76 | Evening |
| 0.81 | 0.037 | 0.708 | 0.81 | 0.756 | 0.974 | Late_Evening |

=== Confusion Matrix ===

| a | b | c | d | e | f | g | h | <-- classified as |
|---|---|---|---|---|---|---|---|---|
| 23 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | a = Sleeping |
| 0 | 18 | 0 | 0 | 0 | 9 | 1 | 0 | b = Early_morning |
| 0 | 0 | 14 | 12 | 2 | 0 | 0 | 0 | c = Late_Morning |
| 0 | 0 | 0 | 22 | 3 | 0 | 0 | 0 | d = Lunch |
| 0 | 0 | 2 | 16 | 4 | 0 | 0 | 3 | e = Early_Afternoon |
| 0 | 1 | 1 | 1 | 0 | 18 | 7 | 0 | f = Late_Afternoon |
| 1 | 4 | 0 | 0 | 0 | 9 | 14 | 0 | g = Evening |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 17 | h = Late_Evening |

# *Appendix C – Material relating to preliminary evaluation*

The material used in the main trial of the system developed in this study was reproduced below.

**Informed Consent Form – Older People**

Name of Participant: ________________________________________________

*Please tick the most appropriate selection:*

| | | | | |
|---|---|---|---|---|
| Age range: | 50-59 | 60-69 | 70-79 | over 80 |
| Computer/Internet experience: | | daily | weekly | Monthly |
| Role: | | cared | cared for | |

Dear Participant

Thank you for your interest of the design of the Domestic Well-being Information System DWIS. This page describes what you will be asked to do for the study. Please read through it and then sign at the bottom to say that you understand and accept the conditions of this study. If you have questions, please feel free to ask the researcher.

The main purpose of the trial is to evaluate the interface of the "Domestic Well-being Indicator System" DWIS and to know how the prototype might support the dialogue of care between the older person and the carer.

You will be asked to use DWIS to carry out a set of tasks and to "think aloud". By verbalizing your thoughts, you enable us to understand how you view the prototype and this helps us to identify the users' misconceptions.

We will be videotaping only what appears on the computer screen. What you say as you carry out the test will also be recorded. Your identity will remain confidential.

Please note that you are helping the researchers to evaluate a prototype. You are not being tested – it is the prototype that is being tested. There are therefore no right or wrong answers to the questions you will be asked.

Your participation in this study is voluntary and you can leave the study at any time without penalty or giving reasons. No undue risk arises from the participation in this study.

The researchers are very grateful for your help.

*Signature:* ________________________________________________

*Date: ___ /______ / 200 _*

**Informed Consent Form - Carers**

Name of Participant: _____________________________________________

*Please tick the most appropriate selection:*

Age range: under 30 30-39 40-49 50-59

Computer/Internet experience: daily weekly Monthly

Role: O.T Physiotherapist Warden Scheme manager

Informal carer Other, specify__________________

Dear Participant

Thank you for your interest of the design of the Domestic Well-being Information System DWIS. This page describes what you will be asked to do for the study. Please read through it and then sign at the bottom to say that you understand and accept the conditions of this study. If you have questions, please feel free to ask the researcher.

The main purpose of the trial is to evaluate the interface of the "Domestic Well-being Indicator System" DWIS and to know how the prototype might support the dialogue of care between the older person and the carer.

You will be asked to use DWIS to carry out a set of tasks and to "think aloud". By verbalizing your thoughts, you enable us to understand how you view the prototype and this helps us to identify the users' misconceptions.

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The researchers are very grateful for your help.

*Signature:* _____________________________________________

*Date: ___ /______ / 200 _*

**List of Tasks**

For this study we are interested in gaining a better understanding of the problems people have when using the Domestic Well-being Information System DWIS, a web application designed to provide well-being information to both the older people and the carer.

Please complete the following tasks. While you are doing your job, it is important for us know what is going on inside your mind. Therefore, as you complete each task please tell us what you are looking at, what are you thinking about, what is confusing to you, and so forth.

**Task #1: Logon to the system and explore DWIS.**

Your first task is to spend 5 minutes exploring DWIS.

User: admin

Password: 1235

**Task #2: The registration process**

15 minutes

1. Register a new occupant
2. Register a new carer

**Task #3: Check the occupant's well-being**

20 minutes

1. Check mobility inside the house
2. Check sleeping patterns
3. Check eating and drinking activity
4. Check toileting usage
5. Check medical conditions: blood sugar, blood pressure and pulse.

**Task #4: Actions**

10 minutes

1. Add an action

Thanks,

**DWIS Usability Testing**

Please evaluate the Domestic Well-being Information System DWIS in terms of the following aspects (circle the answer that best represents your opinion):

1. It was very easy to learn how to use the system.

| | | | | |
|---|---|---|---|---|
| strongly disagree | Disagree | Neutral | agree | strongly agree |

2. It was very easy to remember how to use the system.

| | | | | |
|---|---|---|---|---|
| strongly disagree | disagree | Neutral | agree | strongly agree |

3. I felt that the system allows me to achieve very high productivity.

| | | | | |
|---|---|---|---|---|
| strongly disagree | disagree | Neutral | agree | strongly agree |

4. The logon response time was very appropriate.

| | | | | |
|---|---|---|---|---|
| strongly disagree | disagree | Neutral | agree | strongly agree |

5. The system made it easy for me to undo mistakes.

| | | | | |
|---|---|---|---|---|
| strongly disagree | disagree | Neutral | agree | strongly agree |

6. I found the system very pleasant to work with.

| | | | | |
|---|---|---|---|---|
| strongly disagree | disagree | Neutral | agree | strongly agree |

7. The system could do all the things I think I would need.

| | | | | |
|---|---|---|---|---|
| Strongly disagree | disagree | Neutral | agree | strongly agree |

8. I satisfactory achieved my tasks given using the system.

| strongly disagree | disagree | Neutral | agree | strongly agree |
|---|---|---|---|---|

9. I really like the set of functions provided by the system.

| strongly disagree | disagree | Neutral | agree | strongly agree |
|---|---|---|---|---|

10. I found that all the functions worked correctly.

| strongly disagree | disagree | Neutral | agree | strongly agree |
|---|---|---|---|---|

11. It was easy for me to find all the options.

| strongly disagree | disagree | neutral | agree | strongly agree |
|---|---|---|---|---|

12. I think that all the information presented by the system was relevant and necessary.

| strongly disagree | Disagree | neutral | agree | strongly agree |
|---|---|---|---|---|

## *Appendix D – Material relating to final evaluation*

The material used in the main trials of the system developed in this study was reproduced below.

### Older People Tasks

**Session # . Checking Well-being**

Task # 1: Check the older person's indicators of busyness associated with well-being for **THIS WEEK.**
15 minutes

Check this week mobility inside the house
Check this week sleeping patterns
Check this week eating and drinking activity
Check this week personal hygiene activity

Task # 2: Check the older person's medical conditions for **THIS WEEK**
5 minutes

Check the older person's medical conditions: blood sugar, blood pressure and pulse.

Task # 3: Check older person's indicators of busyness associated with well-being for **TODAY.**
15 minutes

Check today mobility inside the house
Check today sleeping patterns
Check today eating and drinking activity
Check today personal hygiene activity

**Carers Tasks**

Session # . First medication change

Task # 1: Check the **WEEKLY** older person’s medical conditions

5 minutes

Check the older person’s medical conditions: blood sugar, blood pressure and pulse.

Task # 2: Check the **DAILY** older person’s indicators of busyness associated with well-being before first medication change.

15 minutes

Check daily mobility inside the house

Check daily sleeping patterns

Check daily eating and drinking activity

Check daily personal hygiene activity

Task # 3: Check the **DAILY** older person’s indicators of busyness associated with well-being after first medication change.

15 minutes

Check daily mobility inside the house

Check daily sleeping patterns

Check daily eating and drinking activity

Check daily personal hygiene activity

## Tasks for dialogue of care with the user interface for older people

**Session #**

Please carry out the following tasks looking at the chart or the trend graph.

Task # 1: Check the older person's indicators of busyness associated with well-being for **THIS WEEK.**
15 minutes

Check this week mobility inside the house
Check this week sleeping patterns
Check this week eating and drinking activity
Check this week personal hygiene activity

Task #2: Check older person's indicators of busyness associated with well-being for **TODAY.**
15 minutes

Check today mobility inside the house
Check today sleeping patterns
Check today eating and drinking activity
Check today personal hygiene activity

Task # 3: Check the older person's indicators of busyness associated with well-being for **YESTERDAY.**
15 minutes

Check yesterday mobility inside the house
Check yesterday sleeping patterns
Check yesterday eating and drinking activity
Check yesterday personal hygiene activity

## Tasks for Dialogue of care with the user interface for carers

### Session #

Please carry out the following tasks looking at the chart or the trend graph.

Task # 1: Check the MONTHLY older person's indicators of busyness associated with well-being.

15 minutes

Check monthly mobility inside the house
Check monthly sleeping patterns
Check monthly eating and drinking activity
Check monthly personal hygiene activity

Task # 2: Check the WEEKLY older person's indicators of busyness associated with well-being.

15 minutes

Check weekly mobility inside the house
Check weekly sleeping patterns
Check weekly eating and drinking activity
Check weekly personal hygiene activity

Task # 3 Check the older person's medical conditions
10 minutes
Check monthly medical conditions
Check weekly medical conditions

## Questionnaire for Older People

Session # . Checking Well-being

Please answer the questions in the space provide.

Can you tell us when the person has visited the **bathroom** more frequently during **this week**? If so which day?

______________________________________________

______________________________________________

Can you tell us if the person visited the kitchen **yesterday**? If so what time?

______________________________________________

______________________________________________

Can you tell us if the person was moving around **yesterday**? If so what time?

______________________________________________

______________________________________________

How intuitive and self-explanatory is the information presented in the form of graphs, trends and text?

Select and mark a tick the one that most closely matches your answer.

very high

high

moderate

low

very low

Comments: ________________________________________

---

Is the wellness status information at the bottom of the page an effective way to know the general well-being of the older person?

Circle 'Yes' or 'No' whichever applies YES NO

If not, do you have any suggestions?

______________________________________________

______________________________________

Is the prototype DWIS doing what do you expected it to? YES NO
Circle ‘Yes’ or ‘No’ whichever applies
If not, how is it failing?

____________________________________________________________________________________

__________________________________________________________________

How would you measure your level of satisfaction with DWIS as a whole?
Select and mark a tick the one that most closely matches your level of satisfaction.

- very high
- high
- moderate
- low
- very low

Comments: ______________________________________________________________

_________________________________________________________________________

Do you have any further comments and suggestions?

____________________________________________________________________________________

__________________________________________________________________

I would like to thank you in taking the time to participate in the evaluation. If you have any further questions or comments please do not hesitate.

## Questionnaire for Carers

Session # . First medication change

Please answer the questions in the space provide.

Can you notice any change in the **daily mobility** of the person BEFORE and AFTER the first medication change? If so can you describe the change?

______________________________________________________________________

______________________________________________________________________

Can you notice any change in the **daily sleeping** BEFORE and AFTER the first change of medication? If so can you describe the change?

______________________________________________________________________

______________________________________________________________________

Can you notice any change in the **daily eating and drinking** BEFORE and AFTER the first change of medication? If so can you describe the change?

______________________________________________________________________

______________________________________________________________________

How intuitive and self-explanatory is the information presented in the form of graphs, trends and text?

Select and mark a tick the one that most closely matches your answer.

very high

high

moderate

low

very low

Comments: ____________________________________________________

______________________________________________________________

Is the wellness status information at the bottom of the page an effective way to know the general well-being of the older person?

Circle 'Yes' or 'No' whichever applies YES NO

If not, Do you have any suggestions?

______________________________________________________________________

____________________________________________________

Is the prototype DWIS doing what do you expected it to? YES NO
Circle ‘Yes’ or ‘No’ whichever applies
If not, how is it failing?

______________________________________________________________________________
_________________________________________________________

Select and mark a tick the one that most closely matches your level of satisfaction.

- very high
- high
- moderate
- low
- very low

Comments: _________________________________________________________
__________________________________________________________________

Do you have any further comments and suggestions?

____________________________________________________________________________
____________________________________________________________________________

## Questionnaire for Dialogue of Care - Older person's interface

Session #.

Please answer the questions in the space provide.

Can you tell us when the person has visited the **bathroom** more frequently **this week**? If so which day?

____________________________________________________________

____________________________________________________________

Can you notice any change in the **mobility** activity between **today** and **yesterday**? If so can you describe the change?

____________________________________________________________

____________________________________________________________

Can you notice any change in the **sleeping** activity between **today** and **yesterday**? If so can you describe the change?

____________________________________________________________

____________________________________________________________

Can you notice any change in the **eating and drinking** activity between **today** and **yesterday**? If so can you describe the change?

____________________________________________________________

____________________________________________________________

How useful could be the prototype "Domestic Well-being Indicator System" DWIS to support the dialogue of care between the older person and the carer?

Select and mark a tick the one that most closely matches your answer.

very useful

useful

moderate

useless

very useless

Do you have any further comments and suggestions?

____________________________________________________________

____________________________________________________________

## Questionnaire for Dialogue of Care- Carer's interface

Session # .

Please answer the questions in the space provide.

Can you notice any change in the **monthly mobility** of the person over the past 3 months? If so can you describe the change?

______________________________________________________________________

______________________________________________________________________

Can you notice any change in the **monthly personal hygiene** activity over the past 3 months? If so can you describe the change?

______________________________________________________________________

______________________________________________________________________

Can you notice any change in the **weekly sleeping** activity over the past 10 weeks? If so can you describe the change?

______________________________________________________________________

______________________________________________________________________

Can you notice any change in the **weekly eating and drinking** over the past 10 weeks? If so can you describe the change?

______________________________________________________________________

______________________________________________________________________

How useful could be the prototype "Domestic Well-being Indicator System" DWIS to support the dialogue of care between the older person and the carer?

Select and mark a tick the one that most closely matches your answer.

very useful

useful

moderate

useless

very useless

Comments: ________________________________________________________

__________________________________________________________________

Do you have any further comments and suggestions?

______________________________________________________________________

______________________________________________________________________

**Questionnaire for Dialogue of Care - Without interface**

Session #

Please answer the questions in the space provide.

Imagine that the carer is sitting with Anne and she/he obtains the following information from the system:

There is a significant decrease in the mobility today in comparison with the activity registered yesterday. In addition the sensor from the kitchen detects less activity. What could be the reason?

________________________________________________________________________

________________________________________________________________________

The activity in the bathroom increased and the blood sugar level was high over the last 10 weeks. What could be the reason?

________________________________________________________________________

________________________________________________________________________

The sleeping patterns are poor and the person is moving around the house at nigh more than usual over the last 10 days. What do you think has happened?

________________________________________________________________________

________________________________________________________________________

What else could be useful to identify the real situation of Anne?

________________________________________________________________________

________________________________________________________________________

How useful could be the prototype "Domestic Well-being Indicator System" DWIS to support the dialogue of care between the older person and the carer?

Select and mark a tick the one that most closely matches your answer.

very useful

useful

moderate

useless

very useless

Do you have any further comments and suggestions?

________________________________________________________________________

________________________________________________________________________