REFEREED ARTICLE

DOI: 10.5836/ijam/2017-06-80

Involving stakeholders in agricultural decision support systems: Improving user-centred design

DAVID C. ROSE[1,2], CAROLINE PARKER[3], JOE FODEY[3], CAROLINE PARK[3], WILLIAM J. SUTHERLAND[1] and LYNN V. DICKS[1,4]

ABSTRACT

Decision Support Systems (DSS) can improve farm management decisions and offer the opportunity to improve productivity and limit environmental degradation, both key tenets of the sustainable intensification of agriculture. While DSS are becoming increasingly useful for agriculture, the uptake of computer-based support systems by farmers has remained disappointingly low as evidenced by studies spanning at least two decades. This paper explores the reasons behind this continued lack of interest. Is it, as previous researchers have proposed, the lack of user involvement in the design and development of these systems? If so why should this be the case given decades of evidence underlining the value in user centred design (UCD)? The paper reviews literature on the desirable characteristics of DSS, and then uses 78 interviews and five focus groups to explore a case study of system use. The paper suggests that without changes to how systems are developed, particularly in how users are consulted, use of this technology will continue to be low. Practical suggestions are proposed to encourage more effective user-centred design. Chief amongst these, the need for designers to undertake a 'decision support context assessment' before building and launching a product is highlighted. Better knowledge of user-centred design practices, a clear understanding of advice systems, and greater collaboration with human-computer interaction researchers are also required.

KEYWORDS: decision context assessment; decision support systems; decision support tools; participatory research; stakeholder engagement; technology use; user-centred design

1. Introduction

Decision support in agriculture

Researchers in the environmental sciences have found that despite the availability of scientific knowledge, relatively little science is used by practitioners (Dicks *et al.*, 2014). Thus, there is a need to find a way of linking science and practice better, and decision support systems (DSS) are a suggested solution. These are usually software-based, guiding users through clear decision stages using an evidence-based database to support recommendations. In agriculture, DSS for use on-farm are seen as part of a solution to the problem of delivering scientific knowledge directly to the farming community to raise productivity and reduce environmental impact (Rose *et al.*, 2016). Their potential to improve farming decisions are well-recognised (Kragt and Llewellyn, 2014), and if properly designed, Lindblom *et al.* (2017, 311) argue that 'AgriDSS can promote and scaffold environmentally sustainable… decisions'. Despite their alleged value and their availability in a wide range of formats, the actual uptake of computer-based DSS by farmers has been low (Rose *et al.*, 2016). As one farm adviser argued in a focus group for this research (see 'Methods'), 'the pathway to sustainability is littered with the burning wrecks of failed decision support systems'.

Interest in the reasons for failure of this apparently useful technology is not a new phenomenon. DSS and their predecessors, 'Expert Systems', have been considered an option for delivery of science since the early 1990's (e.g. Jones, 1993) and concerns about the lack of uptake by end users have been raised since then. In agriculture, several studies have investigated factors influencing system use (Kerselaers *et al.*, 2015; McCown, 2002; Rose *et al.*, 2016). Alvarez and Nuthall (2006) suggested that specific farmer attributes (e.g. education, skills) and the size of the business were strong determinants of DSS success. Others such as McCown (2002) have argued that the function of the system in relation to the decision task is the key factor: systems which seek to replace the decision-makers' decision processes are resisted, whereas those which present themselves as a tool are more likely to be adopted.

Original submitted February 2017; revision received May 2017; accepted September 2017.

[1] Department of Zoology, University of Cambridge, David Attenborough Building, Pembroke Street, Cambridge, CB2 3QY, UK.
[2] Corresponding author: School of Environmental Sciences, University of East Anglia, NR4 7TJ, UK. david.rose@uea.ac.uk.
[3] School of Engineering and Built Environment, Glasgow Caledonian University, Cowcaddens Road, Glasgow, G4 0BA, UK.
[4] School of Biological Sciences, University of East Anglia, Norwich Research Park, NR4 7TJ, UK.

Box 1: Desirable characteristics of DSS in agriculture (Rose *et al.*, 2016)

	Desirable characteristics
1	Performance
2	Ease of use
3	Peer recommendation
4	Trust
5	Cost
6	Habit
7	Relevance to user
8	Farmer-adviser compatibility
9	Awareness of age
10	Awareness of business scale
11	Awareness of farming type
12	Awareness of IT eductation
13	Facilitating conditions
14	Compliance
15	Level of marketing

The importance of ensuring the compatibility of the system to existing farm practices and technologies is stressed by Aubert *et al.* (2012).

Rose *et al.* (2016) found many of the same influential factors. Fifteen key factors were distinguished (see Box 1).

Participatory approaches/User-Centred Design as a solution

Parker and Sinclair (2001) argued that the reason for lack of uptake was the approach taken to the system development, which had limited understanding of decision-making in practice (see also Lindblom *et al.*, 2017; Rodela *et al.,* 2017). They proposed that the technology-centred methods adopted by many developers were the main reason for the mismatch between the tool delivered and the needs of the end-user. In an ethnography of a software manufacturer, Woolgar (1990) concluded that the lack of UCD of many systems occurred as a direct result of the disconnect between designers and users. This problem was noted by Cooper (1999) who proposed the now well-established design tool of Personas as local fixed representations of key user characteristics and needs.

Parker and Sinclair (2001) concluded that the logical approach to reducing barriers to use would be for DSS developers to adopt user-centred design (UCD) methods, which are widely discussed in human-computer interaction (HCI) research. Although HCI researchers have rarely engaged in agriculture (Lindblom *et al.*, 2017), a UCD approach involves an assessment of the decision-making environment in which decisions are made, including finding out about the workflows of end users. Conducting such a decision context assessment is a key hallmark of UCD, ensuring that systems are adapted towards existing user needs and workflows, rather than trying to force users to change routines (Allen *et al.*, 2017; Aubert *et al.*, 2012; Evans *et al.,* 2017; Lindblom *et al.*, 2017). Evidence from fields such as agriculture (Kragt and Llewellyn, 2014; Oliver *et al.*, 2017; Rossi *et al.*, 2014), and public health (van der Heide *et al.*, 2016), strongly suggests that adapting the tool to existing workflows, and consulting users throughout, is more effective than expecting users to change their behavior. Understanding use workflows is also important to ensure that technologies are relevant to user needs (Weatherdon *et al.*, 2017).

In coastal risk management, Santoro *et al.*, (2013) found that involving users at the beginning of a project to design DSS was essential to meet stakeholder needs. In medicine, UCD methods have also been shown to have a beneficial impact. For example, Thursky and Mahemoff (2006) used a range of UCD techniques in the requirements identification and design stages of an antibiotic prescribing DSS for Intensive Care Unit use. The careful attention taken by the developers to the existing tasks and work patterns of the intended users resulted in a design which substantially reduced the time taken to perform the prescribing task and was thus rapidly adopted into practice.

The problem of validating the impact of user participation

One of the problems in reviewing the issues around uptake, and the value of any particular approach to system development, is that there is little discussion of actual system use within the scientific literature (van Delden *et al.,* 2011). While there are many papers describing DSS within agriculture[5], most focus on the development of systems or innovations in modelling. While this in itself underlines the technology driven nature of DSS development, it makes it difficult to find studies supporting or disproving the notional value of UCD. A good example of this is a piece of work by Oliver *et al.* (2012). Based on a case study of farmers in the Taw region of Devon in the UK, these researchers investigated the role of farmers in designing DSS. They argued that six stages were needed to include farmer knowledge in the design of systems, but follow-up research on whether a trial of this process had improved uptake was not carried out. Despite limited investigations into the effect of UCD on DSS adoption in the long-term, however, a few studies contained within a review by Lindblom *et al.* (2017) do support the link.

In order to elucidate further the role of UCD practice in agriculture, two studies are described in this paper. The first reviews the literature for determinants of success in those DSS that have had active use. The second takes a case study approach to reveal the extent to which farmers and advisers are being consulted in the design of DSS. The output from these investigations is used to promote the value of UCD approaches in DSS development, including better collaboration between agricultural scientists and HCI researchers.

2. Methods

Structured literature review

A literature review was conducted to assess the factors found to be influential in encouraging successful uptake of DSS in a range of disciplines. To place emphasis on user data rather than theory, the review focused on papers that provided evidence that the described systems had been in actual use. Sectors of particular interest are: health, which shares a concern with biological systems; construction, whose activities are similarly impacted by weather; and manufacturing, which shares a focus on production processes. The search was limited to 20 years (1994–2014), and there were four attributes for the initial search:

a) Relevance to decision support. For this a set of terms was used, which were previously validated in a similarly focused systematic review (Wu *et al.*, 2012).

[5] A basic search on the Web of Science database at the time of writing generated over 3000 results.

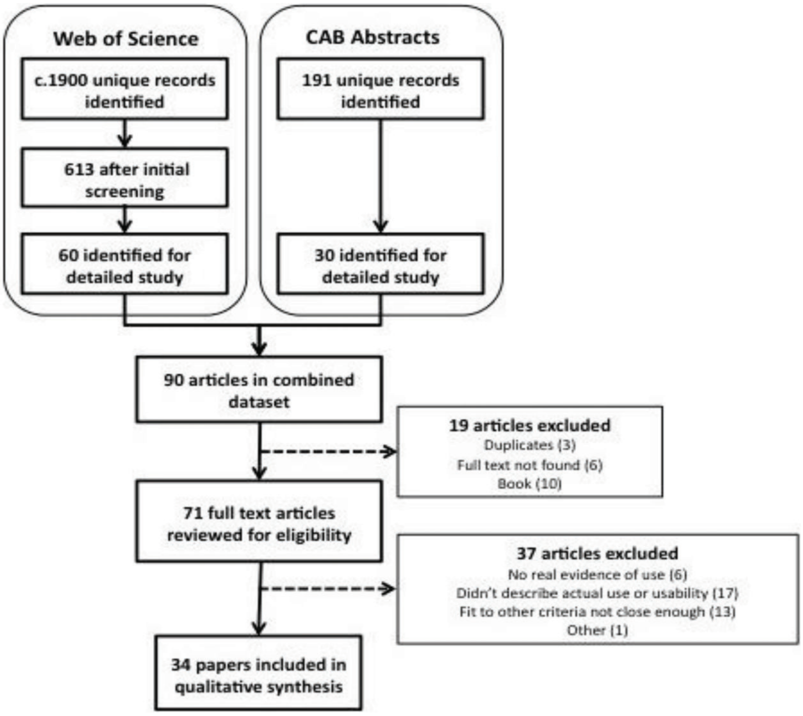

Figure 1: Filtering process used in the selection of papers for the literature review

b) A focus on systems that had been in active use.
c) An evaluation of the success of the system in use.
d) An evaluation focused on the end user.

An overview of the process is illustrated by Figure 1, and further details of the review process are detailed in appendix 1.

DSS uptake in agriculture: an English and Welsh case study

A case study of the use of DSS in English and Welsh agriculture was selected to act as a microcosm for system use in agriculture. End users in this case were defined as farmers, but also professional advisers. Studies have shown that a farm adviser's role in encouraging efficient farming practices is now more central than ever, and their advice is highly valued by farmers (AIC, 2013; Ingram, 2008; Prager & Thomson, 2014). One of their roles can be to encourage farmers to take up new innovations (Jakku & Thorburn, 2010).

Five focus groups lasting up to an hour were held with arable farmers (2), arable advisers, dairy farmers, and red meat farmers. These made use of existing networks of farmer/adviser meeting groups. They were typically attended by 10-15 individuals and were recorded and transcribed. The focus groups centred on the use of DSS, posing questions such as ‘do you use DSS?’, and ‘what influences you to use a new DSS?’. Through group interaction, the factors affecting uptake were discussed, as was the level to which end users felt included in the processes of design and delivery.

For a more in-depth personal view of the use of DSS, and the place for UCD, 78 semi-structured interviews lasting up to an hour were conducted with farmers and advisers in three different study regions across England and Wales (Wensum in Norfolk, Taw in Devon, and Conwy in North Wales). Of these 78 participants, 33 were arable or livestock advisers, and 45 were farmers covering the arable (14), upland livestock (Less Favoured Areas (LFAs) - 19), and lowland livestock sectors (9), but also including dairy (3). These entreprises were chosen as they covered the largest area of land in the UK as compared with entreprises such as horticulture, pigs, and poultry. The farmers were recruited from a survey completed by 244 farmers (across 7 study regions, see Rose *et al.* 2016) as part of Defra's Sustainable Intensification Platform. The adviser sample was generated with assistance from ADAS, who used existing contacts and search engines to develop a list of advisers covering each of the three study areas. These included advisers who provided technical, business, or environmental advice, and included both commercial and independent advisers (see Rose *et al.*, 2016). The interviews asked a number of questions relating to use of DSS, and their semi-structured nature facilitated wider discussion of the researcher-user divide.

3. Results

Literature review

A total of 34 papers were reviewed in the final analysis. The issues identified by each paper as contributing to success, or presenting a barrier to use, were manually clustered and 15 factors emerged. Within each factor duplicate issues were removed to leave a set of distinguishable attributes. Table 1 illustrates that there are clear benefits to designing a system that is easy to use, fits the existing workflow of users, performs well, and commands trust. As a barrier to system use, a poor user interface was the most prevalent obstacle to continued use, whilst a DSS that performed well and provided clear benefits to use was the most important characteristic for successful uptake. In the list of factors, there is a clear focus on the user; for example, a good user interface, a system that fits

Table 1: Results from literature review

Factor heading	Number of times each factor listed in final article set		
	As success factor	As a barrier	Total
Usability/UI design	18	16	34
Fit to task/workflow	16	14	30
Clear benefits to use	19	3	22
Trust/confidence in system	9	8	17
Integration with existing systems/databases	8	3	11
User-focused design	9	1	10
Organisational/peer support	9	0	9
Decision support design	8	0	8
Responsiveness to user comment/issues with system	7	0	7
Training/launch timing	5	2	7
Technical support	3	2	5
Marketing	2	2	4
Job security/job status	2	2	4
Access to software/hardware	2	1	3
Keeping knowledge data/current	2	1	3

end user workflow, user-focused design, responsiveness to user, and peer support. This suggests that better UCD of systems would be beneficial.

Case study of DSS use in UK agriculture

Although Oliver *et al.*, (2012) suggest that agricultural research has shifted towards participatory methods for both the design and implementation of DSS, the empirical case study used here suggests that lessons are still not being widely learned. On UCD, data from both the focus groups and interviews suggested that user-focused practices were not widely utilised. A common theme referred to the perceived divide between developers (including researchers) and end users. The lack of interaction between these two groups therefore restricted the extent to which users were consulted. One arable adviser argued that:

> 'Decision support tools aren't about giving advice to individual farms, they're just about taking knowledge from clever people's heads and then building a computer programme.' (Arable adviser, focus group)

This viewpoint was backed up by several farmers, including a farmer in Devon. He argued:

> 'I'm perfectly happy to come to your university and give a lecture in common sense. I learn from the university of life. Sometimes I feel the researchers who design these things need a bit of common sense. Ask yourself will it work on a farm? Have I ever visited an actual farm?' (Lowland livestock farmer, Taw, 10011)

Similar responses were received in several interviews. For example, a farmer was annoyed by the lack of engagement from developers of systems:

> 'I've been doing this forty years, you get some academic who's come out of college last year and they're telling me what to do. I just laugh at them, I think you stupid idiot you haven't got a clue.' (LFA farmer, Conwy, 20034)

Further discussion in both focus groups and interviews illuminated the impacts of the farmer/researcher divide, but also highlighted the value of trusted advisers (e.g. agronomists, vets) in contrast to 'outsider' researchers. Indeed, throughout the research it was clear that trusted advisers were key to the use of decision support systems (Rose *et al.,* 2016), as noted by other studies of system uptake (Evans *et al.,* 2017).

As a result of low user engagement, technical support tools were designed that were not easy to use or tried to solve the wrong questions. Or DSS required long hours in the office to operate effectively, which did not fit the workflow of small-scale farmers who "make their money getting outside and getting stuck-in" (Red Meat Focus Group). There was also a lack of trust between farmers and researchers.

These opinions reinforce the claim by Parker and Sinclair (2001) that design of DSS is not always user-centred. They remind us of the 'transfer of technology' approach; one in which a sophisticated system is designed in an ivory tower, assumed to be useful for end users, and rolled out with little regard for end user involvement or the decision environment into which the system is launched.

'ToolX' – a User-Centred Nutrient Management System

A farm adviser was interviewed who provided advice to local farmers about using DSS. He encountered problems with a specific software package, which was designed to help farmers with nitrogen application. This package answered relevant questions, and it was free to download. However, it was not easy to use. Echoing criticisms of the systems from other interviewees who described it as a 'nightmare' (Livestcok adviser, 2), the adviser reported that:

> 'I had 27 farmers in the programme. The first day I would think by the evening most people had lost it. So I did another one and within six hours they had lost it again. Farmers couldn't understand it, they could hold the information for about half a day. So, I gave up on it and decided to design my own.' (Livestock adviser, Taw, 11)

Interviewees suggested that the original system design had made little use of end users. In order to improve the user interface, the adviser set out to involve end users throughout the design of a new system ('ToolX').

Crucially, however, he approached the design of a new prototype from a user perspective. He had learned to see flaws in the old system as a result of end user input, and therefore his initial work on the new tool was driven by the user.

Initially, the new system was designed in a basic Excel© spreadsheet. This was then taken to local farms for input from farmers, as illustrated by the following extract:

> 'We tried this basic design on farmers. From the very beginning farmers had to test it and use it. We asked them see if you can go and break it and then come back to us with things. One comment was you've forgotten to put a decimal point in these values!' (Livestock adviser, Taw, 11)

Over the course of the design project, farmers made several suggestions including, (1) changing the given units, (2) improving the ease of data entry, (3) allowing mistakes to be undone easily, (4) providing the ability to deal with multiple fields at any one time, (5) ensuring that a technical helpine was set up. By tweaking the design to take into account these user preferences, initial trials seemed positive. The adviser stated that 'within 10 minutes most farmers can crack this and even if they don't look at it for a while, even for three months, they can go straight back into it'. Whilst some caution may be prudent in announcing success before widespread uptake, the UCD process seemed to have satisfied some of the important determinants of uptake identified in Box 1 and Table 1; specifically, usability, user-focused design, technical support, and responsiveness to user. Furthermore, trust was built through the design process.

4. Discussion

Returning to the top ten factors identified in Table 1, UCD processes would seem to be highly relevant. Taking these in turn, it is possible to see how UCD could contribute to success in each category:

1. *Usability* – defined in HCI literature (ISO 9241-11) as 'the extent to which a product can be used to achieved specific goals with effectiveness, efficiency, and satisfaction in a specific context of use.' Evidence from HCI shows that UCD approaches achieve good usability (Andreasson *et al.*, 2015). Systems will be more effective and efficient, and users more satisfied if they play a role in development.
2. *Good fit to the decision task and workflow* – since developers will have a clear understanding of the decision-making environment and how the decision maker(s) would like the systems to fit in.
3. *Demonstrable value* – since only systems that offered value would be supported by users. Their input would ensure that the right questions were answered.
4. *Trusted output* – Trust in DSS output can be increased by participation in its design (Guillaume *et al.*, 2016).
5. *Integration with other systems used within the task* – through interaction with users, developers will understand what other systems the DSS needs to work with.
6. *User-focused design* – the outcome of a UCD approach.
7. *Peer support* – a good UCD strategy can bring together users and facilitate knowledge exchange (Oliver *et al.*, 2017).
8. *Decision support design* – the mechanisms by which decisions are supported (graphics, data, layout, extent of interactivity, etc) will be directly linked to need.
9. *Responsiveness to user* – awareness of the expectations of a range of users supports flexible and responsive design.
10. *Training* – understanding of existing levels of knowledge will inform training and participant users will have the knowledge to train others.

The apparent success attributed to the UCD of 'ToolX', for example, mirrors other research projects in agriculture that have encouraged participatory engagement. It is encouraging to see that some examples are recent in nature, and therefore perhaps the user-cented design message is getting across. Oliver *et al.* (2017), for example, report on a stakeholder-driven approach to the development of a DSS to visualize *E. coli* risk on agricultural land. By using a series of stakeholder workshops at every stage of the project (conception, design, testing, and plans for continued engagement), the developers were able to design a relevant tool with strong usability. Feedback was welcomed throughout the project and the tool was adjusted in line with user preferences (e.g. desire for ease of use). The process built trust and an excellent rapport between researchers and users. The ability of users to scrutinize decision support systems, and suggest refinement, is also mentioned by Bruce (2016) and Lacoste and Powles (2016) as important in system design. Furthermore, Guillaume *et al.* (2016) suggest that a participatory approach can help to build trust, which far outweighs the inconvenience of a more time-consuming research project. Oliver *et al.* (2017, 233) conclude with the argument that involving stakeholders within all stages of…design… from inception and idea formulation through to testing, is critically important'.

In addition, Rossi *et al.* (2014) report on a project to design a DSS ('vite.net'®) for vineyard farmers in Italy. By involving potential users during its development, researchers were able to gain insights into how users make decisions, and where their tool might fit in with their decision-making routines. Feedback suggested that potential users were likely to use vite.net®, but the paper did not investigate continued uptake in the long-term. Higgins (2007) also illustrates how participatory engagement with farmers helped a Dairy Planning Software (DPS) system Australia. In this project, farmers were invited to workshops to input their own data and the DPS was configured according to this. This made the tool relevant to particular users and gave the farmers ownership of the process. As a result, farmers gained validation of their knowledge and felt empowered by being included in the project. The workshops also enabled farmers to give feedback on the tool, and the DPS was modified in response to criticisms.

The problem with such studies, and the major caveat of this paper, is the lack of long-term engagement with the effects of UCD. For the project described by Higgins (2007), for example, Eastwood *et al.* (2012) suggests that there was limited continued engagement with farmers. Likewise, Oliver *et al.* (2012) argued for the adoption of a specific user-centred strategy of DSS development in Devon (UK), but were not able to test this in the long-term. Certainly, more research is needed that traces a UCD project from conception through delivery and onwards to investigate whether there is sustained used. It is worth noting also that trade-offs between including the views of stakeholders and sticking within a design timetable may be needed, and furthermore designers should have some capacity to innovate since they are best placed to know about technical possibilities (Santoro *et al.* 2013). If we are to accept, however, that the UK case study presented here illustrates many of the same UCD flaws identified by Parker and Sinclair (2001), the experiences of farmers in relation to DSS do not seem to have changed. It is interesting to ask why UCD might not be practised widely.

Lack of knowledge and skills about how to do UCD may be a factor (Lindblom *et al.*, 2017). DSS in agriculture are rarely if ever developed by an established software design team, particularly in the case of a university-driven piece of work. There may be some commercial software development experience within a DSS design team but very often, in the UK at least, the developers will be a small team of scientists which includes, or has access to, individuals with programming capability. It is unlikely that any of the team will have knowledge of UCD methods even if they contain experienced software developers (Lindblom *et al.*, 2017). Indeed, even in mainstream software development it has been shown that the majority of mainstream software organizations perform few usability engineering activities or none at all.

The nature of funding might also be an issue. Since the mid 1980's the funding for agricultural science in the UK and elsewhere has moved away from industry focused research institutes and into universities. At the same time the pressure on researchers to publish has increased and sums of money spent on agricultural research has decreased (Leaver, 2010). Weighing up the costs of UCD against the less tangible benefit of user uptake, a factor which is of less value to the UK research scientist than a peer-reviewed publication (Bruce, 2016), then it is perhaps not surprising that UCD is not widely employed. Even when user involvement has been specified by the funding agency, the level of participation or influence by the users on the final design may be less than optimum. Since DSS, therefore, are being designed in research institutions away from the farm environment in which they are used, the practical decision-making environment is not well understood. Decision support context assessments (Fig 2) are rarely carried out and this increases the chances of poor design.

Encouraging UCD of agricultural DSS

Based on the findings, four recommendations are suggested to improve the quality of UCD of DSS in agriculture and beyond.

1. Promote user-centred design practices

Providing guidance for developers to take UCD seriously from the outset, will help to prevent costly uptake problems at a later stage. The how, why, and when of user involvement are important concepts to clarify with those engaged in DSS development; particularly since studies show a link between user engagement, which uses good communication and focuses on stimulating learning, and uptake of DSS (Evans *et al.*, 2017; Oliver *et al.*, 2017; Rodela *et al.,* 2017). For those developers who are not familiar with effective user facilitation approaches, several useful guides exist on how to engage stakeholders effectively (see review by Reed, 2017). As research by Lynch and Gregor (2004) shows, it is the depth of user influence on design, rather than simple participation that is important. Developers need to be helped to understand not only the benefits of engaging with users during a project (Lindblom *et al.*, 2017), but also at the concept stage and after implementation. Funders and development teams alike need to be made aware that on-farm installation of a DSS is only the beginning of the story (Eastwood *et al.*, 2012), as the lack of continued engagement is responsible for many failed projects. After installation, a DSS must be consistently updated to maintain accuracy (not easy if funding ceases) and developers need ways to maintain the motivation and skills of farmers.

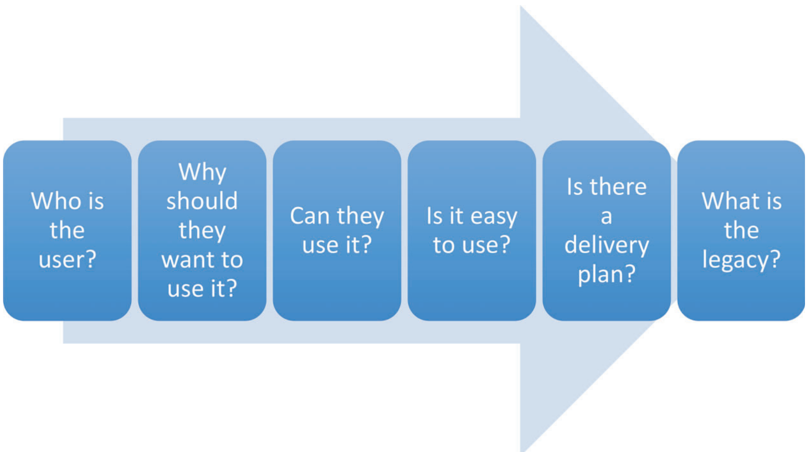

Figure 2: Key Stages in a Decision Support Context Assessment – **1) Who is the user?** – identify a clear user, understand their workflows, and ask about their needs; these will vary for different types of farmers, 2) **Why should they want to use it?** – scientifically, the system might be robust and impressive, but ask whether there is a need for it from a farmer/adviser [user] perspective – asking users whether they need it would help! 3) **Can they use it?** – test whether users are able to use it effectively; also find out whether users can practically use it in a given setting (e.g. is there internet access on-farm?), **4) Is it easy to use?** – related to point 3, however there is a distinction between merely being able to use it, and the ability to use it easily – ask about user design preferences and test tools on actual users rather than like-minded colleagues, **5) Is there a delivery plan?** – ask how farmers/advisers [users] will find out about the system.This might involve making use of existing trusted peer and adviser networks, (6) **What is the legacy?** – if the tool needs to be consistently updated to maintain relevance, then consider how to do this once funding ends.

The nature of funding within this sector in the UK has increasingly placed the task of communicating science on an academic group who have little regular direct contact with end-users. Funding bodies should insist that a 'decision support context assessment' (Figure 2) is undertaken before the design and delivery of a DSS to ensure impact. This will prevent the costly and time-intensive design of unsuitable systems.

2. Encourage cross-disciplinary collaboration with HCI researchers
Lindblom *et al.* (2017) argue that HCI researchers could take a greater interest in agriculture. The knowledge of how to design appropriate and useable systems contained within HCI could be usefully shared with agricultural researchers and developers of decision support. This requires engagement from both communities and a commitment to multi-disciplinary research collaborations, encouraged by the funding landscape.

3. Undertake decision support context asssessments
In addition to promoting the need for UCD, designers of agricultural DSS will need guidance on how to do it. As shown by Allen *et al.* (2017), even when user-centred methods have been used, projects still suffer from a mismatch between stakeholder and researcher expectations. Furthermore, a review by Rodela *et al.* (2017) found that existing user engagement exercises were not underpinned by a coherent methodology. As the results in our study indicate, many systems are poorly targeted, and do not include the end user. From a relevance and usability perspective, systems therefore ask the wrong questions and do not solve problems in an efficient, effective, and satisfactory way.

Given the largely non-commercial and/or low budget nature of DSS development, the solution to this problem may be to create freely available templates (i.e. outlines of UCD tasks with instructions suited to specific types of project), or basic guides to UCD to support developers. These templates would need to be flexible enough to meet the varying demands of a range of project sizes and user access capability, cost-efficient to encourage use (Kujala, 2003), and sufficiently detailed to support a team without any prior knowledge or experience of UCD (Lindblom *et al.*, 2017). A basic template for a 'decision support context assessment', illustrated in Figure 2, should be used by designers throughout the project, and funders should make grant holders report on whether, and how, they have considered each stage. We consider the process outlined in Figure 2 to be relevant for the design of DSS in all fields; crucially, the user must be involved at every stage.

The template shown in Figure 2 encourages the engagement of end user at an upstream stage, and key user facilitation skills are required (see Reed *et al.*, 2017). This approach, described by Santoro *et al.* (2013) as 'involve to improve' may create better prototypes, as in the case of 'ToolX', and ultimately better final products. Following each stage on Figure 2 will satisfy many of the key enablers of success found in the literature review and UK case study; including ensuring that systems (1) fit farm workflows, (2) are easy to use, (3) perform a useful function, (4) are trusted, and (5) can integrate with other systems. These categories are satisfied because a decision support context assessment enables the developer to understand the end user, find out who they are, what problems they need solving, what their preferences are for useful interfaces, and where systems can fit into their existing workflows. This user-centred mentality is vital in the future design of DSS to ensure that we move away from a situation where 'clever people' are designing systems 'in their heads' (arable *adviser in focus group*), which are then unsuitable for use in practice.

4. Understand the governance of on-farm decision-making
As part of a decision support context assessment, developers need to discover the different actors making key on-farm decisions. This will always include the farmer, but it will also usually encompass a wider selection of actors, including paid professional advisers, industry representatives, and other trusted indviduals (AIC, 2013; Ingram, 2008; Prager and Thomson, 2014). Some of these groups, particularly paid professional advisers, will be more likely to use DSS that farmers (Evans *et al.*, 2017; Rose *et al.*, 2016). Since these individuals are usually trusted by farmers (Ingram, 2008; Evans *et al.,* 2017), mainly due to long-standing personal relationships, developers of DSS should make use of these existing trusted networks when delivering products. Building trusted relationships with such key knowledge brokers may allow developers to forge more trusted relationships with farmers by association.

About the authors

David Rose is an environmental geographer interested in the interactions between knowledge, technology, policy, and practice in the environmental sphere.

Caroline Parker's specific research expertise lies in the area of user centred software development approaches and in the presentation of information to support decision making. Her most recent decision based research takes a step back from problem specific DSS work and looks instead at the generic issues facing non-expert users of decision support data.

Joe Fodey was reference librarian at Glasgow Caledonian University.

Caroline Park is the managing director of Carallys Research and Consulting which focuses on the digital media space. At Glasgow Caledonian University she was a Human Factors specialist in multidisciplinary team of scientists and technologists working on the development of new software.

William Sutherland is the Miriam-Rothschild Chair of Conservation Biology at the University of Cambridge. He is interested in the use of evidence in policy.

Lynn Dicks is a Senior Research Fellow at the University of East Anglia, specialising in agri-environmental work for pollinators.

Acknowledgements

Research funded by Defra's Sustainable Intensification Platform (Code LM0201). WJS thanks Arcadia, LVD was funded by the UK Natural Environment Research Council under the Biodiversity and Ecosystem Service Sustainability (BESS) programme, grant code NE/K015419/1 and NE/N014472/1. We acknowledge Susan Twining, Charles Ffoulkes, Matt Lobley, Michael Winter, and Carol Morris, and others on the Defra SIP project.

REFERENCES

AIC (2013). The Value of Advice Report, https://www.agindustries.org.uk/latest-documents/value-of-advice-project-report/

Allen, W., Cruz, J. and Warburton, B. (2017). How Decision Support Systems Can Benefit from a Theory of Change Approach. *Environmental Management* 59 (6), 956–965, doi: 10.1007/s00267-017-0839-y.

Alvarez, J. and Nuthall, P. (2006). Adoption of computer based information systems: The case of dairy farmers in Canterbury. NZ, and Florida, Uruguay, *Computers and Electronics in Agriculture* 50, 48–60, https://doi.org/10.1016/j.compag.2005.08.013.

Andreasson, R., Lindblom, J. and Thorvald, P. (2015). Towards an increased degree of usability work in organizations. *Procedia Manufacturing* 3, 5739–5746, doi: 10.1016/j.promfg.2015.07.814.

Aubert, B.A., Schroeder, A. and Grimaudo, J. (2012). IT as enabler of sustainable farming: An empirical analysis of farmers' adoption decision of precision agriculture technology. *Decision support systems* 54, 510–520, https://doi.org/10.1016/j.dss.2012.07.002.

Bruce, T.J.A. (2016). The CROPROTECT project and wider opportunities to improve farm productivity through web-based knowledge exchange, *Food and Energy Security* 5 (2): 89–96, doi: 10.1002/fes3.80.

Cooper, A. (1999). The Inmates are Running the Asylum: Why High-tech Products Drive Us Crazy and How to Restore the Sanity, Sams Publishing, USA.

Dicks, L.V., Walsh, J.C. and Sutherland, W.J. (2014). Organising evidence for environmental management decisions: a '4S'hierarchy. *Trends in Ecology & Evolution* 29, 607–613, https://doi.org/10.1016/j.tree.2014.09.004.

Eastwood, C., Chapman, D. and Paine, M. (2012). Networks of practice for co-construction of agricultural decision support systems: Case studies of precision dairy farms in Australia. *Agricultural Systems* 108, 10–18, https://doi.org/10.1016/j.agsy.2011.12.005.

Evans, K., Terhorst, A. and Ho Kang, B. (2017). From Data to Decisions: Helping Crop Producers Build Their Actionable Knowledge. *Critical Reviews in Plant Sciences* 36 (2) 71–88, DOI: 10.1080/07352689.2017.1336047.

Guillaume, M., Houben, P., Stilmant, D. and Van Damme, J. (2016). Co-designing a decision-support tool with farmers as the basis for a participatory approach, *BAM 2016 5th Belgian Agroecology Meeting*.

Higgins, V. (2007). Performing Users: The Case of a Computer-Based Dairy Decision-Support System. *Science, Technology & Human Values* 32, 263–286, https://doi.org/10.1177/0162243906298350.

Ingram, J. (2008). Agronomist–farmer knowledge encounters: an analysis of knowledge exchange in the context of best management practices in England. *Agriculture and Human Values* 25, 405–418, https://doi.org/10.1007/s10460-008-9134-0.

ISO 9241-11 (1998). *Guidance on usability*. Geneva, Switzerland: International Organization for Standardization.

Jakku, E. and Thorburn, P. (2010). A conceptual framework for guiding the participatory development of agricultural decision support systems. *Agricultural Systems* 103, 675–682, https://doi.org/10.1016/j.agsy.2010.08.007.

Jones, J. (1993). Decision support systems for agricultural development, Systems approaches for agricultural development. Springer, pp. 459–471.

Kerselaers, E., Rogge, E., Lauwers, L. and Van Huylenbroeck, G. (2015). Decision support for prioritising of land to be preserved for agriculture: Can participatory tool development help? *Computers and Electronics in Agriculture* 110, 208–220, https://doi.org/10.1016/j.compag.2014.10.022.

Kragt, M.E. and Llewellyn, R.S. (2014). Using a Choice Experiment to Improve Decision Support Tool Design. *Applied Economic Perspectives and Policy* 36 (2), 351–371, https://doi.org/10.1093/aepp/ppu001.

Kujala, S. (2003). User involvement: a review of the benefits and challenges. *Behaviour & Information Technology* 22, 1–16, http://dx.doi.org/10.1080/01449290301782.

Lacoste, M. and Powles, S.B. (2016). Beyond modelling: Considering user-centred and post-development aspects to ensure the success of decision support system. *Computers and Electronics in Agriculture* 121, 260–268, https://doi.org/10.1016/j.compag.2016.01.003.

Leaver, J. (2010). Support for Agricultural R&D is Essential to Deliver Sustainable Increases in UK Food Production. All-Party Parliamentary Group on Science and Technology in Agriculture.

Lindblom, J., Lundström, C., Ljung, M. and Jonsson, A. (2017). Promoting sustainable intensification in precision agriculture: review of decision support systems development and strategies. *Precision Agriculture* 18, 309–331, https://doi.org/10.1007/s11119-016-9491-4.

Lynch, T. and Gregor, S. (2004). User participation in decision support systems development: Influencing system outcomes. *European Journal of Information Systems* 13, 286–301, https://doi.org/10.1057/palgrave.ejis.3000512.

McCown, R.L. (2002). Changing systems for supporting farmers' decisions: problems. paradigms, and prospects, *Agricultural Systems* 74, 179–220, https://doi.org/10.1016/S0308-521X(02)00026-4.

Oliver, D.M., Fish, R.D., Winter, M., Hodgson, C.J., Heathwaite, A.L. and Chadwick, D.R. (2012). Valuing local knowledge as a source of expert data: farmer engagement and the design of decision support systems. *Environmental Modelling & Software* 36, 76–85, https://doi.org/10.1016/j.envsoft.2011.09.013.

Oliver, D.M., Bartie, P.J., Louise Heathwaite, A., Pschetz, L. and Quillam, R.S. (2017). Design of a decision support tool for visualising *E. coli* risk on agricultural land using a stakeholder-driven approach. *Land Use Policy* 66, 227–234, https://doi.org/10.1016/j.landusepol.2017.05.005.

Parker, C.G. and Sinclair, M.A. (2001). User-centred design does make a difference. The case of decision support systems in crop production, *Behaviour & Information Technology* 20, 449–460, http://dx.doi.org/10.1080/01449290110089570.

Prager, K. and Thomson, K. (2014). AKIS and advisery services in the United Kingdom. Report for the AKIS inventory (WP3) of the PRO AKIS project. James Hutton Institute.

Reed, M.S., Vella, S., Challies, E., de Vente, J. and Frewer, L., *et al.* (2017). A theory of participation: what makes stakeholder and public engagement in environmental management work? *Resoration Ecology,* DOI: 10.1111/rec.12541.

Rodela, R., Bregt, A.K., Ligtenberg, A., Pérez-Soba, M. and Verweij, P. (2017). The social side of spatial decision support systems: Investigating knowledge integration and learning. *Environmental Science & Policy* 76, 177–184, https://doi.org/10.1016/j.envsci.2017.06.015.

Rose, D.C., Sutherland, W.J., Parker, C.G., Morris, C., Lobley, M., Winter, M., Ffoulkes, C., Twining, S., Amano, T. and Dicks, L.V. (2016). Decision Support Tools in Agriculture: Towards Effective Design and Delivery, *Agricultural Systems*, DOI: 10.1016/j.agsy.2016.09.009.

Rossi, V., Salinari, F., Poni, S., Caffi, T. and Bettati, T. (2014). Addressing the implementation problem in agricultural decision support systems: the example of vite. net®, *Computers and Electronics in Agriculture* 100, 88–99, https://doi.org/10.1016/j.compag.2013.10.011.

Santoro, F., Tonino, M., Torresan, S., Critto, A. and Marcomini, A. (2013). Involve to improve: a participatory approach for a Decision Support System for coastal climate change impacts assessment. The North Adriatic case, *Ocean & Coastal Management* 78, 101–111, https://doi.org/10.1016/j.ocecoaman.2013.03.008.

Thursky, K.A. and Mahemoff, M. (2006). User-centered design techniques for a computerised antibiotic decision support system in an intensive care unit. *International Journal of Medical Informatics* 76, 760–768, DOI: 10.1016/j.ijmedinf.2006.07.011.

van Delden, H., Seppelt, R., White, R. and Jakeman, R.W. (2011). A methodology for the design and development of integrated models for policy support. *Environmental Modelling and Software* 26 (3), 266–279, https://doi.org/10.1016/j.envsoft.2010.03.021.

van der Heide, I., van der Noordt, K., Proper, K., Schoemarker, C., van den Berg, M. and Hamberg-van Reenen, H.H. (2016). Implementation of a tool to enhance evidence-informed decision making in public health: identifying barriers and facilitating factors. *Evidence & Policy: A Journal of Research, Debate, and Practice* 12 (2), 183–197, https://doi.org/10.1332/174426415X14356748943723.

Weatherdon, L., Appeltans, W., Bowles Newark, N., Brooks, T.M. Fletcher, S., Garilao, C., Hirsch, T., Juffe-Bignoli, D., Regan, E., Reyes, K., Rose, D.C., Wilkinson, T. and Martin, C.S. (2017). Blueprints of effective biodiversity knowledge products that inform marine policy instruments and decision-making, *Frontiers in Marine Science,* https://doi.org/10.3389/fmars.2017.00096.

Woolgar, S. (1990). Configuring the user: the case of usability trials. *The Sociological Review* 38 (51), 58–99, DOI: 10.1111/j.1467-954X.1990.tb03349.x.

Wu, H.W., Davis, P.K. and Bell, D.S. (2012). Advancing clinical decision support using lessons from outside of healthcare: an interdisciplinary systematic review. *BMC Medical Informatics and Decision Making* 12, 90, doi: 10.1186/1472-6947-12-90.

Appendix 1 – Structured literature review methodology

A structured literature review was conducted to assess the factors found to be influential in encouraging successful uptake of DSS in a range of disciplines. To place emphasis on user data rather than theory, the review focused on papers that provided evidence that the described systems had been in actual use. The search focused on Web of Science and Centre for Agriculture and Bioscience International (CABI) Abstracts database which give the best coverage of agricultural papers (Kawasaki, 2004). This strategy also allowed the project to learn from domains where DSS implementation, and the processes around it, are more mature. Sectors of particular interest are: health, which shares a concern with biological systems; construction, whose activities are similarly impacted by weather; and manufacturing, which shares a focus on production processes.

The search method was iterative with a starting point of a set of search terms generated by research and local knowledge. A reference librarian was employed to test the utility of these initial terms within the Web of Science database and to refine them into a more robust set. The papers returned during this first search were filtered according to pre-set criteria. The adjusted search terms were applied to CABI Abstracts and the same filtering process applied. The filtered output from the two searches was imported into Endnote™ and a more detailed review of full undertaken. Finally, papers that met the final criteria were reviewed in detail and a summary of their findings produced. There were four distinct attributes that articles in the initial search to contain:

a) Relevance to decision support. For this a set of terms was used, which were previously validated in a similarly focused systematic review (Wu *et al.*, 2012)
b) A focus on systems that had been in active use
c) An evaluation of the success of the system in use
d) An evaluation focused on the end user.

To keep the search space relevant and manageable the research domains selected for the search within the databases were restricted to Science, Technology or Social Science and articles published within the previous 20 years (1994-2014). The types of publication were not restricted. After several iterations in which the hit rate for various terms was analyzed the final search query developed within the Web of Science and then applied within CABI Abstracts was as follows:

(Decision support OR Decision system OR Expert system OR DSS) AND (Adopt* OR Impact OR Uptake OR "Take up" OR Usage OR utiliz* OR "Technology Acceptance") AND (Evaluat* OR review OR overview OR "lessons learned") AND (Users OR operator OR client OR stakeholder) NOT (consumer NEAR/5 "end product" OR fuzzy OR "electronic medical record" OR Techno* implementation)

Papers were filtered out if they did not appear to meet the intent of the four areas described previously. The reviewers also discounted papers that offered conjecture rather than evidence to support their hypotheses for why system failure/success occurred. Just over 2000 records were identified, a manual review and a check for duplicates between the two datasets reduced this to 71 articles. Each of these was reviewed in detail for fit to criteria particularly evidence and description of the system in use. 34 papers were used in the final qualitative analysis. An overview of the process can be seen in Figure 1.

The findings from each of the 34 final papers were summarized in an Excel™ spreadsheet using the following key characteristics:

- Paper ID (author, date)
- Domain (health, forestry etc.)
- Decision description (what area of decision making the system or review focused on)
- Evidence of use (e.g. in use for 5 years, 200 people used, etc.)
- Key characteristics for success (positively or negatively phrased)

Additional reference in appendix:

Kawasaki, J.L. (2004) *Agriculture journal literature indexed in life sciences databases. Issues in Science & Technology Librarianship Summer*, DOI:10.5062/F4M61H61